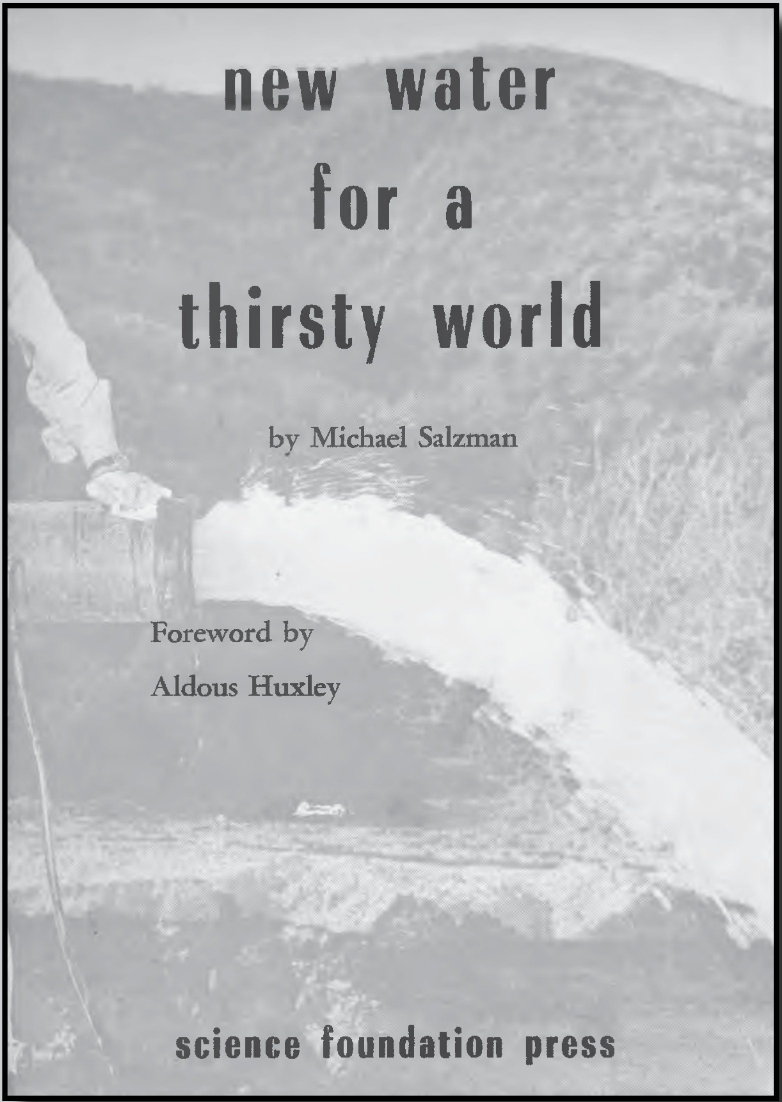

new water for a thirsty world

by Michael Salzman

Foreword by
Aldous Huxley

science foundation press

new water for a thirsty world

by

Michael H. Salzman

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> How odd it is that anyone would not see that all observation must be for or against some view, if it is to be of any service.
>
> —Charles Darwin

New
/ WATER FOR A THIRSTY WORLD

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TO

Stephan Riess

For demonstrating his firm belief in democracy, individual initiative, free enterprise, and the need for open minds to the end that all men may be truly free to think and solve the great problems of their times.

FOREWORD

As a child, born into a rainy country and brought up in the midst of what at that time was advanced modern plumbing, I took water for granted. One turned a tap and water appeared. That was all there was to it. With foreign travel came the discovery that things weren't as simple as all that. I rented a delightful villa in the hills above Florence. What a paradise! But the pump that should have raised the bath water from a well in the courtyard stopped working; and a little later, when the pump had been repaired, there was no water in the well. From one dry hole I moved on to a succession of vast dry regions. I crossed the deserts of Rajputana and what is now Pakistan; I visited the city of Bikaner, where the water supply is hoisted from deep wells by oxen harnessed to a rope, at the other end of which is a leather bucket. Then came the deserts of the American Southwest, seen first at the end of a wet cycle and later lived in during a prolonged drought which finally dried my well and the wells of most of my neighbors. No rain, no water in the wells. It stands to reason, doesn't it? But in some places there is no rain, and yet an unfailing abundance of water in the wells. At Nefta in the Sahara, at Jericho in the Jordan valley, I saw things which, by all the rules of common sense, I had no right to be seeing. Nefta lies in a part of the desert where it rains on the average once every three or four years; for the rest of the time there is only wind and sunshine. But though no water falls from the sky, water comes pouring out of the ground—enough water to support a forest of date palms and a population, in that incredibly fertile oasis, of several thousands. And after Nefta there was Jericho. Jericho is the site of the first walled city, built by a neolithic people thousands of years ago. And for thousands of years before that city was built men had lived on what was to become its site. Jericho is and has always been an island of greenery in the barren land. In a place where, by all the rules, there should be no water, a spring gushes out of the rock and has been gushing from time immemorial. From these two sets of object lessons I learned two significant facts about water; first and most obviously, that over vast expanses of the earth's surface, water is scarce or non-existent; and second (to my extreme puzzlement) that here and there water makes its appearance in places where it seemingly has no right to be present.

Such was the extent of my knowledge when, some few years since, I first met Stephan Riess. After seeing a few of his wells spouting water from the solid granite at the rate of two or three thousand gallons a minute, and after listening to what he had to say about faults and fissures, about juvenile water and primary water, about hydrogen and oxygen coming together at high temperatures and under vast pressures in the bowels of the earth and rising, as H_2O towards the surface, wherever the crust was weak, I began to understand the mystery of Nefta and Jericho; and I began at the same time to feel a little more hopeful about humanity's prospects for survival and a good life on this underwatered and soon to be overpopulated planet.

And now comes Michael Salzman's book. Jack of all trades and master of four or five, Salzman is one of those rare, indispensable men who refuse to confine themselves to a single academic pigeonhole, but with systematic restlessness and a boundless curiosity climb about on the woodwork between the specialists' insulated boxes, peering in now here, now there, and correlating the knowledge they extract from each compartment into a comprehensive pattern that permits a better understanding of the artificially isolated facts and, along with a better understanding, the possibility of new and more fruitful kinds of action.

If Riess is right (and the proof of the pudding is in the eating —or rather, since we are dealing with water, in the drinking), and if Salzman has correctly stated the chemical and geological reasons why Riess finds water in places where orthodox hydrologists affirm that it cannot possibly exist, then clearly we must be prepared to make a number of revolutionary changes in our ideas and our policies. If brand new, primary water can be found near the place where it is to be used, then the building of huge dams to impound old waters, and the digging of long canals to lead the water to its place of use, will become completely unnecessary. Every reservoir behind a dam is bound, sooner or later, to silt up. By the time California has fifty million inhabitants and five or six times its present water needs, Lake Mead will be well on its way to becoming the world's largest beaver meadow, and the Feather River Project, after bankrupting the state, will be hard at work depositing mud. If Riess and Salzman are right, the needs of California's future millions can best be supplied, not by inordinately expensive dams and aqueducts, but by drilling into faults and fractures for local sources of new primary water.

Again, if Riess and Salzman are right, it will be possible to use the applied science of tapping primary water in order to ease the political tensions and alleviate the chronic miseries of the Middle East and Africa. The high dam at Aswan will reach completion at a date when Egypt's population will have already outstripped the yield of the new lands which that future beaver meadow will have made fertile. How much quicker, cheaper and more efficient to start drilling for primary water in the rocks that shut in the Nile Valley! Time is everywhere against us; and unless we can provide enough extra food in the desperate interim between present population explosion and future population stabilization, the social, economic and political consequences of death-control without birth-control are bound to be disastrous. The extra food can be produced most rapidly by supplying the vast dry areas of the earth with water; and this in turn can be done most rapidly by locating and exploiting those deep telluric sources which (if Riess and Salzman are right) are nearly ubiquitous and for all practical purposes inexhaustible.

And even in those regions where rain falls and rivers run, primary water may turn out to be useful and even indispensable. As population grows and technology advances, more and more water is consumed. And not only is more and more water consumed; more and more sources of water are polluted. To the chemical and excrementitious pollution with which we defile our rivers, lakes and beaches there is now added regularly radio-active pollution. Dangerous even in peace time, such radio-active contamination might have the most appalling consequences during and after a war. In the years ahead, and for the inhabitants of densely populated and highly industrialized countries, sources of uncontaminated and uncontaminable water will become increasingly valuable.

For everybody's sake, let us hope that Riess and Salzman are right. Having seen some of Riess's wells and having now read the proofs of Salzman's book, I myself not merely hope, but feel pretty sure that they are right. It remains to be seen whether those who are now regarded as experts in the field of hydrology and the politicians whom they advise will also agree that a good case has been made and that large-scale experimentation is in order. Vested interests are of many kinds. There is the intellectual vested interest of those who have taken their doctorates in a science at a certain stage of its development, who have taught and applied that science at that particular stage, and who regard any questioning of the postulates underlying that science at that stage as a personal affront and a menace to their position in the Establishment. And then, of course, there are the more substantial vested interests of contractors who make money by selling concrete for dams and irrigation works, of bankers who make money by handling state and municipal bonds, of bureaucrats who, obeying Parkinson's Law, feel an urge to expand their departments and extend their authority, of politicians who find it prudent to say yes to powerful pressure groups. But even against vested interest truth (particularly if it be a useful truth) will ultimately prevail. How long is 'ultimately'? That is the question.

—Aldous Huxley

March 21, 1960
Topeka, Kansas

PREFACE

According to an old Hindu legend, all men on earth were Gods. Man sinned and thereupon the Brahma God, the God of all Gods, deciding to remove man's God head and hide it where Man would not find it, called a council of the Gods.

One God recommended that the God head be hidden deep down in the ground. Another God counseled that the God head be hidden atop the highest mountain. A third God suggested that it be sunk in the deepest part of the ocean. Each of these the Brahma God rejected—he said: "Man will dig deep into the earth. Man will climb the highest mountain, Man will search out the bottom of the seas and Man would find the God head."

Finally, the God of Wisdom said: "Let us hide it down in Man himself." "Yes," said the Brahma God, "we will hide the God head there, because Man will never think to look for it within himself."

Everything on the earth, including its very atmosphere but excluding meteorites and meteoritic dust, has come from within the earth. In attempting to solve water shortage problems, man has ignored this basic fact and instead has erected engineering monuments of tremendous proportions which in the future will serve only to attest to man's ignorance.

Our knowledge of life, of the world and universe around us, comes from observation and interpretation of both experimental procedures and various natural phenomena. However, the connection between the interpretation and the observation is frequently more tenuous than most people suspect. That which passes as true is rarely questioned, especially so if the interpretation has been long accepted by both the expert and the non-expert alike. Consequently, propositions which may be most in need of investigation may go by unquestioned.

The hydrologic cycle theory, upon which our current water procurement endeavors hinge, is correct as far as it goes but it doesn't go far enough. Conventional ground water wells are drilled into the unconsolidated rocks, namely the sands and gravels, because they are porous and permeable to the infiltration of surface waters. Such wells, therefore, are completely dependent upon local rates of precipitation which may be adequate or almost non-existent. Where local rates of precipitation are inadequate, either the costly process of water importation is resorted to or the area becomes stymied in its growth. A New York Times survey sees the economic growth of the United States as being limited by water shortages.

This book had its inspiration in the demonstrated discovery by Stephan Riess that fresh, potable water flowing in deep-seated solid rock fissures could be scientifically located from the surface of the earth, and economically intercepted by drilling through the hard, impermeable rocks so as to constitute an abundant water supply which heretofore has been virtually neglected. This initial inspiration has been refueled repeatedly by the adventure of discovering more and more evidence, already in the literature but dispersed throughout many fields of specialization, that support his basic concept. In the words of Rene Descartes: "If anyone wishes to search out the truth of things in earnest, he should not select any one special science; for all the sciences are conjoined with each other and interdependent."

Occasionally, however, an important discovery may go ignored. The science of radio astronomy was accidentally discovered about twenty-five years ago, but for ten years afterward astronomers everywhere pretended that it didn't exist. Yet today, in the land of its discovery, we are feverishly building the world's largest radio telescope in an effort to recapture the lead we' so naturally enjoyed upon its discovery.

During the last twenty-five years of field experience and observation, Stephan Riess has been able to refine his own work and concepts so that his demonstrations demand attention. Instead, because he goes beyond the hydrologic cycle theory, his work has been ignored with but few exceptions which only now are beginning to grow. According to Du Bridge, president of the California Institute of Technology, there is infinitely more to be learned than has been learned. The more science learns the more deeply it realizes its "staggering and overwhelming" ignorance. Those who refuse to even look beyond the hydrologic cycle theory, in the light of Riess' demonstrations, are lost to science. Furthermore, traditionally accepted theories have been overthrown many times. Geikie [1], who had traced its growth, said that geology, more so than any other branch of natural knowledge, lies invitingly open to those who are willing to train their faculty of observation in the field, and to discipline their minds by patiently correlating facts and fearlessly dissecting theories.

In 1931, two Indian chemists isolated crystalline alkaloids from Rauwolfia roots and then two Indian physicians, in the same year, published an account of their clinical work with these new crystalline alkaloids. Gorman [2], executive director of the National Mental Health Committee, says that if the report of the two Indian physicians had been presented before any scientific audience twenty-five years later, in 1956, it would have been hailed as an extraordinary precise description of Rauwolfia's potential uses. Somehow, we refuse to believe that scientists too can become hide-bound.

Likewise, in the field of water supplies, an article by the Swedish mineralogist Nordenskiold, published in 1896, would be news today despite the fact that this article was the basis for his having been nominated for the first Nobel Prize in Physics.

Reproducibility has been a basic tenet of science. Both Nordenskiold and Riess, widely separated in both geography and time, have each independently demonstrated that fresh, potable water could be scientifically located and intercepted as it flowed through fissures in the solid rock and that this economical water supply, independent of local rates of precipitation, could help solve the water shortage problems confronting the world.

The question of the origin of these waters gets us deep into the theories of the genesis of all the waters on the earth's surface. A tremendous body of geologic and other evidence supports the theory that the waters on the surface of the earch have come from within the interior of the earth throughout geologic time and that this process continues today.

Recently, Kozyrev, a Soviet scientist, reported an escape of gases from the crater Alphonsus on the moon. The thought occurred that this phenomenon might be similar to those that take place on the earth. In a letter dated December 16, 1959, Harold C. Urey replied to the author's query: "It does not seem to me unreasonable that gases should be escaping from the moon and I would think if they were that it would be a mixture of water and other substances.

However, I think this has little to do with the escape of water from the earth because of markedly different conditions. If I were you, I would stay away from anything connected with the moon in your studies because of the very doubtful character of all conclusions about the moon."

Under contract with the San Bernardino Valley Municipal Water District, Riess had been asked to give the Yucaipa area his early attention even though he was not optimistic about being able to locate wells of large production in that area. He believed that other areas in the district would be far more productive, but, because of pressures by the District, Riess located a well on the old Webster Ranch at Yucaipa. This most recent demonstration was reported in the San Bernardino (Calif.) Sun-Telegram on January 24, 1960. Preliminary testing indicates a flow of about 850 gallons per minute which may increase after proper development of the well. As pumping continues, the fissure, in cleaning itself out, has disgorged very large amounts of coarse grained, broken rock with completely oxidized particles, highly mineralized hematite, sulphite, pyrite, and some free gold. The water is neither acid nor alkaline, having a pH of 7, which attests to its flowing character, and a temperature of 67° Fahrenheit.

Archibald MacLeish has called our scholars "irresponsible" because they were lost in pedantries and fruitless remote rivalries. It is hoped that this book avoids these pitfalls, and that it is fruitful in opening up an awareness and perhaps a better understanding of the dynamics of water. For instance, it will undoubtedly soon be possible, by fusing the natural deuterium contents from a gallon of ordinary water, where it is found to the extent of 10 parts in one million parts by weight, to yield energy equivalent to 300 gallons of gasoline.

This book should be of value to everyone interested in the water problem, and especially to those scientists, technicians, governmental officials, legislators, students, and taxpayers who are concerned with:

1. The increasing cost of municipal water supplies.
2. Health, and water pollution problems.
3. The world problem of food and water shortages.
4. The development of arid areas of the world.

5. Economic development and the extraction of mineral wealth heretofore untapped because of insufficient water supplies.
6. Industrial plant location; industrial decentralization; community and city planning.
7. Afforestation, reforestation, and conservation.
8. Potable, non-contaminable water supplies for civil and military defense, and the operation of our industrial plant facilities.
9. The sociology of knowledge.

If we, as a nation, are to assure the continuance of our prized value systems, we must recognize the value of an open mind for: "The spirit of science is to set men free — free of superstitions, of chains, of slogans and of dogma." [3]

ACKNOWLEDGMENTS

For the material presented in this book, the author has drawn upon the heritage of learning from many different disciplines. For his first introduction to geology, many years ago, he wants to thank Dr. Ray S. Bassler; and for opening his eyes and mind to the more complex manifestations of the earth's interior, he is forever indebted to Stephan Riess. For their great interest and encouragement extended in this undertaking, he is indebted to Dr. Ralph Arnold, Mr. James G. Scott, Dr. Charles H. Tilden, Mr. Herbert Kern, Mrs. Gary I. Salzman, and Dr. Solomon Levy. He is grateful for the wholehearted cooperation extended by his wife Helen and their two sons Gil and Steve.

Michael H. Salzman

March 1, 1960.
Long Beach 15, Calif.

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Facts that are not frankly faced have
a habit of stabbing us in the back.
—SIR HAROLD BOWDEN

CHAPTER I

INTRODUCTION

I had been asked along to meet a water wizard. Several weeks before this invitation a national magazine had run an article raising the question, "Does He Get Water From Rock?" [4] A faculty member of another university had reacted to this article by publicly labelling this man lucky, a charlatan, a witch, and a fake. But his description of the man had excited my curiosity.

Although the subject matter I was then teaching was pretty far afield from the subject of water exploration, an older interest from my engineering experiences with Soil Conservation Service was easily re-kindled. Questions flashed through my mind. Generally speaking, wasn't water the limiting factor in the production of useful vegetation which supplies the requirements for all animal life? Wasn't water vital, in varying degrees, in all segments of economic activity? Doesn't water contribute, both directly and indirectly to the supplying of more human wants than does any other natural resource? Wasn't it worth leaving no stone unturned in an effort to find a solution to the growing water problem? My answer was in the affirmative, indeed I would be happy to join the group in a visit to Stephan Riess.

I immediately set about to refresh myself on the whys and wherefores of our water dilemmas. I found that the tasks of finding, developing and maintaining suitable water supplies have not been limited to modern times, but that there has always been a continuing struggle for water.

Since historic times, people have settled in regions where water was deficient in amount, inferior in quality, or erratic in behavior. Excavated ruins of five thousand years ago reveal a well planned water supply system in India. Similarly, the people of Assyria, Babylonia, China, Egypt, Greece, Israel, and Rome had built equivalent facilities long before the Christian era. Egypt built the world's oldest dam some five thousand years ago. Jacob's well was excavated through solid rock to a depth of 105 feet, and is reported to be still in use. The Tukiangyien system, built in China about twenty-two hundred years ago was a multipurpose engineering project designed for both flood control and the irrigation of some one-half million acres of fertile soil.

Rome's first aqueduct was only eleven miles long but they soon had to go sixty miles, and indeed, the overthrow of the Roman Empire has been attributed to dwindling rainfall and its concomitant diminishing water supplies. The modern day process in building dams and transporting water is one of building larger and larger dams, impounding more and more water, and transporting it at ever increasing distances.

The basic problem that accounts for the temporary nature of these works is that reservoirs, canals, and ditches tend to fill up with silt carried by the water. Hammurabi, King of Babylon, wrote about four thousand years ago that he had brought the waters and made the desert blossom. Babylonian canals filled up, however, and for many centuries farmers dredged out the silt, making piles on each side of the canal. The farmers, the ditches, and Babylon itself are gone, but after two thousand years the silt piles twenty feet high are a grim reminder that even a great empire perishes when it can no longer secure its water supply.

The water storage capacity at Lake Mead, behind Hoover Dam, is being reduced by 137,000 acre feet of silt annually. At this rate, the greatest reservoir in history loses its effectiveness rapidly and will be completely destroyed in less than 250 years. Another kind of loss, the magnitude of which the ancients were not aware, is the water lost through evaporation. At Lake Mead, for instance, more than 893 million gallons of water are lost through evaporation each day.[5]

Water has loomed up as a major problem because of the following factors:

1. The explosive increases in population being experienced all over the world.
2. The shifts in population.
3. Industrial growth.
4. The periodic droughts.
5. The devastating pollution of streams and lakes.
6. The special kinds of contamination, such as salt water encroachment and radioactivity.

POPULATION GROWTH

In 1954, the population of the world was placed at more than two and one-half billion people with an annual population increase of thirty million people. Currently, an annual growth of 50 million and a world total of 2.9 billion people is estimated. [6] The rate of increase has been accelerating, so that, other factors permitting, the world's population will more than double in less than fifty years.

The crucial factor in world peace is food for all, yet, as through all of human history, the production of food is still the major occupation and preoccupation of the bulk of the world's population. Two-thirds of the people of the world are still engaged in producing food and two-thirds of the people of the world normally do not have enough to eat. The food-population ratio of the future foretells acute conditions. Harrison Brown [7] estimates that, in order to both catch up with food deficiencies and to keep up with an ever-increasing world population, food production fifty years from now might have to be two and one-half times greater than it is today, and that by the year 2050, production might have to be multiplied three and one-half times.

Sometime in the future, man may derive his food supply from the waters of the world, or from synthetic foods. But for now, and the immediate future, man gets nearly all his food from the soil in the form of agricultural crops and animal life. Land is only one of the determinants in the food supply. Water is a major one. The total land area is estimated at thirty-seven billion acres, of which more than half is practically uninhabitable because it is either mountainous, lies in the polar regions, or is desert waste. The remaining land, about seventeen billion acres, is presently thought to be hospitable to man, but more than seven and one-half billion of these acres are at present not usable for food production because of insufficient rainfall.

The estimates of the amount of land that is actually under cultivation vary somewhat, ranging from seven to ten per cent of the land area of the world. Every continent, however, has areas supposedly with good soil, which do not produce crops at present because they are too dry, have irregular rainfall, or rainfall at the wrong season of the year. Some of this land, it is thought, can be made cultivable if water can be brought to it. The extension of irrigation has been presented as the major way of bringing this about, and, as has been shown, irrigation is a very ancient technique in making land cultivable. About a quarter of the world's population lives on irrigated crops and, in the densely populated areas of the world, irrigation has been developed nearly to the limit with present technology. India irrigates about a quarter of its land under cultivation. China about one-half, and Egypt practically all of its cultivated land. [8] It is currently estimated that more than 321 million acres are being irrigated throughout the world.

James H. Breasted [9] described hunting on the Sahara Plateau, when its now desert uplands were still green. He believed that the shrinking rainfall of North Africa transformed the whole vast Sahara into a wasteland of rock and sand. These desert wastelands of the world can once again be green.

In the United States, the population has grown far above expectations, and so has the amount of water needed. In the half century ended with 1950, the national population about doubled and so did the per capita usage of water, so that, the total water usage increased about four-fold. A rising level of living contributes to water shortages. For instance, thirty-five million bathrooms now as against only thirteen million in 1930.

So serious were the disputes raging all over the world, between nations using the same rivers for their water supply, that, in 1953, the United Nations called for advice on the subject. India and Pakistan have been embroiled over the Indus River system since the 1947 partition; Israel and its Arab neighbors Syria, Lebanon, and Jordan are stalemated on the apportionment of the Jordan River, the United Arab Republic and Sudan also have a basic water dispute; Iran and Afghanistan have been arguing for over a century about the Helmand River, and even the United States and Canada have some unsettled disputes over the Columbia and Yukon Rivers. Not only have there been disputes between nations, but in the United States the states of Arizona, California, Colorado, Nevada and Utah have all been at odds concerning the distribution of Colorado River water. Sectionalism exists within the state of California, with southern California battling northern California for water which originates in northern California. Furthermore, there have been conflicts between the city and the state. For instance, the city of Albuquerque relies solely on ground water wells for its water supply, and yet, when the city wished to expand its water supply to fill additional needs, New Mexico's state water engineer ruled that the city of Albuquerque could not drill any additional water wells.

POPULATION SHIFT IN THE UNITED STATES

The outbreak of World War II heralded a major shift of population in the United States. The population of six western states increased twenty-five to fifty-two per cent between 1940 and 1950, whereas the national increase was only fifteen per cent. Industrial expansion, and a concomitant heavy demand for water, moved west and south.

Large increases in the acreage under irrigation in the west, and the introduction of supplemental irrigation throughout the midwest and in the eastern and southern states contributed to the much heavier consumption of water. The lands in irrigated farms in 1954 were estimated to be about twenty-seven and one-half million acres. To grow a bushel of corn by irrigation requires about ten thousand gallons of water; to grow a ton of alfalfa hay, about two hundred thousand gallons of water. At present, irrigation soaks up about half the water withdrawn by the entire nation.

INDUSTRIAL GROWTH IN THE UNITED STATES

Industry is also a big user the nation over. But most of this is by a relatively few industries, chiefly for production and fabrication of metals, oil refining, pulp and paper, chemicals and synthetics, Electric power producers require about the same amount of water daily as all of the other industrial users together. Residential users consume the least amount.

Industrial production in the United States has increased sevenfold since 1900. Only since about 1945 have people thought seriously about the amount of water that industry requires. The President's Materials Policy Commission estimated that industry accounted for thirty-five per cent of the total water used in 1950 and that by 1975 industrial needs would increase to sixty-three per cent of the national total. Most of the water used by industry is for cooling purposes, for water has an amazingly high capacity for heat. A pound of water in a cooling system increases its own temperature by only one degree in the process of lowering the temperature of a pound of steel by ten degrees.

PERIODIC DROUGHTS

Periodic droughts occur throughout the world. To break a drought in Australia, the Duri tribe resort to magic. One technique is to draw blood from the wizards, sprinkle it on other men of the tribe and then throw bird down over their bodies to make them look like clouds.

In the United States, recurring droughts are a normal feature of climate in southern parts of the Great Plains. Similar conditions have existed in parts of the west, the midwest, and the south. The oceans, and especially the Pacific Ocean, act as a medium through which persistent rainfall is maintained in the United States. The regularity of summer droughts on our west coast and the permanency of certain arid regions in our far west and southwest result from the influence of the Pacific Ocean. In fact, the influence of the Pacific is felt strongly in the area between the Rocky Mountains and the Mississippi, to a lesser degree proceeding toward the east and northeast.

Rainfall in the United States is dependent on relatively low temperatures over the northern continent and relatively high temperatures over the northern Pacific. An increase in heat from the sun tends to bring rain farther into the interior of the continent; a decrease causes more of the national rainfall to go to coastal areas. An increase or decrease in solar radiation, if sufficiently large, causes a considerable increase in the circulation of the atmosphere. The increased circulation of the atmosphere in turn causes changes in the distribution of ocean temperatures. First, there is a cooling due to mixing of the waters; second, there is the effect of oceanic circulation. Therefore, when solar radiation increases or diminishes, the ocean temperatures lag behind and are relatively high or relatively low when compared with continental temperatures, causing changes in the amount and distribution of rainfall.

When pressure east of the Rocky Mountains is relatively high in the north and relatively low in the south, there is more than normal rainfall in the United States. Because of the prevailing westerly circulation of the atmosphere in our latitude, the air must come over the mountains into the middle and eastern parts of North America; and if it does not go over in the north, it must accumulate and be forced over in the south. When this occurs, there are profound changes in the distribution of rainfall and droughts become serious and widespread. [10]

POLLUTION OF STREAMS AND LAKES

Everything that goes down the drains of a city and into its sewer system is considered domestic wastes. Industrial wastes are the acids, chemicals, oils, greases and other matter discharged by factories, sometimes into city sewer systems and sometimes through separate outlets directly into the watercourses. Water purification systems have remained a remarkably effective protection against the health hazards of water pollution, but the growth and concentration of population, coupled with the increase in the volume of pollution, both complicate and increase the cost of producing safe and acceptable drinking water. The dangers increase, even a small break in our protective processes can bring disaster.

The State-Federal data collection program in 1950 revealed a total of 22,200 pollution sources. Despite the fact that pollution has been reduced by 6,700 municipal sewage treatment plants and 2,600 industrial treatment plants, untreated or inadequately treated organic sewage and wastes that are equivalent to those from a population of more than one hundred and fifty million is still discharged into rivers and lakes. [11] Carl E. Schwob, Chief of the Water Supply and Water Pollution Control Program of the United States Public Health Service, says that the construction of treatment plants for industrial wastes is lagging behind needs. [11 p. 641]

Salt water encroachment means more than the intrusion of ocean water into fresh water. The original source of all salts, sodium, calcium, magnesium, potassium, and other rarer elements, is in the rocky material of the earth itself. When rain or snow falls on the land, the water contains relatively little dissolved mineral matter. But as it moves over and through the soil and rocks it begins to dissolve their more soluble constituents.

The gradual entrance of salt water into fresh water areas is serious and widespread, occurring in almost every state. When the saline water displaces fresh water, cities may abandon their long used sources of water and search for replacements; industrial plants may close down, and productive farmlands and orchards may be ruined. It is costly in terms of money, time, energy, and productivity.

A slow, worldwide rise of sea level is believed to be taking place. On the Atlantic coast of the United States, since 1930, a definite rise of about two feet in one hundred years began. Since these records are for a very short span of geological time, predictions based on them could be quite misleading. But such a rise of sea level will cause the contact between salt water and fresh water along New Jersey's coast to recede inland at a rate of about one to four miles a century. The Pacific coastal stations have shown a rise of about one-third as much as the sea level rise of the Atlantic stations.

Another source of saline water is deep beneath the earth's crust, where water is a normal chemical constituent of the rock solutions known as magma. This type of water occurs beyond the downward limit of free liquid water in rock interstices. In places where magma rises into the upper parts of the earth's crust, it ultimately solidifies into rocks such as granite, and in the process, water that was formerly dissolved or in chemical combination with other minerals is driven off. Such newly formed water has been given many names, one of which is juvenile water. Juvenile water may escape into the overlying and surrounding pre-existing rocks by seepage, or may be emitted through volcanoes, hot springs, or geysers. Much more about this newly formed water will follow in succeeding chapters.

Some of man's irrigation practices and industrial processes increase the salt content of natural waters. When irrigation water is evaporated from the land surfaces or is transpired by plants, some salts are left behind. If provision is not made for removing the salts, they will accumulate until the land becomes useless for farming. Some industrial, mining, and petroleum operations also create new sources of salinity. Salt water encroachment is a major problem in most oil producing states. For instance, Texas has more than five hundred widely scattered oilfields. Not only were the water wells and fields belonging to individuals encroached upon by brines pumped out of oil wells, but the municipal supplies of such cities as Beaumont, Longview, and Graham were also damaged.

Starting out fresh a river pours its partly mineralized water into the ocean, where the salts are concentrated by evaporation. Some inland lakes have become salty in much the same manner. Water becomes heavier and denser as its salinity increases, so that sea water tends to remain separate from fresh water. The fresh water occupies a position above and upon the salt water, but if there is turbulence where the salt and fresh water comes into contact, they soon become mixed.

The commonest type of salt water encroachment is that induced by the use of wells. Pumping of wells in excess of the natural recharge of water causes a lowering of the water table. The lowering of the water table at Miami by about five feet upset the naturally established equilibrium between salt and fresh water, and salt water began an inland migration that cost the city two major well fields at Springs Garden and Coconut Grove, as well as the use of thousands of private wells along the coastal ridge. [12]

RADIOACTIVE CONTAMINATION

During the month of March, 1958, radioactive rain eight times the standard set as safe for drinking water fell in southern California, and radioactive rain 200 times higher than the safe standard fell in the San Francisco Bay region. [13] This pollution by radioactivity is potentially more dangerous than any we have known and it is likely to increase in the coming years as nuclear power is further developed. [14] The text of a governor's committee on atomic radiation states that the atmospheric air samples, near ground level in the State of Minnesota during 1957, do not approach levels considered to be significantly injurious to life. "However," the report continues, "the levels reported in collected rainwater, surface waters, and river waters in the state exceeded in a significant number of instances during periods following the testing of bombs and for some months thereafter, the limits set by the National Bureau of Standards as the provisional permissable levels for drinking water." [15]

Some fifty-four per cent of the total population served in the United States receive water from surface sources which are easily contaminable. It is recognized that vast numbers of our population receive untreated water, but how effective are treatment plants when it comes to radioactive contamination? Generally speaking, reported the Oak Ridge National Laboratory in 1956, "water treatment processes will not effectively reduce activity in the water to acceptable safe limits except where the initial levels of activity are very low, certainly several orders of magnitude below 1.0 microcurie per ml level." [16] At the same time, the Oak Ridge National Laboratory warned that plans should be made for auxiliary water sources from possible noncontaminable supplies in order to protect the large population centers dependent on surface waters which may become contaminated by radioactive materials.

THE VISIT

Having been engrossed in the foregoing considerations, the following Saturday came fast. Six of us travelled to Simi Valley, Ventura County, California. More than one hundred wells had been put down in the valley but because water had been withdrawn faster than the natural replenishment rate, most of the valley wells were soon drained.

Hundreds of feet above these valley wells we found the residence of Stephan and Thelma Riess. The luxuriant vegetation denoted a plentiful supply of water; the grounds, the trees, and the aviaries indicated an orientation and understanding of nature. Our greeting was cordial and soon after the formalities, when the discussion turned to water, it was unmistakable—Stephan Riess was electrified. The knowledge at his finger tips evidenced the broad scope of his interests and when he started the big diesel engine, which produced a tremendous flow of water from one of his wells, his eyes sparkled and his enthusiasm, somewhat contagious, knew no bounds as he explained why his wells had plentiful supplies despite the fact that the valley wells were dry.

Although much of his discussion differed from the conventional theories with which I was familiar, his answers to questions were direct and concise. In fact, the twinkle in his eyes suggested that he was not only ready to answer questions about his science but that he would welcome being challenged.

The remainder of the day we spent touring other wells that Stephan Riess had located in Ventura County. Each of these wells had been drilled through solid impermeable rock until a fissure containing fresh, potable water had been intercepted. During part of the day I had been walking close to a well surveying engineer who on several occasions had bluntly stated to me that he didn't believe anything he saw or heard. He insisted that if it were possible to find such waters, if indeed they really existed, then other scientists would also know how to locate such waters, and it would have become common knowledge.

I recalled and pointed out to him that the Nobel Foundation had scrutinized the historical course of the majority of great discoveries. They had found that, at a certain moment, knowledge is carried to a stage where the discovery comes more or less by itself to a scientist with an open mind. "This," says the Nobel Foundation, "does not detract from the value of the contribution of the scientist. Only he who has the God-begotten gift intuitively to separate from the trivial observations just the little something which on closer analysis leads to the discovery—only he finds what has escaped many who, in their hands and before their eyes, had the same possibilities of making the discovery." [17]*

Riess' entire demeanor was diametrically opposite to that of a charlatan. He was not secretive, but open and direct in his replies. It's just that one had to know enough to ask the right questions. When Riess said that there were many people who either knew as much as or more than he did, but that he had stumbled onto something that others had overlooked, I knew that he was sincere and that he believed that he had discovered something of tremendous import to mankind.

Riess had once been a mining engineer and his interest in water stemmed from the fact that many of the mines on which he had been employed had been flooded out by water. These experiences coupled

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*By special permission of Professor Manne Siegbahn (Nobel Prize Laureate in Physics of 1924) and the Nobel Foundation. See the reference in the bibliography.

with an early recognition of water shortage problems spurred him to the development of a scientific method of locating these solid rock fissure waters from the surface of the earth.

The simple question remained, was Riess a water witch or one of our greatest earth scientists, albeit unrecognized? As a result of this stimulating visit I resolved to search and research for information that would either dispute or support Riess' theories, and it seemed a good idea to start where he did—in mining.

MINING

In mineral regions where extensive postmineral fracturing due to faulting has occurred, water in the fracture zones frequently introduces difficult problems. Fissure waters are commonly known to miners as "watercourses." These watercourses are encountered underground in mining operations, down to the depth of thousands of feet, as has been corroborated when mine workings tap them and the flood of water which they carry. In the deep workings at Tonapah, Nevada, for example, the rock was entirely dry until one of these great water-bearing fissures was tapped.

Naturally, surface waters may penetrate into faults and fractures, and these infiltrated surface waters may account for all or part of fissure waters. However, Young [18] points out that, in addition to such surface waters, water from deep-seated sources ascends until it either flows out from some surface opening or its further upward movement is stopped by the attainment of equilibrium, in which case, these deep-seated sources feed fissures or systems of fissures. However, our concern at this point is not with the origin of these waters, but with their existence and their availability for man's use.

MINE WATERS

The world renowned Comstock Lode, an area of silver mines at Virginia City, Nevada, provided the most profitable production of silver in the United States until they were flooded by hot waters at a depth of three thousand feet. [19]

At about 1700 feet below the surface, the Mahr Tunnel [20] cut a fissure from which the flow continued at more than 18,000 gallons per minute. Similarly, the newer drainage tunnel at the Carlos Francisco Mine [21] encountered main fissures which produced more than 10,000 gallons per minute. The Natividad Mine [22] on its 1,014 ft. level, with a lift of 520 feet, had an installed capacity of 30,000 gallons per minute. At an altitude of 6,200 feet, the Jarbridge [23] (Nevada) pumped 7,100 gallons per minute to the surface from its 1,000 ft. level.

The experiences at Eureka, Nevada, are worth looking at more closely. In 1947, the Fad shaft, on Ruby Hill one and a half miles west of Eureka, Nevada, was completed to a depth of 2,465 feet at a site adjacent to the down-faulted block in which the ore was found. When the horizontal tunnel on the 2250 level intersected the Martin Fault, a large flow of water was encountered which exceeded the installed pump capacity and flooded the shaft.

In 1948, an unsuccessful attempt was made to recover the shaft. Pumping at a rate of 8,000 gallons per minute did not recover the 2250 level, and when the pumping rate had been increased to 9,000 gpm the water level in the shaft came down to within sixty feet of recovering the 2250 level. However, this higher rate of pumping began to bring gouge into the shaft, muddied the water, and then gradually raised the pumping level until it had risen approximately 340 feet in the shaft. So that, despite the increased and continued pumping at the rate of 9,000 gpm, the water level in the shaft remained at about 400 feet above the 2250 level. It is evident that by increasing the pumping rate much fine sediment was removed from the fractures as the water moved along the Martin Fault and thereby improved the hydraulic connections. [24]

FRESH, POTABLE WATER

Obviously, not all fractures or fissures contain water, and those that do may carry hot and highly mineralized water of various concentrations, or on the other hand, cool, fresh, potable water. Inasmuch as the solubility of most minerals is greater at increased temperatures, there is a relationship between the temperature of the water and the amount of its mineral content.

During the dewatering of the Osceola lode [25], it was noted that the water could be divided into two distinct layers, an upper layer of relatively salt-free water, and a lower of rather high salt content. At the 2000 ft. level, the water contained little or no salt and had a specific gravity very nearly equal to 1.0; whereas, at the bottom of the shaft the chloride content was 62,000 parts per million and the specific gravity was 1.082.

Spurr, an eminent mining geologist, in summing up his many years of experience with mine waters says: [26]

> In short, the result of my own experience is this: I have traversed and studied exhaustively and mapped carefully, either personally or with the help of my associates and assistants, many thousands of mine workings, during a period of many years. These mine workings have been at all depths, frequently thousands of feet below the surface. At all depths I have noticed openings in rocks, especially along fault or fracture zones, and found waters circulating vigorously along them. These waters were cold, lukewarm, or (rarely) hot.

There are three important points that Spurr makes which should be remembered:

1. Openings in rocks exist at all depths, especially along fault or fracture zones;
2. Waters found in these openings circulate vigorously, and
3. These waters range in temperature from cold through lukewarm and on rare occasions to hot.

I was convinced that the existence of mine waters were fairly common; that their occurrence in large volumes is not a rarity, and that they are frequently cool, fresh, and potable. Here was important information apparently of common knowledge to people engaged in mining but otherwise not generally known or understood. I knew then that I must continue my search. Although Young's [18] reference to waters from deep-seated sources opened up another avenue of adventure, I thought it essential to first obtain a better understanding of just what water is.

Water . . . is the image of the ungraspable
phantom of life; and this is the key to
it all.

— HERMAN MELVILLE IN MOBY DICK

CHAPTER II

WHAT IS WATER?

Altogether too many people think of water in terms of a fixed and constant quantity. Even if this were assumed to be true, the almost imperceptible change in both distribution and occurrence that brought the downfall of past civilizations could also eliminate ours. However, the supply in and on the earth is not a fixed and immutable quantity but is decreased by disassociation; by hydration; by life itself — and increased by association; by dehydration of rocks, and by death.

MATTER AND ENVIRONMENT

Everyone recognizes that all life is dynamic, that it is in a state of constant change, but far too many people believe that matter is static. A dichotomy has been created, life on one hand and matter on the other. However, matter is never inert, never indifferent to its environment or to changes of environment. Even the diamond, which is the hardest and most firmly fixed of crystals known to man, yields to the agitation of very high temperature and burns to a gas in oxygen. Other minerals, formed under great pressure in the depths of the earth, break down when brought to the surface. But the fact is, that they are adjusting themselves to their new environment of relatively slight pressure and lower temperature. Matter, under conditions where there is no tendency to change, is said to be in equilibrium with its surroundings, and can so exist indefinitely provided external conditions remain unchanged. Matter, then, is not inert. It is simply balanced energy that is poised waiting for readjustment to changing environment. Man, the highest form of animal life, differs from matter and the lower forms of life in his ability to make faster and, perhaps, better adjustments to a changing environment or to change his environment.

A practical illustration of the readjustment of matter to environment is contained in a warning to contractors issued by the Division of Industrial Safety of California's Department of Industrial Relations in their bulletin 105 as follows:

> Upon exposure to air and moisture, some rocks, like the greenish serpentines found in California, undergo a softening change called air-slacking. Walls of such rock are hard and solid at the time of excavation, but soften into a slippery, dangerous mass soon after exposure to air. To prevent this air-slacking, some contractors apply a protective coating of gunite to such walls, in addition to shoring and bracing.

Aristotle, in the fourth century B.C., devised a "four-element" theory of matter whereby everything on earth could be regarded as a mixture of the four primary substances: water, earth, fire, and air. As late as the year 1781, water was the only one that still remained as an "element" from the original four, but in that year Joseph Priestley exploded a mixture of air and "inflammable air" inside a closed vessel and produced water. Inflammable air was an inflammable gas made by putting metals into acids. In 1787, Lavoisier gave inflammable air the name "hydrogen" which in Greek means "water producer."

For over one hundred years after Priestley's discovery, experiments continued in an effort to determine the densities and the ratio of atomic weights for oxygen and hydrogen. For instance: "A quantity of hydrogen was weighed while absorbed in palladium, a quantity of oxygen was weighed in a globe . . . The two gases were brought together at two platinum jets enclosed in a small glass apparatus . . . and the water produced was weighed." [27] In the aforementioned series of experiments the oxygen used was produced by heating potassium chlorate, and the hydrogen was prepared by the electrolysis of pure dilute sulphuric acid. [27 pp. 57 and 96] From this comes a first glimpse as to how water may be formed within the earth.

Water is about eighty-nine per cent oxygen and eleven per cent hydrogen by weight. Actually, 0.303 grams of hydrogen combines with 2.405 grams of oxygen to form 2.708 grams of water. Although mixtures of hydrogen and oxygen are inert at ordinary temperatures, the reaction of creating water becomes perceptible as the temperature is increased. At three hundred degrees centigrade, several days are required for a small part to have reacted and formed water vapor, whereas at 518 degrees centigrade only several hours are required to complete the reaction, and at seven hundred degrees centigrade the combination is almost instantaneous. If a body at red heat, or a burning match, is introduced into a mixture of hydrogen and oxygen, the combustion wave starts from the hot body and immediately spreads to all parts of the mixture. Certain finely divided metals act as a catalyst so that when they are introduced into a mixture of hydrogen and oxygen they cause a similar explosion.

For hydrogen to react, however, it must be in the atomic state. When a mixture of hydrogen and oxygen is ignited, the heat of the hot body is sufficient to dissociate some of the hydrogen molecules into atoms and some of the oxygen molecules into atoms. The reaction between the atoms is exothermic, that is, the association of hydrogen and oxygen into water produces heat, and the heat so liberated dissociates more molecules into atoms, and so on—a chain reaction. These changes are extremely rapid, so that the entire reaction proceeds with explosive violence.

WATER FUNDAMENTALS

At zero degrees centigrade, water becomes solid ice, and at one hundred degrees centigrade it becomes a gas called water vapor or steam. Water vapor in the atmosphere protects us from the burning rays of the sun. Actually, it acts as does any other large body of water, it prevents extreme fluctuations in temperature. Studies of compounds related to water show that the freezing point of pure water should he at minus 150 degrees centigrade and its boiling point at minus one hundred degrees centigrade. The actual values at which freezing and boiling do occur are explained by the polymerization of water. By polymerization is meant the chemical union of two or more molecules of the same compound to form larger molecules but of greater molecular weight. But rather than a mere enumeration of the properties of water, it would be far more useful to approach the subject at hand by getting at the fundamentals.

Today, almost everyone knows that the water molecule is formed of three atoms, two of hydrogen (H) and one of oxygen (O), or expressed as a symbol, H_2O.

When atoms of the same element differ in atomic weight they are called isotopes of that element. For instance, there are two isotopes of hydrogen, known as deuterium and tritium. Likewise, there are two isotopes of oxygen, known as O^{17} and O^{18}. The different isotopes of an element contain different numbers of neutrons in their nuclei so that the isotopes of an element are identical in chemical and physical properties with the exception of those determined by the mass of the atom. If the water molecule is made up of different combinations of hydrogen, oxygen, and their isotopes, complexities increase for then eighteen different water molecules actually exist. Nearly all elements found in nature are mixtures of several isotopes. Further reference to isotopes will occur later, so for now let us return to the three atoms, two of hydrogen (H) and one of oxygen (O).

These three atoms are held together by two chemical bonds, thus H-O-H, which is one of the simplest compounds. Several molecules of water, however, are held together by a hydrogen bond which is about six per cent as great as that of the H-O chemical bond. The hydrogen bond results from the fact that the H attached to O in the water is unsymmetrically surrounded by electrons, so that there is a separation of charge or polar character. In other words, if there are non-binding outer electrons of other molecules present, there is a tendency for H to increase the symmetry of its surroundings by approaching a pair of electrons in line with its chemical bond to oxygen.

The properties of water are of two types. Those of the first type depend on whether the chemical bonds between the H and O atoms are broken in the action involved, thereby dissociating water into its two elemental gases, hydrogen and oxygen. Those of the second type leave the H_2O molecules intact but sever the hydrogen bonds. Chemical changes in which the chemical bonds are broken are illustrated by the evolution of oxygen resulting from photosynthesis, the rusting of iron, the formation of clay in soils, and the splitting of cane sugar in the stomach. Physical changes in which the hydrogen bonds are broken are illustrated by the melting of ice, evaporation from a reservoir, and the viscous resistance to flow in a stream or pipe. The growth of water droplets into rain droplets may be attributed to the hydrogen bond. The carrying of sediments in a flowing body of water is due, in addition to movement of the water, to the hydrogen bond.

Near the melting point of ice every molecule is associated with other molecules, while at the boiling point, only forty-two per cent of the molecules are so associated. [28] The space occupied by water molecules as a gas is about 1,200 times as great as that occupied by them as a liquid. In other words, when completely vaporized, the molecules in a teaspoon of water would become a gallon of water vapor. To convert one cubic centimeter of water, at one hundred degrees centigrade and under atmospheric pressure, into water vapor at the same temperature requires the addition of 538 calories. This heat requirement ranges from 574 calories at forty degrees centigrade to 596 calories at zero degrees centigrade. Consequently, evaporation can occcur as a continuing process only while energy is being received from some outside source. This latent heat of vaporization must be given up whenever water vapor is condensed back into water.

The solvent properties of water are what makes water so important in the life of plants and animals. These solvent properties are of two types, in both of which water is outstanding among liquids.

The first type is hydrogen bonding which holds in water solution the compounds—like sugars, alcohols, acetic acid and other organic acids, phosphates, nitrates, ammonium compounds, and many other substances that have oxygen atoms—which are involved in the storage and transfer of energy by the living plant or animal. Water, through its hydrogen bonding solvent action, is the medium of transfer in the blood fluid or in the sap of plants.

The second type depends on the fact that water has a high separation of the electric charge between the hydrogen and the oxygen atoms in the H_2O molecules. By charge interaction, various salts, like sodium chloride, which man needs for the acid in his stomach and for the action of blood serum, are held in solution. Pure water is slightly dissociated, the separation of charge in a few molecules is so complete as to give two oppositely charged particles or ions, H+ and OH^-. The H+ is the hydrogen ion or the ion of acids and the OH^- is hydroxyl or the ion of bases. The separation of charge also dissolves potassium salts involved in muscle action; and many compounds can be split by water to form two compounds. For example, cane sugar is split into equal parts of glucose and fructose using up one water molecule in the process.

Stewart [29] discusses the influence of ions in solution on the liquid structure of water. He concludes that all of the experimental evidence is consistent with and seems to emphasize that the tetrahedral structure of water changes with increasing temperature, and that this structure and these changes account for the unique characteristics of water.

True solution is an endothermic process, it absorbs heat, and therefore solubility is increased as the temperature is raised. Water at ordinary temperatures reacts rapidly with active metals such as potassium, sodium, and calcium, to form the hydroxide of the metal and to liberate hydrogen. At higher temperatures it reacts with less active metals, such as zinc or iron, to form the oxide of the metal and hydrogen. Water, at temperatures above the critical point of water vapor, is a gas and can be highly compressed. With increasing pressure the solubility of silicates increases in such a supercritical gas.

A list of metals arranged in order of their respective ability to displace hydrogen, as well as each other, is known as the electromotive series. The activity refers to various types of reactions involving the metals, among which is the relative activity of the metals in displacing hydrogen from acids and water. The farther an element is above hydrogen in this series, the more energetic is the displacement. The metals below hydrogen in the series do not displace it. Metals with high negative electrode potentials stand at the head of the electromotive series.

The listing also represents the order in which the metals replace one another from their salts, a metal higher in the series replacing one lower down. In general, a metal will displace any other element from its compound if the former is above the latter in the series. For instance, iron is above copper in the series and if metallic iron is placed into a solution of copper sulphate, the copper is displaced by the iron—the metallic copper is set free and the iron dissolves. The chief metals are generally given in the following order:

potassium
strontium
calcium
sodium
magnesium
aluminum
manganese
zinc
cadmium
iron
cobalt
nickel
tin
lead
hydrogen
copper
mercury
silver
platinum
gold

PHOTOSYNTHESIS

Water has an essential part in photosynthesis, the process by which the sun's energy is harnessed first for the life of plants and then for animal life. Photosynthesis is the reverse of combustion, sunlight on the green plant breaks the chemical bonds of water, dissociating water into its elemental gases, liberating the oxygen and causing the hydrogen atoms to be transferred eventually in such a way as to form carbohydrates. In this manner, the green plants are able to synthesize organic compounds from inorganic substances. That the chemical bonds of water are broken during this process, has been known only since heavy oxygen, isotopic O^{18}, has been used in water—for the oxygen evolved by plant life in these experiments has been O^{18}.

Some experimenters have gone even further and dealt directly with isolated chloroplasts. After referring to the previous use, by other experimenters, of O^{18} as a tracer in demonstrating the splitting of water by photosynthesis as the source of oxygen, they say: "We have been able to demonstrate that the oxygen evolved by isolated chloroplasts also originates from water, which is in accord with the stoichiometry of the reaction." [30]

Inasmuch as it had been thought for many years that the evolved oxygen had been liberated from carbon dioxide, experimenters have introduced the O^{18} into either the water or the carbon dioxide in order to ascertain whether the evolved oxygen was in part liberated from the carbon dioxide. "The results are consistent with the interpretation that the whole of the oxygen originates from the water molecules..." [31]*

It can be seen that the green plants make available to animal life the great resources of solar energy, as well as, the constant renewal of vital atmospheric oxygen supplies. The dissociation of water by photosynthesis, not only provides animal life with the needed oxygen, but also provides the hydrogen which combines with the carbon dioxide, also taken in by the plant, to form the food for the plant's growth. Ultimately, plant carbohydrates are the sole source of energy foods for all animal life, including man. However, the dissociation of water into its two elemental gases, abstracts water from the earth's supply. How much water is so lost, requires the prior quantification of other data. But, before proceeding with such quantification, it should be understood that combustion, the processes of metabolism in both animal and plant life produces water. This fact, however, does not destroy the significance of the calculations for if metabolic water produced by plants were to equal the water lost by photosynthesis there would be no growth.

Apparently a similar process of extracting hydrogen from water takes place in animal cells. The cells replace their stores of fat by synthesis and also synthesize new acids. Evidently, says Downes [32], these syntheses build up the acid chains by the use of a two-carbon fragment and that approximately half of the hydrogen contained in the acid comes from body water.

WATER LOST BY PHOTOCHEMICAL DISSOCIATION, ETC.

Two molecules of water are required to form one O_2 molecule, and the ratio of O_2 liberated to the CO_2 consumed, is approximately unity. [30 p. 54]

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*Reprinted with permission from Robert Hill and C. P. Whittingham, "Photosynthesis", 1955, John Wiley & Sons, Inc.

According to Gordon Riley [33], about 146 billion tons of carbon are fixed by plant life annually, including both sea plants and land plants. If we assume the fixation of 146 billion tons of carbon annually, then this amount is produced from about 535 billion tons of carbon dioxide. If 535 billion tons of carbon dioxide are reduced annually, then approximately 535 billion tons of O_2 are liberated annually. And 535 billion tons of O_2 liberated annually from water represents the destruction of about six hundred billion tons of water each year, a rate in excess of 390 billion gallons each day. The total mass of the oceans, which for all practical purposes represents the hydrosphere of the earth, is 14,060 Geograms [34], which equals 1,405 x 10^{15} tons, or 1,406,000,000 billion tons of water. At the rate of six hundred billion tons of water being dissociated annually, it would take about two and one-third million years for all the waters in the oceans to be depleted. If new water were not being produced in the interior of the earth and added to the surface supplies, the earth would have run out of water a long time ago.

The initial small supply of oxygen present in the atmosphere, Poole [35] reasons, was the product of photochemical dissociation of water vapor. The atmosphere contains water vapor in amounts ranging from two-hundreths of one per cent to four per cent by weight. The content diminishes rapidly with height and varies according to latitude. At the equator, it is 2.63 per cent by volume; at fifty degrees north latitude, it is 0.92 per cent, and only 0.22 per cent at seventy degrees north latitude. The total mass of water vapor in the troposphere is estimated to be 0.13 Geograms, or thirteen trillion tons of water.

It is currently believed that high in the troposphere, above about 70 km., especially over the equatorial belt, water vapor is bombarded by cosmic rays and dissociated into hydrogen and oxygen. The hydrogen, being lighter, escapes up to the higher strata of the atmosphere and may even dissipate into the void. Kuiper [36] has carefully analyzed this photochemical dissociation of water vapor in the upper atmosphere. His estimates of the production of oxygen by this method would mean that almost two and one-half million tons of water are dissociated annually, and that throughout the four and one-half billion years of the earth's existence more than 11 x 10^{15} tons of water would have been so dissociated.

There can be no question, that the water fixed by the weathering process had been temporarily removed from the earth's hydrosphere. The decomposition of rocks, known as weathering, consists of several processes that gradually break down the solid rocks into an aggregate of loose material. One of the most important of these processes is the rain water which falls on the surface of a rock and, flowing over it, dissolves the rock minerals or decomposes it, and in the process some of the water becomes fixed with the rock minerals. "If there were no additions to the atmospheric and to the terrestrial water supply," says Tolman, "fixation of water by weathering would ultimately exhaust the earth's water supply." [37]* However, the amount estimated to be fixed by the weathering process is about two and one-fifth per cent of the total quantity of water in the earth's hydrosphere, or about thirty thousand trillion tons of water. [38]

Man made weathering, that is, the water chemically combined with cement, sand, and gravel to make concrete, or combined in plaster, becomes unavailable for further use by man until these materials are decomposed. When portland cement, for instance, is mixed with enough water to form a paste, the compounds of the cement react with the water to form both crystalline and jelly-like products. These products adhere to the aggregate and to each other. The water-cement ratio is the single most important factor in the strength of concrete. In other words, regardless of what quantities of aggregate are used, so long as they are clean and of sound particles and the mixture is plastic and workable, the strength of the concrete at a certain age is practically fixed by the quantity of water used for each sack of cement in the mixture.

World wide production of cement, during the year 1956, was estimated at 235 million metric tons. This amount converts to about four and one-half billion sacks of cement. If a relatively dry mix of five gallons per sack of cement is used, then approximately twenty-two billion gallons of water are used in one year. Only about one-third of this water is evaporated, the balance entering into chemical combination and hence no longer available for use by man until disintegration takes place. Throughout history, man must have fixed, in this manner, tremendous quantities of water.

*By permission from "Ground Water", by Cyrus F. Tolman, Copyright 1937, McGraw-Hill Book Company, Inc.

Recent investigations have shown that the total body water, as a percentage of total human body weight, averages seventy-seven per cent for infants, sixty per cent for adult males and fifty-four per cent for adult females. Of course, the various body tissues contain different amounts of water. For example: the cerebrospinal fluid is ninety-nine per cent water; blood plasma or serum is ninety-two per cent; gray matter of nerve tissue, eighty-five per cent; spinal cord, seventy-five per cent; muscle, seventy-seven per cent; skin, seventy-two per cent, and so on down to tooth enamel which is three per cent water. As an average for the total population, it is generally assumed that the total body water comprises approximately sixty per cent of total body weight.

If it is assumed that the average body weighs about one hundred pounds, approximatey sixty pounds of water is contained in each average body and therefore unavailable for water supply. Using the currently estimated world population of two and nine-tenths billion people, then eighty-seven million tons of water are tied up in people. The annual population increase, an estimated fifty million people, would likewise withhold an additional one and one-half million tons of water each year. The population of the larger domestic animals in the United States, for instance, is some twenty million in excess of the human population, and they too withhold water.

All animals obtain water from three sources: (1) the free water that is consumed; (2) the water contained in food, and (3) the water produced during the metabolic process, known as metabolic water. For every gram of fat, starch, or protein that is oxidized in the body, an estimated 1.07, 0.56, and 0.40 grams of water are produced respectively. It has also been shown that in their synthesizing processes the cells dissociate water into its elemental gases.

UNAVAILABLE WATERS?

In almost all modern handbooks of mineralogy the crystal structure is the basis of the classification of minerals. Crystalline rocks contain water in varying amounts. For instance: Brucite contains thirty-one per cent; Kernite contains 26.3 per cent, and Chalcanthite contains 36.1 per cent. Arie Poldervaart [39] estimates that there is about 22,000 x 10^{15} tons of crystalline rocks in the earth's crust and that the total amount of water contained therein is probably 1,800 to 2,700 x 10^{15} tons, which is in excess of the 1,405 x

10^{15} tons of water estimated to be in the earth's hydrosphere. Horton [40] says that the science of hydrology is not concerned with such waters of crystallization. Although these waters are generally regarded as being unavailable, it will be shown that they constitute a potential supply.

WATER, THE MINERAL

H_2O is a mineral, which Dana, one of the world's foremost mineralogists, referred to as hydrogen oxide. That water is a mineral is commonly accepted. The waters of the hydrologic cycle are frequently referred to as natural waters. Rankama and Sahama have said that the natural waters in their various states, liquid, gas, or solid, are actually rocks formed by the mineral water, H_2O. [34 p. 265] This is properly interpreted, by saying that all natural waters, the waters of the hydrologic cycle, are formed by the mineral water which has its origin deep within the earth as do the other minerals of economic value.

Washington [41], referring to Hillebrand's classification of water in rocks, speaks of "essential hydrogen" and "nonessential hydrogen" depending upon whether its presence is necessary for the constitution of a mineral. Realizing that the mineral water, H_2O, comes into being as a result of applying heat or a catalyst to a proper mixture of hydrogen and oxygen, the occurrence of hydrogen and oxygen within the earth must also be examined.

HYDROGEN

Most astrophysicists believe that the proton-proton set of reactions and the carbon cycle are responsible for the energy production of most stars. Both the proton-proton set of reactions and the carbon cycle consume hydrogen which is the most abundant element in the stars. As a primary source of cosmic energy, the proton-proton set of reactions is now thought to be the more important one resulting in the synthesis of a helium nucleus through the fusion of four hydrogen protons. It has been estimated that fifty-five per cent of the total mass of the sun is hydrogen and that through the proton-proton set of reactions and the carbon cycle four million tons of solar hydrogen are converted into radiant energy each second and 560 million tons of solar hydrogen are converted into 560 million tons of helium each second.

Hydrogen is an element that occurs in the earth, in the waters in and on the surface of the earth, in the atmosphere, and in plant and animal life. Hydrogen forms more compounds than any of the other elements, including carbon. In the earth, hydrogen is found combined in mineral structures, also as a constituent of water, and as an occlusion in metals as follows:

1. Hydrogen is combined with oxygen to form independent hydroxyl groups, (OH). The OH^- ion forms an essential constituent of the structure and cannot be removed without the collapse of the structure. The hydroxyl form replaces part of the acid so as to make a basic salt, as in malachite. In a few minerals, known as hydroxides, hydroxyl is present to the entire exclusion of an acid, as in brucite. In rare cases hydroxyl is present without a base, as in sassolite. In all of these hydroxyl cases, says Winchell [42], the breaking up of the minerals during analysis yields water even though the water molecule as such is probably not present in the original material.

The role of hydrogen in hydroxides depends on the size of the cation (a positively charged ion) and on its polarizing power. As the polarization increases the bond goes through three stages—first an ionic bond, then a hydroxyl bond, and finally a hydrogen bond. When the polarization is small, the OH^- ion retains its polar symmetry when bound to a cation, an ionic bond is formed and the hydroxide is readily soluble. As the polarization is increased, the binegative oxygen undergoes tetrahedral splitting so that the negative charge of oxygen, in one hydroxyl group, is attracted to the positive charge of hydrogen belonging to a neighboring hydroxyl group, thereby forming an hydroxyl bond. As the polarization is still further increased to an electrostatic valence greater than one, a hydrogen bond is formed, which is weak enough to cause the formation of a soluble complex anion. [34 pp. 239-240]

2. Hydrogen is combined with oxygen to form water molecules which are present in minerals as "water of crystallization." Water of crystallization is clearly in some kind of chemical combination with the other constitutents present, and the expulsion of water occurs at a definite temperature, with the absorption of heat, accompanied by the destruction of the crystal structure. Gypsum, for instance, contains two molecules of water of crystallization, three-fourths of which may be expelled at 130° C, and the remainder at about 165°

C. Its properties, however, are abruptly changed when it loses its water.

3. Hydrogen is combined with oxygen to form water molecules, but, in this case, the water molecules are only loosely combined within the structure and may be removed by heating without damage to the structure or alteration of its properties. The amount of water present is indefinite, depending upon the temperature and vapor pressure, and is not expelled at a definite temperature, but through a wide temperature range. Upon cooling, in the presence of water, the crystal will take up water again and commonly will absorb many times its own volume.

4. Hydrogen occurs as independent $H+$ and H^- ions. The former are found, for example, in certain salt minerals and the latter occur in hydrides. As far as the upper crust of the earth is concerned, this manner of occurrence of hydrogen is quantitatively of minor importance.

5. Rocks also contain hydrogen as a constituent of the water in inclusions and in their pore spaces.

6. Considerable hydrogen is produced in recent sediments as a result of the anaerobic decomposition of organic matter.

7. The H_2 molecule has two protons which may be spinning in the same direction (known as ortho-hydrogen) or may be spinning in opposite directions, one clockwise and the other counter-clockwise (para-hydrogen). At very low temperatures, the para-hydrogen form prevails but as the temperature is raised the mixture becomes richer in ortho-hydrogen until the limiting ortho-para ratio of three-to-one is reached. Sudden temperature changes, however, do not cause rapid shifts in the ortho-para ratio unless a good ortho-para catalyst, such as the platinum and palladium metals, are also present. Platinum and palladium, along with several other metals, such as iron, gold, and a few others, have the property of occluding or absorbing large volumes of hydrogen, and palladium, for instance, in the form of a powder, will adsorb over eight hundred times its own volume of hydrogen.

8. More than a hundred years ago, the French geologist Boisse suggested that the meteorites formed a counterpart of the interior composition of the earth. Today, in addition to the knowledge offered by geophysics, the chemical composition of the meteorites are still

taken into account in the formulation of the chemical composition of the earth, and, of its various geochemical spheres. Hydrogen, along with carbon monoxide and nitrogen are the most abundant gases occluded in the irons of meteorites, and hydrogen, carbon monoxide, and carbon dioxide are the most abundant gaseous constituents of the stones of meteorites. [43] It is known that the volume of gases released by meteorites, upon heating, may be as high as sixty times the volume of the heated material.

According to Daly [44], it is quite possible that much hydrogen and other volatile gases were trapped in the interior of the condensing gaseous body in the geochemical evolution of the earth, and that, therefore, the upper layer of the iron core of the earth may be relatively rich in dissolved hydrogen and the other gases. Kuhn and Rittman have propounded a theory, which has not received widespread acceptance, that the interior of the earth consists of compressed solar material rich in hydrogen and helium, surrounded by a layer very rich in iron and the heavy atoms, and encircled by a silicate crust.

9. In 1815, Prout advanced the hypothesis that hydrogen is a primordial substance of which the other elements are compounds. This concept was based upon the fact that the values of atomic weights of the elements, as then known, were approximately integral multiples of the atomic weight of hydrogen. According to Venable [45], if chemical atoms are composed of or contain hydrogen atoms in their structure, it might be possible to liberate hydrogen, at least temporarily, which should show itself in the spectra emitted by the arc or spark in which the dissociation occurred. Venable, as the result of much spectroscopic investigation, believes that the large number of factual data he presents shows unmistakable evidence of the contribution of hydrogen to the spectra characteristics and that hydrogen is a dissociation product of lithium, nitrogen, and oxygen, but not of beryllium, boron, or carbon. Venable says that the relative abundance of the chemical elements does not indicate sufficient hydrogen in the earth to enter into the structures of all the chemical atoms that require hydrogen as well as to supply the hydrogen in all the chemical compounds that contain it, but that this is explained by the fact that the relative abundance of the chemical elements does not directly indicate the relative abundance of the sub-atoms into which they may be resolved. [45 p. 101]

OXYGEN

We live on an oxygenated earth. The bulk of the earth's oxygen is neither in its atmosphere nor in its hydrosphere, but is in the upper crust of the earth known as the upper lithosphere. Oxygen fills more than nine-tenths of the space occupied by the atoms in the rocks of the upper lithosphere [34 p. 612] comprising 91.83 per cent of its volume or 46.42 per cent by weight, on a water free basis. In fact, oxygen is the only important anion (a negatively charged ion) in the upper lithosphere, whereas all other quantitatively important elements occur as either cations (positively charged ions), or form anion complexes with oxygen. The oxygen content is lower in the basic rocks than in the acidic ones. Outside the crust of the earth, oxygen is distributed in both the atmosphere and in the hydrosphere. The amount of oxygen in the atmosphere is only about a thousandth part of the quantity present in the hydrosphere. Oxygen comprises about eighty-six per cent of the hydrosphere and only about twenty-three per cent of the atmosphere.

A FIXED AND IMMUTABLE QUANTITY?

At the beginning of this chapter, reference was made to the fact that too many people think of water in terms of a fixed and immutable quantity. It has been noted that water is the product of the chemical combination of hydrogen and oxygen and that water is also dissociated, by many processes, into its two elemental gases when the chemical bonds of water are broken. It is, therefore, almost unbelievable that based on the concept that matter can neither be created nor destroyed, the following statements could be made: "Water is matter. There is as much now as there ever was—no more, no less." And the subsequent statement: "Since in the strict sense water is never lost, it might be argued . . ." [46]

In a democracy, the task of keeping the citizenry informed is difficult but necessary and vital to the continuation of that democracy. The League of Women Voters is a continuing and effective force in keeping our citizenry alert, but unfortunately, due to the complexities of modern life and as is illustrated by the aforesaid quotations, they too must rely on the experts.

How someone could conclude that water is matter and that there is as much now as there ever was might be explained by Bertrand

Russell as follows: "First, when a set of events are all in accordance with some law, we expect other similar events to be in accordance with it. Secondly, when a set of events appear irregular, we invent hypotheses to regularize it." [47]*

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*From "The Analysis of Matter" by Bertrand Russell, reprinted by permission of Dover Publications, Inc., New York 14, New York. ($1.95)

> Courage is a special kind of knowledge: the knowledge of how to fear what ought to be feared and how not to fear what ought not to be feared.
>
> —DAVID BEN-GURION

CHAPTER III

NEW WATER

If water can be located in the earth in areas, other than where conventional practice would explore, then for all practical purposes such water may be termed "new" water, irrespective of its origin, for otherwise this water would not have been obtained. Young [18] had mentioned water from deep-seated sources ascending until it either flows out from some surface opening or its further upward movement is stopped by the attainment of equilibrium and it feeds fissures or systems of fissures. Certainly, if water has its genesis within the earth and this water can be tapped in areas other than where conventional practice would explore, it is "new" water.

Perhaps it is to Aristotle that we may attribute the earliest concept of the origination of water occurring within the earth itself. His views on the origin of springs and rivers are to be found in his Meteorologica. Aristotle held that water which flowed out of the earth in the form of springs consisted in part of: rain water which had percolated into the earth's crust; water which formed from the condensation in the earth of atmospheric air, and from water which "rose" from some source which he does not state.

Although we have learned to distinguish water vapor from air, Kuenen [48], a well known Dutch geologist says that the reality of the process is not questioned but that the amount of ground water formed by condensation from the air in the ground is a point of contention. Kuenen points out that this idea of Aristotle's exemplifies the fact that a theory may be the plaything of time for it has had a long history of acceptance, then rejection, refurbishment and then again tossed out only to be resuscitated again only a few decades ago.

Georgius Agricola, considered to be the father of modern mineralogy, writing in the sixteenth century, discusses two kinds of ground water. The first being the surface waters which have percolated into the earth and now called meteoric water, and the second being the waters which originate in deep seated sources within the earth itself. [49]

Another special exponent of the theory of juvenile water was Edward Suess, whose principal paper on the subject was published in 1902. He described how the students of ore deposits came from various vague theories to a clear understanding of the important functions of circulating ground water and later to a belief in the importance of magmatic separation, which involves the segregation of water from the magma and that this water is closely related to the genesis of metalliferous deposits. [50] Since Suess, there have been many prominent scientists who have expounded the theory and also pointed out the geologic evidence that water has its genesis within the earth. The evidence shall be examined later.

Although "new" water theories have existed for many centuries, the important question which should and does arise is—can these waters be located through scientific knowledge and at economic cost?

Piper, writing about the nation wide water situation, has said: "Ground-water reservoirs contain the largest fresh-water storage in the Nation—in the aggregate several times the estimated storage in the Great Lakes and possibly in the order of 10 years' average rainfall or about 35 years' average run-off. This underground storage is nature's accumulation over the centuries; a small part and only a small part, is available for use by man." [51] Piper does not say how such vast quantities of water came into being. However, the salient point is that the existence of such tremendous quantities of water, from whatever source, is acknowledged even though it is believed that the bulk of it is unavailable for man's use.

These quantities of water are tremendous. If calculated by an average annual rainfall of thirty inches, it would amount to over forty-eight billion acre feet of water under the surface of the United States. If calculated by the average nation wide run-off (the 1921-1945 average was 8.6 inches), it would also amount to over forty-eight billion acre feet, which means more than fifteen billion billion gallons of water, also expressed as 15 x 10^{18} gallons of water. At our present high rate of water consumption, it would last for over two hundred years, and even at the astronomically high daily consumption of 450 billion gallons daily, foreseen by The New York Times by 1975, it would still last for more than ninety-five years.

Water costs are continually going up, but even at the average price paid for the last eight years by the city of San Diego for Colorado River water, $11.35 per acre foot, the ground waters of the United States would be worth some $530 billions. Or if Santa Barbara's cost of thirty-five dollars an acre foot were used, these underground waters would be worth $1,680 billions.

It would certainly appear reasonable to say that research expenditures in the tens of millions of dollars would be more than justified if thereby these heretofore "unavailable" waters could be produced and made available at economic cost.

If the answer to our earlier question concerning the location of "new" waters through scientific knowledge be answered in the affirmative, and if it were also contended that it can be found in areas where conventional ground water cannot be found, it is most certain that many people will say that these "new" waters are only a part of nature's accumulation over the centuries. It may be that the waters stored by nature are also mixed with newly added meteoric water as well as with new water formed within the earth. At this juncture no one is able to determine the degree and the extent to which such waters may be mixed. However, the following should also be recognized. From the practical standpoint of the benefits a solution to a very difficult problem may hold for mankind, one usually isn't concerned with what name is ascribed to the solution. Also from the point of view of being practical in money matters, one usually doesn't mind what the product is called as long as it makes money. And certainly, a method of making the "unavailable" available would be worth millions.

But from a scientific viewpoint, there is one difficulty with this line of reasoning, and it is a major one. Neither the "unavailable" waters nor the "new" waters can be either located or produced at economic cost by the modern science of hydrology. However, the "new" waters can, have been, and are being located by scientific methods based on the theory that the genesis of water occurs within the interior of the earth.

It must be that a hypothesis becomes verified, even if not proved beyond every doubt, through the successful predictions it makes. It is also true that human inquiry, throughout the course of history, has been guided, both frequently and usefully, by hypotheses which were later proved to be incorrect. The phlogiston theory of combustion in chemistry, for instance, was useful and generally accepted during the eighteenth century, but was finally refuted by Lavoisier. The corpuscular theory of light, that light consists of minute corpuscles in rapid motion, was not abandoned until the middle of the nineteenth century. But when it was abandoned, it was done so in favor of the wave theory of light which was first put forward, almost two hundred years before, by Huygens in 1673. Later research, however, has shown that all light phenomena can be interpreted in terms of photons or waves, so that the two descriptions are now merely two different ways of viewing one and the same reality.

In addition to the predictive occurrence of new water, which will be discussed shortly, there have also been accidental as well as natural occurrences of new water.

NATURAL OCCURRENCE

In the United States, according to Meinzer [52], there are doubtless thousands of springs that yield 650,000 or more gallons a day, hundreds that yield 6,500,000 or more gallons per day, and there are sixty-five springs that have an average yield of sixty-five million or more gallons a day. Of these first magnitude springs, which discharge not less than sixty-five million gallons daily, thirty-seven rise in volcanic rock, one is in gravel underlain with volcanic rock not far below the surface, twenty-four are in limestone and three are in sandstone. The first magnitude springs which rise in the volcanics are closely associated with faults, and the first magnitude springs that issue from sandstone, do so from large fissures produced by faulting or other agency.

"The present study," says Meinzer, "has shown that the fluctuations of the large limestone springs, whether in Florida, Missouri, or Texas, are as a rule much greater and more sudden than those of the springs in volcanic rock, whether in Idaho, California, or Oregon." [52 p. 7] Meinzer also found that the water of most large springs in volcanic rocks is remarkably low in dissolved mineral matter. A few of the largest springs that rise in volcanics and their respective flows are given as follows:

Spring or spring group	Gallons per day (in millions)
Sheep Bridge Spring, Oregon	209
Opal Springs and vicinity	650
Springs in the upper ten miles of Metolius River, Oregon	692
Springs at the head and along ten miles of Fall River, California	905
Malade Springs, Idaho	732
Thousand Springs, Idaho	558
Springs along fifty mile stretch of Snake River, Idaho	3,787

The drainage area of the Metolius River is approximately 325 square miles, and the mean yearly run-off is 1,023,900 acre feet, or 58.50 inches depth on the drainage area. The drainage area of the Metolius River is only three per cent of that of the Deschutes River, of which it is a tributary, yet its mean run-off is 24 per cent of that of the Deschutes River. "In terms of depth of the drainage area, the mean yearly run-off from the basin of the Metolius River is 7.8 times that from all the basin of the Deschutes; probably it exceeds mean yearly precipitation on the drainage area." [53]

Using this data, but focusing on the upper ten miles of the Metolius River which is approximately forty miles long—the springs yield 692 million gallons daily, or approximately 775,000 acre feet yearly, constituting more than seventy-five per cent of the yearly run-off for the whole of the Metolius River. The drainage area for the first ten miles of the river, at most, would not exceed one hundred square miles. If fifty-eight and one-half inches depth on the entire drainage area exceeds mean yearly precipitation, then it becomes apparent that the yield of the springs, equivalent to approximately 145 inches for the drainage area of the first ten miles, is far in excess of the mean annual precipitation.

Of the twelve major drainage basins in the United States, the state of Oregon falls into that region wherein the ratio of run-off to precipitation is the greatest. In other words, the run-off is approximately fifty-seven per cent of the total precipitation. Whereas the remaining forty-three per cent is comprised of evaporation, transpiration, and infiltration into the underground. [51 p. 5]

The Snake River, with its tributaries, the Salmon, Boise, Payette, and Clearwater rivers, drains some sixty thousand square miles of land in Idaho. The Snake River Springs, with a daily discharge of 3,787,000,000 gallons, is said to equal the surface run-off from seven thousand square miles. The Snake River Springs are located in what is known as the Columbia Lava Plateau which encompasses parts of Idaho, Washingon, and Oregon. It is interesting to note in passing, that lavas that may be cool enough to walk on still contain tremendous heat only several inches below. Even twelve years after a Vesuvian eruption, steam had been seen issuing from vents in its lavas, and lava was still steaming in 1830 from an eruption of Etna in 1787.

ACCIDENTAL OCCURRENCE

"In drilling Tecolete, work was impeded by subterranean water flows of 9,000 gallons a minute. Temperatures of 112 F° were encountered and the humidity often ran 200 per cent at the heading." [54] Some of these waters were cool and fresh, whereas others were hot and mineralized. Tecolete refers to the Tecolete tunnel which runs 6.4 miles through Santa Ynez mountain range to carry water from Cachuma Reservoir to Santa Barbara, California, and other coastal cities. Construction work started on Tecolete tunnel in January 1950; the first unit of the Cachuma Water Project to be started and the last to be completed. The Cachuma Water Project was completed in the spring of 1957 at a cost of forty million dollars and when in full operation should yield an estimated thirty thousand acre feet of water to the coastal cities at a cost of thirty-five dollars per acre foot and twenty-five dollars per acre foot for coastal agricultural districts.

Another recent illustration of the accidental occurrence of new water is just across the continent from our first, in the city of New York. Under a contract with New York's Department of Public Works, the firm of Psaty and Fuhrman, Inc., contractors and engineers, began construction of an addition to the city's Harlem Hospital on a lot 130 by 175 feet at the intersection of Fifth Avenue and 136th street.

On February 14, 1956, after having excavated little more than twelve feet below the first floor of the adjacent, existing hospital building, water was encountered which was pumped out at a rate exceeding 2,200 gallons per minute, or more than three million gallons per day. When these waters were first met and the pumps put to them, the contractor noticed that the water level dropped in all areas of the excavation with the exception of its western end.

Contractor's representatives, city officials, and consulting engineers retained by both, tried to find the source of the water and to account for its temperature. The temperature posed a riddle, for, during the months of February and March of 1956, the temperature held firm at sixty-four degrees fahrenheit but, then gradually, it increased until in the middle of August, 1956, it reached sixty-eight degrees. From then until pumping was stopped seven months later, in March, the temperature of the water remained fairly constant. In other words, no matter what the air temperature was, whether during the summer or winter, the temperature of the water remained constant.

Tests, conducted by the city's Department of Water, Gas and Electricity, proved that this water was not from the regular city supply sources for the area, the Croton Reservoir. Uranine, a green dye, was poured into the adjacent sewers, but none appeared in the water being pumped out. Finally, when hospital chemists certified that the water was fresh, completely free of sewage and in fact fit for human consumption without treatment or chlorination, it also ruled out the nearby polluted Harlem River as the source of these waters. More than one and a quarter billion gallons of water were pumped during the thirteen month period. The pumps kept working until twelve stories of structural steel were erected and several floors had been decked with concrete slabs. "Only at that point did engineers decide there was enough weight to hold the foundation down against the hydrostatic pressure." [55]

Several months had gone by after the appearance of this story in Engineering News-Record, and despite the fact that the story had ended on a note of mystery in not being able to explain either the origin of the tremendous quantity of water or its constant and elevated temperature, still there were no comments from any of its readers. In answer to a brief article submitted, Salzman received a letter from the Senior Editor of Engineering News-Record stating that: "since the matters that you have discussed were a bit beyond the knowledge of any present staff members, I have taken the liberty of asking a number of experts of my acquaintance for their opinion on the article. This letter is to advise you that most of our consultants agree that we should print your discussion of the matter, since it presents an interesting and little-discussed theory on the replenishment of water supplies."

When Salzman's article was published five months after the original story, it carried an editor's note which in part said: "It is surprising that despite efforts of many agencies, the source of the flow has apparently never been determined, and more surprising that there has been no comment to this journal on possible reasons for the flow and its origin. The first such comment is included in the following material. .." [56]

In the New York City Folio of the Geologic Atlas of the United States, is an interesting statement: "There is, perhaps no more important consideration in the founding and growth of a city than the municipal water supply. The city of New York, located on a rocky island, is not favorably situated for the collection and use of surface streams." In that publication, several wells which had been prosecuted through solid rock are mentioned. For instance, in the year 1834 at Thirteenth street near Broadway, a well one hundred feet deep produced twenty-one thousand gallons daily, and at Broadway and Bleecker, a well 442 feet deep yielded forty-four thousand gallons a day. [57] What those old New Yorkers would have given to have a well at only twelve feet deep and yielding in excess of three million gallons daily.

But in spite of the fact that New York city has its water shortages, no effort was made to utilize this new water. Obviously, three million gallons per day is in reality only about a drop in the bucket of that city's water supply needs, but certainly instead of being diverted and poured into the storm drains it could have been put to some specialized use. Then, when construction had proceeded to a point where pumping could be stopped, the water was blocked off. One would imagine that this naturally pure water could have been put to some use. There can be but one reason why this water, despite its purity and constant flow, is not used, and that lies in the many fears associated with it since its existence cannot be explained by conventional hydrologic practice.

One other comment about this New York city occurrence. The New York City Geologic Folio, referred to above, indicates that a sedimentary stockbridge dolomite underlies the thin till or the stratified drift which is locally very thin. However, the stockbridge dolomite is described as coarsely crystalline, dolomite, often containing diopside and tremolite. Bateman states that epigenetic replacement of limestone results in many dolomites and therefore many are not sedimentary. [58] Magnesium rich hydrothermal solutions which come in contact with calcium carbonate form dolomite. [34 p. 456] Furthermore, both diopside and tremolite, which were often found to be contained in the dolomite, are not products of surface weathering and are not associated with sedimentary rock. Both of these minerals are formed by either hypothermal deposition or by contact metamorphism, and in addition diopside may be formed by pegmatites. These terms will be explained later.

In addition to the above recent illustrations of the accidental occurrences of new water at Tecolete and in the city of New York, past experiences in mine shafts have also revealed the occurrence of new water. Many shafts that were dry at intermediate depth were later flooded out by ascending new water at greater depth. The mine at Eureka, Nevada, operated by The Eureka Mining Co., Ltd., was flooded out more than ten years ago and even now, in order to continue mining operations, 7,500 gallons of water are pumped per minute with a lift of 1,800 feet. A flow of 7,500 gallons per minute means 10,800,000 gallons per day. The caption under the photograph understates the condition when it says: "Overabundance of water is a rare affliction in the arid-basin region." [59] Tombstone mine in Arizona was flooded out by ascending new water, and it is recalled that not too long ago there had been a decision made to utilize these waters for a municipal water supply.

PREDICTIVE OCCURRENCE

In the Britannica 1957 Book of the Year, which covers events of 1956, is the following statement:

"Stephan Riess of California formulated a theory that 'new water', which never existed before, is constantly being formed within the earth by the combination of elemental hydrogen and oxygen, and that this water finds its way to the surface and can be located and tapped, to constitute a steady and unfailing new supply." [60]

A brief unpublished statement by Stephan Riess, in March 1954, explains that it has been known for a century that under certain conditions some rocks yield hydrogen and oxygen gases which subsequently combine to form new water. Riess continues: "In connection with the mining and recovery of gold, a natural coincidence led me to suspect, many years ago, that such a laboratory reaction might proceed within the earth. Coexisting with the natural reagents occurring separately and together in rock were necessary physical conditions such as temperature and pressure. From this basic approach followed years of comparative study, in many parts of the world, of geological formations and their contained minerals in mines of varying depth and physical conditions. Ultimately, it was established that certain fundamental conditions, chemical and geological, occurring simultaneously, were essential and did indeed create new water within the earth. Like other earth-making natural resources, then, water was determined to have a natural, scientifically explained genesis, with a predictable occurrence. While practical use of this discovery can and is being made," says Riess, "there is much to be learned to perfect techniques regarding quality and quantity estimations for each new well presents a new situation, development of which adds to the general store of knowledge. At present, in an unfamiliar area, considerable expense is involved in laboratory analyses of rock to get the location leads on unexposed subsurface production areas." [61]

Riess calls the new water he finds "primary" water because of its close association with the primary minerals. According to Tarr, the primary mineral deposits are those formed by direct magmatic action. Tarr [62] states that the splitting of magmas results in the basic igneous rocks and their accompanying group of accessory minerals formed by the first crystallization in the magma, on the one hand, and in the acidic igneous rocks and a second group of accessory minerals which were formed by deposition from the residual mother liquors.

Hatch, Wells, and Wells [63] divide the cooling and crystallization of a magma into a number of stages which are based largely on the dominance of the roles of temperature and concentration of volatiles. The first stage, the orthomagmatic stage, accounts for the crystallization of the greater part of the component minerals in the case of a basic rock. These early, pyrogenetic minerals comprise the majority of silicates found as primary constituents in the basic rocks, that is, the olivines, most pyroxenes, the calcic plagioclases, etc. The orthomagmatic stage is followed by the pegmatitic stage of crystallization, then the pneumatolytic and hydrothermal stages. The pegmatitic, pneumatolytic, and hydrothermal stages are the result of the gradual enrichment of the volatiles in the residual mother liquors and the deposition therefrom—and water is by far the greatest single volatile.

Primary mineral deposits are classified as syngenetic, if they were formed at the same time as the parent rock, and epigenetic, if they were subsequently introduced into a rock from an outside source. Epigenetic magmatic ore deposits consist of various types of deposits which are governed by the varying conditions the residual liquors encountered after they passed into the surrounding rocks, such as: the compatibility or incompatibility of the host rock, the temperature, the pressure, and the presence or absence of various gases. In other words, deposition occurs whenever the physical and chemical conditions bring about the saturation of a given substance.

The various types of epigenetic magmatic ore deposits are contact-metamorphic deposits, pegmatites, deposits of the deep-seated vein zone called hypothermal deposits, deposits of the intermediate vein zone called mesothermal, deposits of the shallow vein zone called epithermal deposits, and surface deposits by magmatic springs. The hypothermal, mesothermal, and epithermal are all forms of hydrothermal deposition. All primary mineral deposits are subsequently and eventually subjected to alteration and weathering, thereby resulting in new deposits called secondary mineral deposits.

Ralph Arnold [64], an eminent geologist who has been honored by many leading universities of the world, writes that Riess has found that water is created in those particular areas of certain rock formations where the following conditions exist:

1. The occurrence of a rather broad combination of minerals; some of which contribute adequate amounts of oxygen and some of which prepare the oxygen-bearing minerals for the dissociation of their contained oxygen.
2. Where hydrogen occurs in an "available" state, and

3. Where essential geologic conditions prevail that are necessary both to complete the liberation of the two elements and supply the action required to bring about their combination in the formation of water.

Arnold agrees with Riess' [65] conclusions that: "These requisite conditions are obscure but not uncommon and must because of their nature, universally obtain at depth." Arnold [64] says: "A fracture or rupture by either natural means, such as faulting or artificial penetration of a water potential area initiates the action that produces water. The purely physical character of the enclosing rock mass has no influence on the water originating properties of the essential feature, except that the rock must be firmly consolidated and of reasonable hard and 'solid' character." Inasmuch as chemical rather than physical properties control, the denser and impermeable rock formations present the more fundamental characteristics for potential water origin—quite contrary to what would be the requirement for the location of meteoric ground water.

Before examining the record of recent locations made by Riess for the production of primary water, it should be prefaced by his statement in 1954. "My discovery was then put to a field test by locating and drilling many water wells. The record to date (1954) from these 'tests' is 70 producing wells out of 72 attempts, all drilled in hard rock, all located in distress areas generally considered unproductive." He continues by saying that production rates vary from a few hundred thousand to approximately three million gallons per day, with the high rates on more recently developed wells, and that several of the earliest wells were never properly completed because of inadequate funds and hard rock drilling know-how. [61]

Simi Valley

In Simi Valley, Ventura County, California, over one hundred conventional wells have been put down, but due to a greater withdrawal of water than the natural replenishment, the valley aquifer was soon drained. Hundreds of feet above these valley wells are three primary water wells having a capacity of 750, one thousand, and two thousand gallons per minute each. These three wells, producing 5,400,000 gallons per day, are all located within an area of less than an acre, vary in depth between four hundred and eight hundred feet, are drilled near a small diabase dike in a north dipping monocline of coarse Eocene sandstone, and were tested over a period of a year during the past five years.

Russell George [66] has said that magmatic or juvenile waters, because of their intimate association with magmas, follow and accompany the magma when it is forced into the outer part of the earth as dikes, latholiths, batholiths, and stocks.

Two of these three Riess wells were included in a study made for the Atomic Energy Commission by the University of California at Los Angeles [67], and in an article published in the Journal of the American Water Works Association in July 1954. [68] It is interesting to note that the number of strontium atoms per one thousand calcium atoms were less in the untreated primary water of these Riess wells above the Simi Valley than in many of the untreated and treated water supplies of the fifty cities surveyed. The aforementioned ratio was less in the Riess wells than in all of the sampled water of the following cities: Boise, Idaho; Boston, Mass.; Great Falls, Mont.; Houston, Tex.; Las Vegas, Nev.; Metropolitan Water District, Los Angeles, Calif.; Owens Valley Aqueduct, Los Angeles, Calif.; Miami, Fla.; New Orleans, La.; Oklahoma City, Okla.; Omaha, Neb.; Phoenix, Ariz.; Portland, Ore.; St. Louis, Mo.; Salt Lake City, Utah; San Francisco, Calif.; and Wichita, Kansas.

Furthermore, the ratio was less in the primary water wells than in at least one or two of the three samples taken of the several water supplies of the following cities: Atlanta, Ga.; Charlotte, N.C.; Dallas, Tex.; Denver, Colo.; Kansas City, Mo.; Little Rock, Ark.; Memphis, Tenn.; Norfolk, Va.; Portland, Me.; Providence, R.I.; Rapid City, S.D.; San Diego, Calif.; and Washington, D.C. [68 pp. 646-650]

The water samples, of the cities to which the primary water was compared, represent the following types of water: raw ground water; raw surface water; untreated tap water; tap water from treated ground water; tap water from treated surface water, and tap water blend.

In some instances the primary water contained greater quantities of calcium, and hence the strontium-calcium ratio could easily be less for the primary water, even though the presence of strontium might be the same or even higher in the primary water. However, this argument is meaningless since this situation occurs in only six of the sixteen cities listed in the first group compared. In addition, the report states that a reduction of strontium concentration accompanies the removal of calcium. [68 p. 653] Hence it is advantageous to have a somewhat higher quantity of calcium, providing that its presence does not exceed the limitations of high quality water and the primary water herein discussed meet this criteria.

These primary wells and the small parcel of land they are situated on received quite a bit of publicity when, after exhaustive testing, they were purchased by Clinton W. Murchison of Dallas for one million dollars. [69]

In a succeeding chapter, reference is made to the Ventura County Investigation of the California State Water Resources Board, which was published in October 1953, and revised in April 1956. Yet despite the publicity attending these Riess wells, and the knowledge of their existence by the state water authorities, no mention was made, in this exhaustive, comprehensive, and expensive investigation, of a supply equal to almost five and one-half million gallons per day. One cannot help wondering, why?

Lakeside, San Diego County, California

A letter from Burton H. Arnds, President of Sparkletts Drinking Water Corporation, dated October 30, 1956, gives a most adequate description. In part Arnds writes: "A couple of years ago, after reading an article in a national publication [4] extolling the unorthodox theory of Mr. Steve Riess developing potable water in areas previously proven arid and devoid of any possibilities of securing more than a trickle of water, I became interested in learning more about Mr. Riess' unusual theory." After mentioning his visits to the Riess wells above Simi Valley, Arnds [70] continues:

> I was so intrigued by these results that I arranged with Mr. Riess to survey our ranch property located two miles north of Lakeside in San Diego County where we had drilled eight holes, five of which produced no water and the remaining tiiree perhaps 100 gallons, or thereabouts, per minute. After studying the terrain, Mr. Riess selected a location, upon which we diamond cored a 3" hole, seeking a deep-seated rock fissure that Mr. Riess stated we would find which should furnish us water that was not produced by rainfall or run-off. The 3" diamond coring was started from the bottom of an 8"—400' well; three hundred feet of coring was in solid granite. The 8" hole was completely sealed off and the diamond core rig continued to a depth of approximately 900' where an 18" to 20" crevice was encountered and the water proceeded to come within twenty feet of the surface.

Arnds says: "This well has now been producing constantly for the past ten months, approximately 300 gallons a minute, of fine high-grade water, with only a drawdown of about sixty feet and also, as predicted, a temperature slightly in excess of seventy degrees." [70]

The production of the well still remains the same, but the significant point to mention here is that the previously existing eight inch diameter well had been drilled to a depth of four hundred feet in unconsolidated rock structures, producing little or no water, and that the drilling had been stopped before getting into the consolidated rock structures—which is typical of present day practice in ground water hydrology. Only after drilling another five hundred feet deeper than the previously existing hole, three hundred feet of which was through solid granite, and hitting a fissure, was the water produced. Like all primary water wells, the water encountered is under tremendous pressure, and in this case, under sufficient pressure to raise the water about 880 feet, to within twenty feet of the surface.

If a greater diameter hole had been drilled, a greater volume of water could have been produced, but the quantity needed could be met by the size hole that was drilled and therefore there was no purpose in going to the additional expense of drilling a larger hole. In passing, it might be well to point out that diamond core drilling can be used for small diameter holes in consolidated rock structures, but that, at present, the prosecution of a large diameter hole in consolidated rock structures—twenty inch for instance—requires the use of the old-fashioned cable tool drill which is far from satisfactory.

Three Rivers, Tulare County, California

Both the Visalia Times-Delta of June 20, 1957 and The Fresno Bee, Fresno, California, of June 23, 1957 carried news stories of the location of a Riess primary water well on the Double Dee Guest Ranch in Three Rivers, owned and operated by Mr. and Mrs. de Lespinasse and Jack Garrity.

In the spring of 1957, after Riess had first made the location, the Continental Drilling Company of Los Angeles went down with a diamond drill to a depth of 439 feet, of which 435 feet was through solid rock. The water rose and came over the surface. The free flowing well runs at ten gallons a minute, at eighty-three degrees fahrenheit, and if the owners wished, the installation of a pump would assure them about one hundred gallons a minute. The article in The Fresno Bee states that an engineer staying at the Double Dee, while making core tests for Terminus Dam, told Mrs. de Lespinasse that she would never get water from the rock formation chosen.

According to the Visalia Times-Delta article, the water shortage in the Three Rivers area is often a serious one, and that many promising sites for homebuilding have not been utilized because of the apparent impossibility of obtaining adequate water supplies. Actually Riess had located two potential well sites. The other well site almost at the doorstep of the Lodge would have been sufficient to supply the whole Three Rivers village with domestic water, but would have cost about $35,000 to develop. The guest ranch owners, however, chose the less expensive location, feeling it would supply sufficient water for their needs.

In a letter dated June 19, 1957, Myna M. de Lespinasse writes: "We encountered a fissure at 439 feet deep in the 3 inch diamond core hole and the water came over the top. The general public, the drillers and government engineers came here telling me that it was stupidity to try and find water in solid granite like this." Mrs. de Lespinasse says that in addition to finding the water flowing as an artesian well, they are doubly pleased that the water happens to be one of the softest and purest to be had anywhere. She closes her letter as follows: "Without water our place would be a total loss, since without it no matter how ideally we are located, easy accessibility and climate, luxurious accommodations, all of this becomes valueless or useless."

Tale of Two Cities

An Associated Press story of May 28, 1958, dateline Coalinga, in Fresno County, California, describes the fact that this little city is planning the first municipal water de-salting plant in the United States. "Coalinga always has had plenty of well water," said Mayor Steele, "but it is too salty to drink. We have had to haul in fresh water 45 miles by rail since about 1900 and the expense has been very great. Last year the city's water freight bill was over $43,000 for a supply of about 17,000 gallons a day." This constantly recurring cost is about $6.90 per one thousand gallons of water, whereas the Double Dee Guest Ranch well, flowing at the rate of ten gallons a minute, or 14,400 gallons a day, cost only eight and one-half cents per thousand gallons if the cost of drlling the well is amortized over a ten year period.

This first municipal water de-salting plant in the United States is a 28,000 gallon-per-day electric membrane plant built by Ionics, Inc., of Cambridge, Mass. It has been estimated that this plant will save the city more than $400,000 during the first ten years of its operation. Certainly a worth-while savings. However, such a savings, based on 28,000 gallons per day, would still mean a cost to the city of about $2.98 per thousand gallons of water. Actually, 28,000 gallons per day is equivalent to about nineteen and one-half gallons per minute.

The other little city, in our tale of two cities, is Cottonwood, Idaho. Cottonwood after a ten year effort to secure an adequate water supply to meet the community's needs, found itself in desperate circumstances. The city was broke, they had drilled seven wells, varying in depth from two hundred to 1,015 feet, during those ten years. Five were dry holes, and the other two supplied amounts far short of the city's needs. Water consultants and water experts from several organizations had said that there was just no possiblity of water production in the area and had, in effect, signed the death certificate for Cottonwood. So that late in 1955, there was serious consideration being given to abandon the city.

The situation appeared hopeless, but someone had read about the successful location of primary water wells in other hopeless areas, and so, an appeal was made to Riess. Hearing of the city's dire circumstances, and always ready to prove his science, Riess set out to make his studies of the area. He located three potential primary water sites. Drilling began on the first location, encountering water at a depth of 540 feet, but drilling continued down to nine hundred feet where a fissure was met, and the water then came to within three hundred feet of the surface. The well was completed in March 1956, producing 250 gallons per minute. Since then the second of the three locations was drilled successfully and the third location is currently being drilled. H. W. Simon, Water Commissioner of Cottonwood, says that the city is growing and prospering and only because of the work that Stephan Riess was able to do for them.

The cost of drilling a large diameter hole through solid rock is about fifteen dollars a foot. This cost plus the other costs incidental to the completion of such a well through to the production and operational stage, and even including the costs of location, add up to about $40,000. Inasmuch as many of the costs may vary somewhat, $50,000 would be a good conservative figure for our purposes. A yield of 250 gallons per minute is 360,000 gallons a day, or more than 131 million gallons a year. Therefore, using a total cost of $50,000 and amortizing this capital investment over a ten or twenty year period, the cost of the water would be less than four cents and two cents per thousand gallons respectively. Even amortizing the cost over a one year period results in a cost of less than forty cents a thousand gallons. The costs of operating pumps, and the maintenance and replacement required would certainly add somewhat to this cost, but comparatively only an insignificant amount.

This is a tale of two cities, not only because of the obvious cost comparison that can be made, but also for another reason. The same person, who had located the new water supplies for Cottonwood, and thereby prevented the origin of a modern day "ghost town," had offered to supply the people of Coalinga with all the water they needed, at twenty cents per thousand gallons, some ten years ago. Instead they have been paying up to $6.90 per thousand gallons in freight costs alone, and now they will be operating a saline water conversion system that will provide them with water at a cost at least ten times as much as the primary water which still can be located and developed in Coalinga's backyard.

In attempting to surmise how such a situation can come to pass, only one possibility clearly stands out—that given expert opinion, by practicing conventional ground water hydrologists, that water production is impossible and that there is no such thing as "new" water, how many people would have the imagination, the faith, and just enough fortitude to try. Where the situation has been described as hopeless, but the stakes are high, some may try. But where other alternatives exist, and the situation is not so desperate, how many will?

The small city of Craigmont, twenty-one miles from Cottonwood on highway ninety-five, finding themselves in a similar position of being short of water and viewing Cottonwood's success, also asked Riess to make a primary water location. Craigmont now has a successful well at a depth of 908 feet and preliminary test pumping indicates a yield of from one to two thousand gallons a minute of fine high quality water. Grangeville, also nearby, is now drilling a Riess located primary water well.

Avalon

The city of Avalon is situated on Santa Catalina Island, in Los Angeles County, California. Located in the Pacific Ocean, twenty-seven miles south from Los Angeles Harbor (Wilmington), its rugged, picturesque mountains rise abruptly from the ocean to a maximum elevation of 2,125 feet—its highest peak, Mt. Orizaba. The island is twenty-one miles long and from one-half to eight miles wide, a total of 48,438 acres, or approximately seventy-six square miles. The average rainfall measured in the city of Avalon, which is at sea level, since 1909 is 12.68 inches, and as the elevation increases, the amount of precipitation on the island increases from two to three inches for each thousand feet. Nearly all the rainfall occurs during the months from November to May. It is said, that during the last twenty years over forty dry holes have been drilled on this island and that many water experts have finally taken the position that no adequate ground water source exists.

The drainage pattern of the island is established by the main mountain ridge which extends the whole length of the island. The island's largest drainage basin, the Middle Creek watershed, is 7.96 square miles in total extent and is situated in the central part of the island southwest of the mountain ridge. The highest elevations on the watershed are Orizaba Mountain with 2,125 feet and Black Mountain with 2,010 feet: the lowest elevation at the lower end of Middle Ranch Reservoir is 640 feet. The water supply has been primarily from the surface run-off contained in the reservoir and the ground water basin of the Middle Creek drainage area. The basin itself is filled to a maximum depth of sixty feet with unconsolidated alluvium, ranging from gravel to clay. There are some older wells near the city but several years ago they became contaminated by sea water encroachment and have become too salty. One of these older wells will be mentioned again. The latest study of the water situation of this island was made in 1957, by a consulting hydrologist, who states: "There do not exist any deep-seated aquifers on the island." [71]

The water consumption during the water year 1955-56 amounted to 130 acre feet. During the water year 1956-57, because of little precipitation that year, the water delivery to the city was cut in half, and then in January 1958, it was cut in half again.

Geologically, Santa Catalina Island is grouped with the Continental Shelf and Island Province and within it with the Southern Franciscan Island Province. Half of the island is formed by the basement complex of Franciscan schists, a metamorphosed sandstone series. One fourth is intrusive rock, quartz-diorite-porphyry, and one fourth is volcanic rock. The basin itself is filled with alluvial, unconsolidated sediments, ranging from gravel over sand to clay, overlying the intrusive rock, quartz-diorite-porphyry. "Only the alluvium is water bearing, from a practical standpoint." [71 p. 10]

Less than one mile south of the city of Avalon and towering above it approximately five hundred feet a potential primary water site was located by Riess. At about the same elevation, but at about one and one-half miles from the city in a southwesterly direction, a second site was selected. These two sites were selected for the production of water to meet Avalon's present and future requirements, and being at much higher elevation than the city itself, gravity flow would carry the water down to the city. Several other potential water sites were selected in other parts of the island for other purposes.

The first drilling site selected was to be the location that had been made closest to the city, and drilling began in the middle of April, 1958. When the hole had been drilled to 190 feet, through solid rock, water came up to within eighteen feet from the surface under its own pressure. Drilling proceeded and at 594 feet a large crevice was encountered, and so were problems, for several cave-ins occurred in the crevice and when the water level dropped in the hole, it became apparent that water was being lost.

One of the older wells, closer to the city and at a much lower elevation, heretofore could not be pumped more than eight or nine consecutive hours without increasing the water's salinity to a point that made it useless. But since the loss of water was noticed in the hole of the primary water well, this old well has been pumped whenever needed producing acceptable water at a rate of about three and one-half million gallons a month without having to shut down because of increased salt content.

Meanwhile, drilling in the primary well has proceeded down to 990 feet, and the water is static at eighty-three feet from the surface. Power lines have been strung into the site. Prior to a determination of the exact yield of this well, pumping is necessary to help clean out the cavities of the fissure after which the depth at which the submersible pump should be installed will be determined. Perhaps there are no deep-seated aquifers on Santa Catalina Island, but there are many potential primary water sites. It is interesting to note that this hole, drilled approximately 490 feet below sea level, nonetheless contains potable water of fine quality having a temperature of about seventy degrees fahrenheit.

Salton Sea Area

The State of California has set aside six million dollars for the improvement and development of the Salton Sea State Park. This area is heavily alkaline and good useable water is at a premium. On a 440 acre site, adjacent to areas where wells had been drilled only to find waters that were excessively alkaline, Riess located and drilled a primary well. In May, 1957 the well was finished and test pumping over a long period showed a yield of almost three thousand gallons per minute with a drawdown of fifty-one feet. Water was first encountered at two hundred feet in depth, drilling was completed at four hundred feet and the static level of the water is ninety feet from the surface—the temperature is eighty-three degrees.

Mohave Desert

The Mohave Desert (sometimes spelled Mojave) is an upland desert which, for the exception of the five hundred some odd square miles of Death Valley which lies below sea level, has elevations ranging between 2,000 and 5,000 feet above sea level. The Mohave Desert's meager rainfall measures between 1.4 and 5 inches per year, falling mostly during winter and spring. There is ample evidence that in the Mohave's not too distant past widespread volcanism occurred. At Little Lake as well as near Amboy there are well-formed cinder cones, symmetrical craters and lava flows, and in a small area just northwest of Kelso there are more than twenty symmetrical cinder cones.

In 1957, a Riess located well of substantial water production was completed and capped awaiting the future needs of a private development group which had acquired about 80,000 acres, now owned by the California City group of companies headed by N. K. Mendelsohn. The California City companies decided that it was necessary to reexamine and verify Riess' findings as to availability of rock fissure water in large volume as part of a larger investigation to determine the total water inventory within the area. Early in 1958 Mendelsohn engaged O. R. Angelillo, a registered civil engineer of highly diversified experience in many fields of engineering, to report on all water resources economically usable.

The "Mojave Deep Water Report" by O. R. Angelillo [72] dated January 20, 1959, consists essentially of 52 charts which detail voluminous evidence to substantiate his conclusions. The evidence is in the nature of: chemical analyses of rocks, water samples, and drilling cores; precipitation records of the Sierra Nevada mountain range as well as that of the Mohave Desert; the analysis of dissolved gases in the water taken from the Riess wells showed clearly that this water had not percolated through soil, the measurement of minor trace elements enabling a more positive identification as to the source of the water, and the use of several other novel and refined measurements. Angelillo had conferred with Drs. Hugo Benioff, Charles F. Richter, and Richard F. Jahns of the California Institute of Technology as well as with Dr. Thomas W. Dibblee Jr. of the U. S. Geological Survey, and with Walter Hopkins of the Forest Service. The outstanding new feature brought out by the report was the existence of the Mendelsohn Fault, as a link connecting the well-known Lockhart Fault with the Sierra Nevada Fault, and that thereby the waters from the snowpack of the Sierras flow beneath the Mohave desert.

On January 29, 1959, Riess issued a statement on the Mojave Deep Water Report by O. R. Angelillo. It is important to what follows that part of it appear here. Riess indicates that he has developed a technique of intercepting waters from rock fissure aquifer locations on the basis of field examination of terrain and laboratory petrographic and crystallographic tests. He has been the only person who has been publicly identified over a period of years and a wide range of areas with the proposition that the search for water locations can be prosecuted with a high percentage of probability in rock fissure aquifers. Riess specifically points out that:

> Side by side with the study and location of deep-seated rock fissure aquifers I have also been impressed with an existing body of geological data and opinion as to the genesis of water in the zone of rock flowage, often referred to as new, primary, juvenile or make-up water. In the course of the extensive experience in field research and drilling which I have mentioned, I have found reason to believe in many cases that the chemistry of these deep-seated rock fissure waters, often quite distinct from the chemistry of waters from alluvial or sedimentary formations, reflects the admixture of such new or make-up waters.

Under our earlier definition of "new" water as being water which is not being located by conventional ground water hydrological methods, fissure water would be included therein. Obviously, some fissure waters may have their origin from meteoric water whereas others have their origin from primary sources within the earth itself, and then, of course, it is most probable that fissure waters represent admixtures of these primary and meteoric waters.

Negev Desert, Israel

In the Negev Desert of Israel, a twenty inch diameter hole has been prosecuted on a Riess location, through solid rock. The drilling had been slow, cumbersome, and tedious, but water was found 150 feet below the surface. Drilling continued to greater depths until a large fissure was encountered.

Riess had met with Prime Minister Ben-Gurion and his advisers, as well as with a group of top geologists in Israel. Referring to those meetings, Riess said: "There was opposition among the geologists to my theories of water development, but after a long session of explanation they agreed the proposal had merit." In a letter dated the 18th of March, 1958, Arie Isseroff, Israel's chief water geologist, writes: "I think that I am also expressing Mr. Riess' opinion when I say that we found a striking closeness of our points of view on everything concerning the role of the scientist and, especially, that of the water geologist in raising the standard of living and enhancing the peaceful productive development of the world's welfare." Isseroff continues: "As a geologist who is occupied with water research in arid zones, I am fully aware of the limitation of our orthodox methods in geohydrological prospecting and am much impressed by the glimpse I got of the new methods offered by Mr. Riess. Recognizing the unfathomed possibilities which may be opening up before us while applying these methods, I decided, encouraged by my superiors, to cooperate with Mr. Riess' research for primary waters in our arid zones." [73]

On his trip back to the United States, Riess responded to invitations to visit the FAO offices of the United Nations in Rome, and the Papal State for a private audience with the late Pope.

News articles, appearing in the Jerusalem Post of May 25th and May 29th, 1959, estimated that the amount of water in the Riess located well would be enough for a city of at least 100,000 people, with water for industry, air conditioning, parks, and gardens and a dozen thriving villages to boot. Upon analysis, the first samples of the water revealed a far smaller proportion of dissolved minerals than the Eilatis have been accustomed to drink—only 500 parts to a million instead of the 3,000 parts to a million in existing well water.

This description appeared in the May 29th article by Meir Ben-Dov:

> The site they have chosen is where a five metre-wide cleft, running vertically through the mountain, is crossed at right angles by a similar cleft, hardly 20 centimetres across. The bowels of the earth in erupting have filled the clefts with an igneous intrusion of a soft, soapy-feeling, mottled brown rock, called gabbro.
>
> The drill slowly worked its way downwards, alternately in igneous intrusion and again in granite, as the cleft in the rocks snaked its way downwards. But the attendant cave-ins of the rock and jamming of the drill pieces was beyond the Israel team's experience, and so this year Scott came back to supervise the work right to the end.

The reference is to James G. Scott, an outstandingly capable engineer and long time associate of Riess', who has supervised the drilling operations of only those Riess located wells which have presented many difficult drilling problems. A full appreciation of Scott's versatility and ingeniousness as well as the problems he must cope with can be gleaned only by those closely associated with him.

Other Recent Wells

In 1953, Riess located a well in Independence Valley, about fifty-five miles northwest of Elko, Nevada, which yields 1,200 gallons per minute.

In the Santa Ynez mountain range, wherein the accidental encounter with new water occurred in Tecolete tunnel, Riess located water in a fissure at a depth of 1,619 feet which came through an eight inch casing to within twenty feet of the surface.

In the Pacific Palisades section of the city of Los Angeles, at an elevation beyond the point to which the city's water supply lines went, Riess located two primary water wells of excellent quality.

Today, Riess is engaged in locating primary water under the terms of a five year contract with the San Bernardino Valley Municipal Water District, which comprises several cities the largest of which is San Bernardino, California with a population in excess of 90,000.

A.E.NORDENSKIOLD

Diligent probing in hydrologic literature had failed to uncover any predecessor in the Riess method of locating water by intercepting fissures in solid rock. One day after I had, at quite some length, explained Riess' work to him, Dr. Linus Pauling surprised me by saying that Riess' successes reminded him of the Swedish mineralogist Nordenskiold who had been nominated for a Nobel Prize for his ability to locate fresh water in the solid rocks.

I was elated, a possible antecedent had been found. Research on Nordenskiold proved to be an exciting experience, inasmuch as I was feverishly attempting to ascertain whether the resemblance would prove to be a true counterpart. In addition to material found locally, there was correspondence with the Nobel Foundation and the Swedish Academy of Sciences.

Adolf Erik Nordenskiold was born at Helsingfors (now Helsinki), Finland, on November 18, 1832. He was the son of Nils Gustav Nordenskiold, a mineralogist, traveller, and head of mining in Finland. During 1853 to 1857, Adolf visited Berlin where he engaged in research in mineral analysis at Rose's laboratory, after which he settled in Stockholm and there became Professor of Mineralogy in 1858. Later he became a prominent arctic explorer and was knighted by the King for his explorations.

Nordenskiold's nomination, made by Dr. P. E. Sidenbladh, a member of the Swedish Academy of Sciences, was for his ability to find drinking-water by drilling through solid rocks into rock fissures. Nordenskiold died on August 12, 1901, before the Academy of Sciences had convened on the question of prizes so that his candidacy never really materialized. [74]

It is safe to say, just as Gorman's statement concerning the published report by the two Indian physicians, that an article by Nordenskiold, if presented before an audience of ground water hydrologists, would also be hailed as something new, something they hadn't studied about, hadn't practiced, and hadn't even known about, despite the fact that this article was published in 1896 and was the basis for his nomination as a candidate for the first Nobel Prize in Physics.

Nordenskiold located and had drilled thirty-one wells in the primary or primeval rocks of Scandinavia and in every instance found the fissure he was looking for. All but one of the fissures contained water, the one exception contained only clay. In the light of the work done by Riess, it is interesting to read Nordenskiold's account even though the fissures he found were at about one hundred feet below the surface, quite shallow compared to those located by Riess. Nonetheless, many of Nordenskiold's experiences bear similarities to those of Riess, and the water found by both constitute high quality potable water. Nordenskiold's article [75], translated by the author, follows.

ABOUT DRILLING FOR WATER IN PRIMARY ROCKS

By A. E. Nordenskiold

Drilling in our primary rock for supplies of water has now been going on for two years, during which time twenty-eight well holes had been finished. Perhaps it may be appropriate to give our geological society a review of the results obtained and thereby give its members the opportunity to test the correctness of the assumptions upon which this work was based, and the legitimacy of the deductions I have derived therefrom.

It is no mere question, here, of someone who is more or less successful in drilling for water, but a fresh new principle within geology, not only of enormous importance from both a hygienical and economical standpoint, but also of sweeping theoretical significance able to correct the theoretical construction of geology. Specifically, by this construction there must exist a great difference between primary rock, in which all formation ceased a long time ago, and primary rock in whose interior an everlasting circulation of water takes place. There, a continual process, even though slow, of displacement of layers and the new formation not only of calcite, but also of quartz, feldspar, prehnite, augite, pegmatite—and other silicates can continually be observed. In a figurative sense, it reconciles to this summation, one primary rock dead since a million or forty million years ago, the other primary rock with vitality and a day to day evolution.

It is my desire to bring up the difficulties and questions surrounding the first drilling attempt to obtain usable drinking water on the various rock-bound or smaller islands on which beacon lights are situated and for pilot stations near the coast. In connection with this, I remember an observation of my father, Nils Nordenskiold, who was chief of mining in Finland and who died in 1866, that salt water did not penetrate the iron mines situated near the Finnish coast and which were beneath sea level, despite the fact that there was always, more or less, what miners call bad water. Part of an observation I made during the years 1861 and 1864 on an expedition to Spitzbergen, where on a walk I came across a strongly folded and reversed tertiary layer resting on a perfectly horizontal permo-carbon-stratum. This later observation I recorded in "Sketch of the Geology of Spitsbergen" in the following way:

> The strata of the mountain-limestone which, at Hinlopen Strait, alternate with plutonic rocks, are almost horizontal; but the Tertiary beds at Kings Bay and Cape Staratschin are, on the contrary, quite folded, notwithstanding no eruptive rock could be discovered in the vicinity, excepting a little vein of diabase (?) at Cape Staratschin. There must, consequently, be some other reason for the folding occurring in these places; and it appears to me that too much importance has been generally ascribed to the influence of the eruptive masses in connection with the folding, upheaval, and dislocation that is almost everywhere observed in the earth's crust. As is the case with innumerable other geological phenomena, this, also, very likely results less from any violent revolution than from some almost imperceptible but nevertheless continually operating power. The upper part of the earth's crust is, of course, subjected to periodical variations of temperature, which, at Stockholm, for instance, at a depth of seventy or eighty feet, rise to 0.01°C. If the earth's crust were continuous, and the change of volume, caused by these variations of temperature, did not exceed the limits of elasticity of the rock, they would not exercise any disturbing influence. But as to a greater or lesser degree, there are in all mountains fissures and clefts, these will widen in lower temperature, but become narrower as soon as the temperature rises. If however, as may often be the case, the fissures when enlarged by lower temperature are filled up either with chemical or mechanical sediments, a powerful lateral pressure will naturally ensue when the temperature again rises and extends the rock; and thus every variation of temperature will cause a

> slight dislocation of the strata. When we consider that this agency is working from year to year, in the same direction, and that the extensive movement of many hundred miles of the earth's crust may cause folds only at some narrow spot where the resistance is a minimum, it should not surprise us to find even the newest formation gready reversed, whereas old formations in the vicinity, may be quite undisturbed.

Upon reflection, the above advanced outline is correct, and therefore a horizontal displacement fissure ought to generally occur in every solid species of rock at relatively slight depth under the surface of the earth. Probably these fissures are conveying water. If so, in our primary rock one likewise ought to be able to obtain water through a bore hole to these fissures. But how good is this water on promontories and islands skirting a coast, the only prospective places to have to attempt such drilling? This was the question faced upon such an undertaking. Relative to its practicableness, in 1885 I had already concerned myself to obtain some further data before passing judgment on this question, when several private persons and authorities jointly made inquiries touching on the salinity of waters in wells and mines near the seacoast. In connection with this, I received much valuable information. Mineral surveyor Anton Sjogren wrote as follows in this note of September 30, 1885.

> The following mines have reached the indicated approximate depths below sea level:

	Meters below sea level
Finnmossen	15
Taberg i Vermland	90
Nordmarken	15
Uto	120
Dannemora, Mellanfaltgruvan	192
Dannemora, Sodra faltgrufvan	180
Bersbo, Atvidaberg	390
Mormorsgrufvan, Atvidaberg	300
Falu grufva	222
Kallmora grufva vid Norberg	15
Sala	270

> Relative to questions on mine water salinity, I never knew the water in our iron mines to be other than salt free. In your letter you ask questions as to whether mine water contains the salts that occur in sea water. I believe that we are thus agreed that these quesdons can be answered with no.

Lord-lieutenant C. Nordenfalk communicates that many wells, found in Hallandia (in sedimentary layers) in close proximity to the seacoast, give this salt free water, notwithstanding that it comes from a depth of thirty to seventy-five meters below sea level. In a well that was also drilled in loose sedimentary stratum, at the square in Jungsbacka, produced ample water that comes 3 to 4 m above sea level, but this water is salty. To conclude, these questions are taken up and discussed in Geologiska Foreningan (se dess forhandl, 1891, s. 13, 143 och 296).

From the knowledge that was obtained in this manner, even though only slightly decisive, that this water that could be obtained at depth by drilling in our rocky archipelego would not consist of sea water devoid of potable fresh water, I therefore proposed to the then chief of the pilotage branch of the Board of Admiralty that some suitably located pilotage station permit the conducting of a drilling attempt in a specifiable location.

It was for this reason that the first drilling for water in our primary rock was attempted in 1891 on the little Svangen south of Kosterfjordan. Drilling was given up before sufficient depth was attained because they thought that a fissure leading in from the sea stretched itself to the well hole. The place for drilling had not proven to be selected by a person competent to judge, and the work supervised, if I know, not by someone who believed in the possibility of success. Hence the presumably hasty abandonment of the work.

After that, the question was pigeon-holed and inactive for some years; it was ended until taken up by the Director General of the Pilot Service, Baron Ruuth, who except for considering the reputed unsuccessful drilling near Svangen light agreed to conduct a new drilling attempt at Arko near Braviken. Craftsmen made the drilling spot (a)* level, directly near the pilot station, located on a ledge of rock on a hill a couple of meters above the sea. The species of rock was composed of hornblende leaded gneiss and diorite. The outcome was particularly favorable, in that soon after a depth of 35.5 was attained, 450 liters per hour of first-rate good water was produced. The drilling hole had a diameter of 64 mm. The water con-

*a) For this purpose the place was visited, in the beginning of May 1894, with me by geologist Svenonius, graduate G. Nordenkiold and Director Casselli.

veying fissures lay at 32-33 m depth below the opening, (b)* The water, at the beginning, was a little yellowish, having been mixed up with borings and with mud from the water conveying fissures, but after a short time perfectly clear, and besides which the amount of water increased.

With at least the possibility of water veins occurring in primary rock entirely proven—and certain difficulties avoided through improved drilling technology developed in drilling beyond the sands in our mines, the "Diamond Rock Drilling Company" received orders for new well drilling. Drilling for water in our primary rock was executed and proven in the following places, by this writer, which are here given in chronological order.

1. Arko. Species of gneiss, hornblende gneiss, etc. Well-hole depth 35.5 m. Diameter 64 mm. The water bearing fissures were reached here, just as in most of the well holes, at a depth of about 32 m. Abundant supply of first-rate good water, which still was a little hard. This water was used for purposes common to drinking water and all sorts of cooking, not only by the population near the pilot station but also by vessels that lay to near the pilot station.

2. Stockholm; Saltsjobaden. Gneiss mixed granite. Well hole depth 35.5 m. Diameter 64 mm. Abundant supply of good water. With reference to blasting with dynamite near the mouth of the well hole, surface crevices originate, that possibly can carry dirt to the well hole. Temperature 4-7°.

3. Stockholm; Tacka Cape. Depth 35.5 m in hard Stockholm granite. Diameter 64 mm. Abundant water. The water still continually mixed up with a yellow clay and possibly fouled by muddy water from an adjacent garden plot. Considerable dynamite blasting was precluded by well cleaning. Nevertheless, after several days of

*(b) The water has always been found at a depth of 30 to 35 (generally 32-33) m under the rock surface, but the drilling usually continues a couple of meters under the water bearing fissures, which drillers recognize because the rock there is "in tatters." In a few places, without my knowledge, the drilling continued "out of curiosity" to a considerable depth. Any increase of the water supply has never been obtained in this manner. On the contrary, this drilling below the water bearing fissures had the disadvantage that a quantity of dirty water is pumped in, which with difficulty is worked off afterwards. Efforts to increase the water supply through blasting with dynamite has not been crowned with success, maybe because the dynamite shots were in beds too deep under the water bearing fissures.

pumping it clean with a steam pump, it should give a good water. Temperature 7° to 8°.

4. Dalbyo; south of Hallsviken. Well hole diameter 64 mm; its depth 35 m. Diorite and hornblende gneiss. The water conveying fissure lay at 32 m deep. Wells that for long gave a weakly yellowish, somewhat salty water and a perceptible oil film, are now colorless, crystal clear, the best drinking water man himself can wish. Temperature 7.5°-7.8°.

5. Ryby yard south of Linkoping. Here they had previously blasted a 23.3 m deep well in gneiss, which still did not give any water. From its bottom a 64 mm drill head was first bored to 24.3 m and thereafter 6.5 m with a drill head of 35 mm. At 7 m below the 64 mm well bottom, thus at a depth of 31.3 m under the rock surface, we hit the water. It. was a good water, but only 1,675 liters per day. It is utilized with advantage for the washing of butter by a creamery.

6. Stockholm, Aktiebolaget Separators gard a Kungsholmen. We attempted drilling from the bottom of a 27 m deep well in Stockholm granite. At 8.5 m drill depth we intersected a water conveying fissure, that gives 15,000 liters per 24 hours. There was a question about making use of the water for feeding a steam engine, but it was said to be calciferous.

7. Trollhattan I. Rocks consisting of gneiss with pegmatite courses, varying with hornblende schist. Well hole 39.7 m. The water bearing fissure encountered within the depth attained. Diameter 64 mm. Ample, crystal clear, palatable water, containing 35 parts solids in 100,000. Temperature +8°.

8. Smogen on an island in Bohuslans Archipelego. Rocks consisting of a regularly vertical lifted red granite. The well hole opening located 5 m above sea level. The water conveying fissure found at a depth of 35.4 m. At that depth down fissure intersects with fissure. Fissures conveying water less liberally had been found at 10.5, 14 and 19 m deep. The water supply is ample, but the water is, as yet, a little salty.

9. Marstrand. The well opening located 8 m above sea level. The well was bored to a depth of 44 m in mica rich gneiss, the water conveying fissure encountered handsomely as before. The supply of water 600 liters per hour. The water first-rate good. The water in the well rises to 3.5 m from the rock's rim.

10. Stenungso near coast of Bohuslan. The rocks are principally gneiss. The well hole mouth 10 m above sea level, about 25 m from the sea-beach. Depth 45 m. The well hole sunk, in the usual manner, considerably below the water conveying fissure. The supply of water is not particularly ample (60 liters per hour). But the water, first-rate good, is perfectly salt free.

11. Koon midst to Marstrand. The same rocks that are near Marstrand. The well sunk to a depth of 50 m, but the quantity of water from it is not worth mentioning, the usual horizontal fissure, which here is very thick, is entirely clay filled.

12. Trollhattan n. In the pharmacist's cellar. The water of the same quality and about the same quantity that was obtained in drilling Trollhattan I. The well depth 36 m. Diameter 64 mm.

13. Trollhattan III. Situated only about 12 m from Trollhattan No. II. The well like Trollhattan II. The water is withdrawn here by means of a little steam engine. It delivers water of the same quantity and of the same fresh quality as that of the two previously cited wells at Trollhattan.

14. Hango. The well hole 49 m. Diameter 64 mm. The water conveying fissure encountered as usual at about 32 m. The well produces at least 500 liters per hour. In the beginning the water was strongly befouled with borings, oil from the drilling machine and pump rinsing-water. But the well has, after repeated running and draw pumping during its intense use in the summer drought of 1896, considerably improved. The water proved entirely clean, in short, perfectly good. The water quantity at least 1000 liters per hour. Temperature +6.9°.

15. Stockholm; Vinterviken. The rocks are principally gneiss. The well hole was sunk considerably below the water bearing fissure, which was encountered at the usual depth. A shot of 3 kg dynamite was let off below, with the previous very ample amount of water increasing. The water is good, but was colored with fissure clay for a long time.

16. Dannemora: Haglosa. The drilling began from the bottom of a 4.5 m deep well and continued to a well depth of 21.3 m. Diameter 64 mm. The rocks—petrosilex (hornstone). Rich with water, that in the beginning was, as usual, fouled with clay and borings. After pump cleaning, the water improved considerably and remained sufficiently up to standard.

17-19. Tolkis holme near Borga in Finland. Three well holes at 19, 35.5 and 36.5 m for obtaining water for manufacturing purposes are here drilled in granite gneiss. Diameter 64 mm. The amount of water was inadequate for manufacturing purposes, but why give up the wells without properly pump cleaning? The owners have unnecessarily become frightened by an analysis, that gave 85 parts solid constituents, thereof 17 parts chlorine per 100,000. By continued pumping on account of this problem, in and of itself not a little forbidding, the residual would be reduced considerably. The chlorine is, of course, combined with sodium as sodium chloride. The taste imperceptible, the quantity of this element is not in the slightest degree injurious to health.

20. Bokedalen near Goteborg. From a 64 mm well hole, sunk to depth of 30 m in gneiss, an ample supply of water is received. The water flows over the well opening. It is slightly irony. The per cent of iron was still gradually reducing and the water should later on remain perfectly good.

21. Hufvudskar in Ostersjon. Drilled in gneiss to a depth of 53 m, still without increasing the quantity of water that was obtained at about 32 m deep. This is only 60 liters per hour, but should gradually increase. Even now the water is still completely sufficient for the pilot station's needs and perfectly good.

22. Gellivare. The well gives ample water, even with the accessible pump and not the customer's bilge-pump. Here is obtained up to 40 liters per minute, corresponding to 2,400 liters per hour. The temperature after several hours' pumping is +3.1°. The water is pure and clear and without taste. Depth 40 m. Diameter 64 mm.

23. Katrinefors nara Mariestad. The drilling, done for manufacturing purposes, to a depth of 30 m from the bottom of a 6.5 m deep well in primary rock. Diameter 64 mm. Gave 600 to 700 liters water per hour. It was clear and had a temperature of 7°. The amount of water was not enough for manufacturing, for which reason the well hole is not seen used.

24. Stockholm; Liljeholmens stearin manufacturing. The well hole has a diameter of 100 mm. Depth 37 m. It was sunk in Stockholm granite. The supply of water is at least 1,200 liters per hour, without diminution after 12 hours pumping. Temperature 7°. The water is first-rate good.

25. Stockholm; Sodra yeast manufacturing. The well hole was like the former (no. 24), 100 mm in section. It was sunk in Stockholm granite to a depth of 31.5 m. The water supply is extremely ample. The well gives 3 to 4,000 liters per hour under uninterrupted steam pumping for 24 hours. The temperature, after the water went through a long lead above the earth, 8.7°, probably originally 7° to 7.5°. The water is first-rate good and palatable, if even a little hard.

26. Oregrund. The well hole's diameter 64 mm. Depth 29 m. The rock, gneiss. The water supply is ample. In the beginning there were moans over it, that the water had a salty taste, was yellowish and covered with an oil film on its surface. It is already much improved, so that it is used for drinking water, and it is entirely certain to remain perfectly good for some time. The temperature ranges to 8.5°, but was probably a little lower.

27. Stockholm, Skonvik. Drilled through the medium of a percussion drill in gneiss. Diameter 64 mm. Depth 30 m. It has provided an ample supply of good water.

28. Kungsholms fortress outside Kariskrona. The well hole's diameter 64 mm. Ample supply of water. At this writing, the drilled well has as yet not been pumped clean, so that a definitive opinion on the water's condition can not yet be given. (c)* The well hole was sunk to a depth of 31 m. in gneiss.

In all of these well holes, with the exception of no. 11 Koon, (d)* water has been obtained sufficiently satisfactorily, generally in ample quantity, by which I mean a water supply of 600 to 1,000 and all the way up to 3,000 liters per hour. The water quantity increases perceptibly, after the wells are used for a time, whereby the opening of a new vein in the rock's interior is usually, for a short time, accompanied with renewed dirtying of the water by an extremely fine clay mud.

The water that is found is in the beginning substantially dirtied by boring mud, by oil from the drilling machine and the pumps put

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*(c) After the above was written, three additional drilled wells have been completed, namely 29 Haparanda, 30 Trollhattan IV and 31 Svenska Hogarna: as far as I know, with good results.

*(d)The horizontal fissure, that usually contains water, is greater at Koon than at other places where drilling has heretofore been undertaken, but it is completely stopped by clay. One has hopes that this clay damming can be worked off through persevering bilge-pumping, in which case even this well will come to supply ample water.

into it and also generally of a little clean water, that under drilling and with the turbulence of the pumping in the well hole carries away the boring mud. To this must be added the mud from the water bearing fissures in the rock. An extremely large quantity is added by pumping the water below the drilling; after the well hole is at greater depth, not more returns up immediately, but is distributed in the rock's fissure system; there it mixes with the water in the horizontal fissure and only slowly is brought off. If, as it often happens, sea water is used for washing and priming the pump continual pumping removes all trace of it. This gives cause for illegitimate complaints about the water coming out of a new well. Soon, after the pump is installed, a man complains that the water is unfit. "Oil film deposits on the water's surface, the water tastes of oil, is salty and mixed with clay." It usually stays a long time, but this difficulty is completely conquered, for within the water is crystal clear, palatable, and specially suitable for drinking water, even though a little hard for certain domestic needs—a disadvantage that is nevertheless in rich measure counter-balanced by the water's hygienic quality. It is, to be sure, free from organisms injurious to health and free from organic detritus.

According to tests that have been made up till now, the water pours from these wells 20 to 62 parts solid constituents of 100,000. Until now only one little nearly complete analysis has been made of the composition of the mineral constituents that comes in the water, namely that of the assistant G. Lindstrom on the residue after evaporating the water fetched up on 25 March 1895 from the well hole at Dalbyo. These were the contents of 100,000 parts water:

Silicic Acid	1.18
Clay, ferric oxide	0.10
CaO	4.90
Magnesia	trace (?)
Sodium oxide	24.52
Potash	1.70
Chlorine	11.34
Sulphuric Acid	10.42
Carbonic Acid	7.30
	61.46

or:

Silicic Acid	1.18
Clay, ferric oxide	0.10
Sodium chloride	18.70
Sodium carbonate (e)*	22.32
Calcium sulphate	11.10
Sodium sulphate	3.52
Potassium sulphate	3.14
	60.06

Water from No, 20, Bokedalen, sample taken a short time after the drilling was finished, from within the hole according to an investigation made in Goteborg; the constituent parts per 100,000, after drying up 28.8, after heating to red hot 22.80. Acid consumption 0.22. Ferric oxide (with clay?) 0.10. No ammonia, nitric acid or nitrogen trioxide. Only a slight trace of chlorine and sulphuric acid.

Water from No. 2, Saltsjobaden, taken shortly after the drilling was finished, according to a first-rate test by Stockholm's Water Works laboratory; the evaporated residue (per 100,000) 44.3. Acid consumption 0.193. Neither nitrate nor nitrite. Ammonia 0.002. Chlorine 12.0. Hardness 6.9.

Any complete analysis has not yet been made. In many of the drilled wells the water previously freed has scarcely yet obtained its normal composition. The contamination lingers for very long, namely, the water is certainly frequently salty and never entirely clean while drilling, putting the pump in and, especially after the horizontal fissure is opened, until the greatest parts which remained spread in the rock's fissure system are so completely removed therefrom, that it does not have influence on the well water's composition. The drilling company has had many difficulties, before it became attentive to these circumstances and as a consequence of this gave its work order for the removal of the borings that makes, in this way, clean water possible. So inadequate are analyses that those made show in all cases, that the water corresponds in its composition to a good spring water, perhaps still with the difference that the water in the drilled wells, sunk in the archipelago rocks surrounded by

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*(e) It is very likely that bicarbonate enters into the water. Soon after being pumped up the water is neutral, but after boiling down to half the volume reacts weakly alkaline.

the sea, contains more sodium chloride and sodium carbonate than the usual spring water.

When the water channel stands in a heated place, the water pumped out evolves no slight amount of gases. It would be interesting to know the composition of these gases, but the determination thereof has as yet not been arrived at. Then the mineral, Cleveite, in which Helium is especially found, which is by no means a mineral crystallized out from a molten magma for it doesn't even contain quartz, feldspar, mica, etc., is crystallized in fissures of primary rock. It is newly formed at present under prevailing geological conditions, so it would be particularly interesting to have an analysis of the gases in the fissure water of primary rocks, and I shall use the first occasion to have such an investigation performed. Then, I hope also to be able to communicate complete analysis of the additional composition, quite certainly varying in the water from a number of dissimilar wells drilled in the primary rock. Then, after this, the meaning of the movement in our primary rock of granite, pegmatite and of other mixed silicates ought to be known even slightly by the unprejudiced, the open-minded researchers who are free of scientific dogma; equally as valuable are the movements of calcite, pyrite, etc., formed and continually forming through crystallization from the water, which in the manner I now point out, circulates everywhere in the primary rock's fissure system (f)*, so a series of similar analyses ought to prove of extremely great geognostical interest. They ought to make certain that the first attempts are made after the wells are in use for a long time, so that one can be fully confident about the fact that the boring water pumped into the bore-hole (and fissure system) was completely removed.

Sixteen of the above-mentioned bore-holes, namely No. 1 Arko, 2 Saltsjobaden, 3 Tacka udden, 4 Dalbyo, 8 Smogen, 9 Marstrand,

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*(f) I point out, that with reason, I was confounded for a long time after I had been shown that quartz and feldspar occur as newly formed in fissures in pegmatite dikes. Near Morefjar near Arendal, I have found at the entrance to a similar stuffed fissure, so newly formed that the fragment of feldspar had still not weathered, that through crystallizing out quartz, as if glued together, formed surfaces of great size; that at a lateral fissure near a clear surface, loose quartz crystals formed; that new forming of garnet, diopside, epidote, apatite, titanite, magnetite, calcite, chlorite, galenite, occur as pretty loose crystals in a clay like that of the foliated lamina formed mass that filled the Tabergs mine in Vermland.

10 Stenungso, 11 Koon, 14 Hango, 17, 18, 19 Tolkis Holme, 21 Hufvudskar, 26 Oregrund, 27 Skonvik, 28 Kungsholms fortress, were sunk in rocks located immediately near the sea beaches or on islands in the archipelago. The water they have given, with a mere trace of no consequence, exists free of sea salt, with the exception of the water from No. 8 Smogen. Yet each well amply productive gave a water that was a little salty. An enormous body of sea water had been pumped in while drilling, and I take it that the complained of saltiness is due only thereupon, that the wells have still not been pumped clean. It must still be agreed that the rock here is very full of fissures and that the wells therein became stocked too near a sand-filled depression that yet within the memory of man was filled with stagnating sea water.

No one has taken measurements of the water's temperature at the bottom of the wells. The pumped up well water has a temperature that in unlike wells vary between 7° and 9° and that is constant in each well the year around, apart from all regard of the influence exerted by the season's varying temperatures in the 20 to 30m long pump pipe. The water's temperature was 2° to 4° higher than the place's average temperature. In consequence of the slight depth of the wells, does not this behavior depend on the interior earth temperatures? It appears to depend on a slight heat production by the endless chemical alterations that take place even in primary rocks. I need not bother to point out that a temperature of 7° to 9° is especially suitable for the water that is used for drinking water and other household needs. It is healthily cool in the summer and drinkable directly even in the winter.

It appears from the above, that everywhere that one drills in the primary rock in Sweden and Finland, at a constant depth of a little over 30m under the surface of the earth, a water bearing horizontal fissure is encountered. The theories about folding and the displacement of the primary rocks' surface layers by temperature variation have been clearly corroborated hereby.

Even in lands other than Scandinavian and even in hard species of rocks other than the primary rock, the identical causes ought to have the identical effects. Everywhere that the surface layers are made of hard, firm rock, it appears to me that a displacement of the surface layers ought to take place through folding brought about by daily, yearly, or secular temperature variations. Having been folded, these almost parallel displacement fissures ought to emerge at a greater or lesser depth under the earth's surface. Even though the species of rocks themselves are impermeable to water, and even though atmospheric precipitation doesn't take place in the region or the fissure system does not connect with water collecting on the earth's surface, one ought to question the manner in which the water is received, presumably at the same quantity that was obtained by ourselves, i.e., as a rule not fountains, but wells, that through a little heavy pumping delivers 500 to 2,000 liters per hour. One ought in this manner to get productive water wells around the year, e.g., in many parts of Africa's north coast, in rocks round the Nile delta, in Abyssinia, in south Africa, in appropriate places of the Mediterranean's north coast, on Spain's high plateau, near the base of Sinai and of other snow-covered or heavily rained mountains, in Greece and the whole of Asia Minor and in vicinities where for the whole or greater parts of the year there are dried river beds, in Colorado's Canyons, in tropics that are dry in certain times of the year and rain-drenched at other times. One such water well will be sufficient for household needs in smaller communities, for irrigating a garden, and so on, but not for vast cultivating enterprises. In most of them the water comes in the same condition as that of good spring water. It comes free from the bacteria that exist in the earth's surface layers, from organic detritus, from decay produced and other things injurious to health and for our purposes it is unexcelled in hygienic respects, having a temperature transcending a little the average temperature at the place where the wells were drilled.

If A equals success, then the formula is A equals X plus Y plus Z. X is work, Y is play and Z is keep your mouth shut.

—ALBERT EINSTEIN

CHAPTER IV

THE MODERN SCIENCE OF HYDROLOGY AND ITS LIMITATIONS

Hydrology, in its broadest sense, is the study of water which encompasses biology, the chemistry and physics of water, geology, hydraulics, and meteorology. Using this as a point of departure, it may be well to first review some of the current areas of water research to discover their potentialities in solving our water problems. A mere recital of them implies the urgency of our water problem and the desperate need for solution is apparent when consideration is given to a New York Times survey, published in March 1957, which sees the economic growth of the United States as being limited by water shortages and foresees a daily need of 450 billion gallons by 1975.

Topping the publicized list, is the conversion of saline water which, from a cost standpoint, has proven to be full of difficult problems. The other important research programs are: cloud seeding; reclamation of used water, the building of barriers against sea water intrusion; the replenishment of underground storage basins, and the reduction of evaporation from lakes and reservoirs.

The waters of the oceans and the brackish waters now found inland are possible sources of fresh water. Although saline water is only a simple system of inorganic salts dissolved in water, it is a stable solution which requires relatively large quantities of energy to separate the salts from the water. Theoretical calculations based on one hundred per cent efficiency, which neither man nor his machines have been able to achieve, indicate a power cost of two and eight-tenths cents for one thousand gallons, or more than nine dollars for one acre foot (325,850 gallons) of water. [76]

In translating these theoretical calculations into practice, the minimum power costs must be expected to increase several fold, and to determine the total economy of the process both the capital investment and the operation charges must be added to the power costs. It is true that revenue from marketable by-products might offset costs, but it doesn't appear that the credit per unit of water processed could make conventional conversion systems economically suitable.

Some of the more optimistic scientists point out the fact that sea water conversion costs have been reduced from about three dollars per thousand gallons, five years ago, to one dollar and seventy-five cents in the new plant producing 2,700,000 gallons a day on the Caribbean island of Aruba. They predict that, in ten years, they will be able to reduce conversion costs to about fifty cents per one thousand gallons, or $160 per acre foot, based on a huge fifty million gallon per day conversion unit using a nuclear energy system. These cost figures, unattainable today but a possibility sometime in the future, are nonetheless considerably higher than current water costs in most areas. Low cost energy from the sun perhaps, or from other sources, plus new conversion processes may provide a more economic answer sometime in the future.

Robert W. Kerr [77], president of Fairbanks, Morse & Co., estimates that pure water can be developed at a cost of about forty cents a thousand gallons by two small capacity plants to be built in Israel near Elath on the Gulf of Aqaba. The small capacity plants will be able to produce only enough for drinking purposes alone. These plants will produce water based on principles developed by Alexander Zarchin, an Israeli, whereby the sea water will be chilled just below the freezing mark and then the pure ice crystals will be separated from the impure slush and then thawed by the heat of incoming sea water.

In further recognition of the growing water shortages, the Congress has extended the research activities under the Saline Water Act of 1952 until 1966, increasing its total authorization from two to ten million dollars. Congress has also provided ten million dollars for the construction of five saline water conversion demonstration plants. According to the August, 1957 issue of "The Reclamation Era," the Government's saline water program has set a limit of twelve cents per one thousand gallons, or thirty-nine dollars per acre foot for irrigation water. A figure which even the more optimistic of scientists cannot predict for the foreseeable future.

CLOUD SEEDING

Man's attempts at rainmaking have been going on for centuries. Dousing holy men with quantities of water has been widely practiced in many countries where droughts are frequent and severe. Zulu women, for instance, would bury their children up to their necks in the ground, and then go away wailing in the hope that the heavens would be opened up through pity.

In the United States, the first actual appropriation for experiments in rainmaking was authorized by the Congress in 1891. This experiment, under the direction of General Dyrenforth acting as a "special agent" for the Department of Agriculture, was carried out in Texas using dynamite and gas filled balloons. A little rain came, but the Weather Bureau appraisal said that it would have rained anyway.

Whether or not there are clouds in the sky, there is water vapor in the sky. The clouds, however, containing droplets of water are a step ahead in the process of becoming rain. Sometimes, clouds merely dissolve into vapor and fade away, or water vapor may flow into and become a cloud or become part of a larger cloud. In order to have rain there must be clouds, but just because there are clouds does not mean that it will rain. In the atmosphere, there are minute particles of dust which act as nuclei for raindrops, providing something for the droplets to cluster to and grow. Cyclic salts, very small particles of salt which remain suspended in the air semi-permanently and travel long distances, also act as condensation nuclei. The droplets of water in a cloud may fail to grow up to raindrops heavy enough to fall to the ground.

The scientific basis for creating precipitation is "artificial nucleation" which hypothesizes that at quite low temperatures, perhaps at minus forty degrees fahrenheit, ice crystals form naturally. It is presumed that the crystals then grow by attracting other moisture particles until they become heavy enough to fall out of the clouds as snow, which melts on the way down and becomes rain. If the clouds are near the temperature at which ice crystals form naturally, the dropping of dry ice (carbon dioxide) cools areas of these clouds and starts the process of crystal formation.

The minute dust particles start the process of ice crystal formation at temperatures between minus forty degrees fahrenheit and plus five degrees fahrenheit. But artificial nucleation using silver iodide starts it between plus five degrees and plus twenty-five degrees fahrenheit. So it can be seen, that supplying nuclei to clouds does not cool them but permits the formation of ice crystals at higher temperatures. In warm regions, non-freezing clouds release rain, obviously by some process other than the formation of ice crystals. Such clouds have been successfully seeded by water sprayed from airplanes.

Admittedly, seeding with dry ice, silver iodide, or water has modified clouds and produced precipitation, but because the effects of seeding have not been completely determined research continues. Preliminary estimates from the operation of a state and federal government experimental seeding program in Santa Barbara County, California are that seeding may increase rainfall twenty-three per cent.

Many people, including state legislators, have been worried that increasing the rainfall in upwind areas may be at the expense of downwind areas which may be deprived of rainfall. The rainmakers contend, however, that only about one per cent of a cloud's moisture falls to the ground in an ordinary storm and that by supplying more nuclei this efficiency may be increased to two per cent. These amounts, they say, are insignificant because the water vapor in the sky will almost immediately replenish the clouds. Further discussion of precipitation appears later in this chapter.

The sewer system is the counterpart of the water system, and domestic sewage is ordinarily more than ninety-nine and nine-tenths per cent water. Of the remaining one-tenth of one per cent (one thousand parts per million by weight), a considerable part is the same mineral matter that was originally present in the water. The increase in solid content because of use is actually only a few hundred parts per million, but it is the nature of the added material, rather than the amount, that makes treatment necessary.

The added material is made up of the chemically complex organic and mineral wastes of living and therefore demanding that sewage must always be considered potentially dangerous. Any parasite hazardous to man is certain to find its way into his used water supply. One outbreak in 1956, classified as shigellosis, involved about eight hundred persons. There was substantial proof that the city supply had been contaminated with raw water from a mountain stream along which fecal evidence was found. In another outbreak in 1956, about seven hundred persons in a small town became ill after the public water supply became heavily contaminated with surface drainage following a sudden rainstorm. There were six outbreaks of gastroenteritis with 903 cases which were waterborne, and an outbreak of 276 cases of hepatitis which was considered to be waterborne. [78]

By natural processes, water can purify itself up to a point determined by the load of pollution. Self purification is brought about by a combination of biological, chemical, and physical factors. In water that is saturated with dissolved oxygen, which is absorbed from the atmosphere and also given off by the green water plants, self purification takes place more rapidly. The dissolved oxygen in the water is used in the process by which the bacteria, in the water and in the wastes themselves, break down the unstable wastes. But unfortunately, fish and other aquatic life must also depend on the dissolved oxygen in the water. Replenishment of dissolved oxygen permits the purification process to proceed, and it takes place rapidly in a swiftly flowing, turbulent stream.

When large volumes of wastes are discharged into a stream, the water becomes murky and prevents the sunlight from penetrating to the water plants, causing the plants to die because they are unable to carry out the process of photosynthesis, which process produces food for the plants and contributes further to the oxygen supply of the water. The amount of oxygen, dissolved in the water, is critically important to the condition of the water, because of its role in the overall decomposition process, and is therefore a major standard of the quantity of pollutants that may be discharged into a watercourse. The allowable loading is then determined from the quantity and oxygen demand of the sewage.

Sewage treatment brings about the required reduction in the pollutional effects of sewage wastes before they are discharged into the watercourses. There are various degrees of sewage treatment. During primary treatment about twenty-five to forty per cent of the pollution load of sewage waters are removed. The sewage first passes through a screen, then slowly through a grit chamber, and then into a settling tank where it stands for an hour or more. The sludge settles to the bottom and the scum rises to the top, and the water between the two layers is then drained off. Then by the activated sludge process or by trickling filtration, and a secondary sedimentation, up to ninety-five per cent of the pollution load may be removed. Secondary treatment methods are essentially bacteriological oxidation units.

The most common practice in the treatment of municipal sewage is digestion. Digestion consists of holding the sludge, in enclosed and sometimes heated tanks, for thirty days or more. Under anaerobic conditions, achieved by the complete exclusion of light and air, the solids are decomposed by bacterial action into simple inoffensive compounds.

Following the sewage treatment, the water extracted, known as the effluent, is available for some uses or may be subjected to further treatment for additional uses. In industry, the use of reclaimed water is being practiced more and more as a way to get needed water. This is being done primarily by the big water users, the steel mills, oil refineries, metal-processing plants, and the railroads.

At the Bethlehem Steel Company plant at Sparrows Point, Maryland, they use from fifty to one hundred million gallons of reclaimed water daily, in addition to their use of from thirty-five to fifty million gallons of fresh water and 135 to 150 million gallons of sea water. The reclaimed water is obtained from the Baltimore sewage treatment works and then the steel mill treats the effluent with alum to reduce turbidity and with chlorine to prevent the growth of slimes and algae.

In 1953, the Texas Company negotiated a thirty-year contract with the city of Amarillo, by which the city is to furnish the refinery reclaimed water of a quality satisfactory for refining purposes. The payments by the Texas Company are to be adjusted on the basis of actual costs, varying from three and three-quarter cents to six cents for one thousand gallons depending on whether it is necessary to maintain a free chlorine residual in order to eliminate ammonia from the reclaimed water.

As industrial production and urban populations grow, we can expect that industry and cities will intensify their research efforts and increase the number of stages of their purification systems to extend the use of reclaimed water.

THE REDUCTION OF EVAPORATION

About eighty thousand cubic miles of water are evaporated each year from the oceans and about fifteen cubic miles are evaporated from the lakes and land surfaces of the continents. The water lost daily through evaporation at Lake Mead was mentioned earlier, and proportionate losses occur from all reservoirs depending upon the mass of water, the surface exposure, and the average temperature of the area. Experiments to reduce evaporation from reservoirs and other bodies of water have been taking place since Irving Langmuir and Vincent Schaefer, of the General Electric Company, described substances that would form a tight monomolecular film over water and thereby prevent evaporation.

Laboratory and preliminary field tests indicate that cetyl alcohol is the most promising of chemicals to date, for it appears to have no detrimental effect on biological life in the water, and doesn't inhibit the transfer of oxygen to and from the air. Before cetyl alcohol, or any other evaporation suppressor, can be approved for general use certain criteria must be met. It must be proven that the chemical used has no toxic effect on fish, vegetation, plankton or algae. It must also be determined whether the covering film will increase the temperature of the lake or reservoir, a risk that could have deleterious effects on its biological content. Furthermore, the big practical problem is how to spread the chemical film over large bodies of water and how to prevent the film from piling up at the leeward end of the lake or reservoir.

THE HYDROLOGIC CYCLE

The central concept in the science of hydrology is the so called hydrologic cycle, a convenient term which denotes the circulation of the water from the sea, through the atmosphere, to the land, and then back to the sea through the atmosphere and by run-off on the surface and under the ground. The hydrologic cycle, for convenience, has often been thought of as being composed of three major segments: (1) precipitation over the land masses; (2) surface run-off and infiltration into soils and rock materials, and (3) evaporation and transpiration.

The science of hydrology is especially concerned with the water from the time it is precipitated until it is either discharged into the sea or returned to the atmosphere. The major factor which distinguishes the practice of modern hydrology, from that of much earlier practice, is quantification. It involves the measurement of the quantities and rates of movement of water at all times and at every stage. For instance: rain and snow gaging determine the quantities and rates of precipitation; snow surveying determines the quantities of water stored as snow and the rates of its accumulation and disappearance; observations of the advance and retreat of glaciers determines their rates of gain or loss and the quantities of water they contain; stream gaging gives continuous long term records of their flow at many points, and the gaging of lake levels and ground water table levels computes the gains or losses in their storage.

Essentially, hydrologists state the law of the conservation of matter as follows. During a given time span, the total inflow into a given area must equal the total outflow from the area plus the change in storage, which may be either depletion or addition.

Circulation

The water, evaporated from the oceans and from the lakes and land surfaces of the continents, is subject to circulation along with the earth's atmosphere. Because more of the sun's energy is received near the Equator greater evaporation and rising air occurs there. The warm, moist air flows outward from the Equator at high altitudes and because of the earth's rotation it moves in a generally northeasterly direction in the Northern Hemisphere. It cools gradually and at about thirty degrees north latitude it has lost enough heat so that it begins to sink. At the earth's surface it subdivides into the trade winds which move southwesterly back toward the Equator and the winds which move northeasterly across the Temperate Zone.

Near the North Pole another circulation pattern operates. A mass of cold air builds up and flows outward in a southwesterly direction which gradually warms it, so that, at about sixty degrees north latitude it has warmed sufficiently to rise and flow back toward the North Pole. Occasionally, this cold polar air breaks out and moves across the Temperate Zone.

The general circulation patterns just described would occur if not for the fact that the heating effect of the sun is different over land than over water and, therefore, the presence of large land masses changes these general patterns. There are four broad conditions that are operative within these general movements that result in precipitation.

Precipitation

The first broad category is the cyclonic storm producing rains over wide areas and prevalent during the winter season. These storms are formed by the interaction of the cold polar air masses and the warm tropical air masses.

The second, the convectional or thunderstorm, occurs throughout the country but more frequently in the summer, in the south, and over relatively small areas. These storms are formed as the result of uneven heating, when the air over a locality becomes warmer than the surrounding air. The ascending warm air expands and cools as it rises, and if it cools sufficiently with enough moisture present, precipitation occurs.

The third is the orographic or mountain storm wherein the mountain, acting as a barrier, forces the warm moist air driven toward it to lift and cool to the point where precipitation occurs. The fourth is the hurricane, where great quantities of warm, moist, tropical air are drawn up through the central low pressure area of the hurricane.

The effects of all types of storms may sometimes be combined, and, in all types, the lifting and cooling process reaches the point of atmospheric condensation forming small droplets of water having a minute particle as its nuclei. The amount of precipitation depends on the extent to which saturated air loses its capacity to hold moisture. In the range of temperature, from twenty degrees to eighty degrees fahrenheit, the amount of moisture in the saturated atmosphere is reduced about eighteen per cent for each five degrees fahrenheit decrease in temperature. Precipitation generally increases with elevation, and for equal elevations is greater on the windward side than on the leeward side.

Vegetation, by its leaves and branches, intercepts precipitation so that only a part reaches the soil beneath. Vegetation thus affects both the quantity and distribution of precipitation that reaches the soil surface. Of the part intercepted by vegetation, some is held and evaporated later, some flows to the ground along stems, and some spills from drip points.

Infiltration

Rain that reaches the soil surface is wholly or partly absorbed by the soil depending upon the rate of precipitation and the infiltration rate or receptiveness of the soil. When the precipitation rate exceeds the infiltration rate, the excess quickly runs off to streams and may erode the soil. Water that enters the soil either increases the moisture content of the soil or drains through it. In dry soil, the entering water wets each successive layer to its capacity and any excess water drains into the underground. Water held within the soil after drainage has ceased may be transpired by plants or lost by evaporation. Evapo-transpiration is a natural process that occurs wherever there is vegetation.

Excess water passes through the soil belt and continues downward by gravitational action into the intermediate belt. In both the soil belt and the intermediate belt, suspended water is held by molecular attraction. If the intermediate belt is filled to capacity, excess water continues down to the capillary fringe, which lies immediately below the intermediate belt and above the zone of saturation. The capillary fringe contains water that is held above the zone of saturation by capillary forces and, if it is filled, the water continues its downward movement to the zone of saturation, known as ground water. The soil water belt, the intermediate belt, and the capillary fringe make up what is known as the zone of aeration. Water, moving by gravity through the belts of the zone of aeration, enters the upper surface of the zone of saturation, which is referred to as the ground water table. All the pores and spaces in the zone of saturation are filled with water.

Briefly then, with respect to the hydrologic cycle, the principal function of the zone of aeration is to receive and hold water for plant use in the belt of soil water and to allow the downward movement of excess water. The principal function of the zone of saturation is to receive, store and provide a naturally regulated discharge of water to wells, springs, and streams.

Porosity and Permeability

There are many kinds of rock materials within the crust of the earth, and they differ greatly in size, shape, and number. All subterranean water occurs in the open spaces in and between these materials. The zone of saturation may include loose, unconsolidated deposits of sand and gravel, as well as porous rock formations such as sandstone and limestone. The term porous is applied to various substances that contain openings or pores. Some rocks have pores so numerous that the rock is hardly more than a froth of solid material, like a solidified sponge would be. Even some of the so-called solid rocks contain microscopic pores and those rocks which are so dense and compact, as to be free of pores, are commonly fractured or jointed enough so that they too form openings that can contain water.

Porosity is commonly expressed as a percentage of the total volume that is not occupied by solid material, and therefore is dependent upon the sizes, shapes, and porosity of its constituents. For instance, uniformly sized gravel has a high porosity, but if sand is added the large pore spaces between the gravel are reduced by the infiltrating sand particles. Rocks of low porosity are limited in their capacity to absorb, hold, or yield water though they occur close to the earth's surface or at depth.

Rock materials which may be porous but contain small pores, wherein the water is held by molecular attraction, do not permit the rapid movement of water through it for molecular forces are far more powerful than the force of gravity, or hydrostatic pressure, which, in this instance, is the pressure caused by the weight of water above. The rock that permits water to move through it by gravity is far more permeable than the one that holds water by molecular attraction.

The rate of movement of water beneath the surface is dependent to an important degree upon the permeability of the rock material, which is its capacity for transmitting water under pressure. The rocks of low porosity are generally impermeable because of the dearth of avenues for movement, except for those instances where fractures or fissures exist, and rocks of high porosity may also be impermeable if their pores are so small that the water is held in them by molecular forces. The depth of the zone of saturation depends on local geology and may vary from a few feet to hundreds of feet. Geologic formations also cause variations in the ground water table. These geological formations constitute the framework through which ground water moves or is barred from movement.

Ground Water Reservoirs

The term ground water reservoir is commonly used interchangeably with the term aquifer, which has been defined as a water bearing formation containing gravity ground water, or simply as a body of earth materials capable of transmitting water through its porous openings in sufficient quantity to be a source of water supply. Therefore permeability, rather than porosity, is the main qualifying characteristic for an aquifer.

The amount of ground water storage is equal to the bulk volume of the saturated aquifer times the porosity of the aquifer. The amount of ground water storage is no indication of that reservoir's capabilities for sustained water yield to wells and springs. The limit of perennial yield is set by the average annual recharge to the ground water reservoir, just as the inflow into a surface reservoir determines its useful yield. Probably more than ninety per cent of all wells do not reach bedrock, and a similar proportion of all water pumped comes from unconsolidated rocks, chiefly gravel and sand. The types of occurrences of these aquifers may be broadly grouped as (1) watercourses and buried valleys, and (2) plains and intermontane valleys.

Watercourses include the water in a stream channel plus the ground water in the alluvium that underlies the channel and forms the bordering flood plains. Many wells are situated so that the water pumped from them is readily replaced by infiltration from the river.

Buried valleys are no longer occupied by the streams that formed them, but they may still resemble watercourses in permeability of materials and in quantity of ground water storage, but the recharge and, therefore, the perennial yield capabilities are likely to be far less.

East of the Rocky Mountains there are extensive plains which are underlain by unconsolidated sediments. The ground water reservoirs under all these plains are recharged chiefly in areas where they are accessible to downward percolation of water from precipitation or, in some places, from streams. The intermontane valleys of the west are similar to the Great Plains in that they are also underlain by a tremendous volume of unconsolidated rock materials derived by the erosion of the mountains. Sand and gravel beds are the aquifers in the intermontane valleys, wherein there is some recharge by infiltration of precipitation, but as a rule the ground water reservoirs are replenished chiefly by seepage from streams into the alluvial fans at the mouths of their mountain canyons.

In addition to the unconsolidated sand and gravel aquifers, there are consolidated water bearing rocks of which limestone, sandstone, and basalt are the more important. Limestones, in which a sizable proportion of the original rock has been dissolved and removed, contain large pore spaces that are very permeable to the infiltration of precipitation and ground water movement. The cemented consolidated equivalents of sand and gravel are the sandstones and conglomerates. To the extent that the cementing is complete the porosity is reduced, hence the best sandstone aquifers are only partly cemented, and are believed to yield most of their water from the pores between the grains. Thin sheets of basalt, a volcanic rock, may spread to form extensive plains which have a range of permeability equivalent to limestone. Less than ten per cent of all water pumped comes from the aforementioned consolidated rocks.

Other volcanic rocks, notably the rhyolites, are generally less permeable than basalt. Shallow intrusive rocks, such as dikes, sills, and plugs, are practically impermeable or have low permeability. Thus they act chiefly to interrupt the flow of water in permeable rocks cut by them. Sometimes, because of intervening layers, two or more water tables may occur at different levels, or because water is confined under hydrostatic pressure below an impervious layer, a flowing or artesian well may occur.

Ground water surveys require the determination of the areal extent of the aquifer, the aquifer's thickness, the level of the ground water table, and the specific yield. The size and location of an aquifer can be determined by surface geology, by driller's logs of samples taken when wells are drilled, by electrical logs which are the records of electrical resistivity tests, and sometimes by sonic reflection from the bottom of an aquifer as the result of small dynamite explosions. The electrical resistivity method makes use of the fact that sedimentary fill and bedrock have different resistivities, and is considered generally as being the most efficient tool in geohydrological investigations.

Determining the elevation of the ground water table may be accomplished by lowering a steel tape or wire down to the water in a well, or by the operation of a recording float gage in a well, or by the installation of a specific length of air line and recording the air pressure necessary to blow the water out of the air line, which denotes the depth of water to the bottom of the air line.

The specific yield of an aquifer is the ratio of the volume of water which will drain out by gravity, when the rock materials are saturated, to the total volume occupied by such materials. It is less than the porosity of an aquifer because part of the pore space is occupied by water which will not drain. Specific yield is useful in determining, from ground water level changes, the quantities of water extracted or necessary to recharge an aquifer. Specific yield, therefore, permits the computation of the amount of change in storage even if an aquifer may not be adequately surveyed. For instance, if an aquifer has a surface area of six square miles, 3,840 acres, and an average specific yield of seven and one-half per cent has been determined, each one foot rise or fall in water level over the area represents a change of 288 acre feet of water. This is obtained by merely multiplying 3,840 acres by seven and one-half per cent.

Infiltration is not easy to measure accurately and on large watersheds it is customary to take the difference between rainfall and run-off as an index of intake even though it does not take into account either the interception by plant life or the process of evapotranspiration. The infiltration rate, the rate at which surface infiltration occurs at a given time, does not remain constant. For instance, the infiltration rate for sandy loam grassland may be eight or ten inches per hour at first, but gradually this rate decreases until a fairly constant rate of about one-half inch per hour, called the "ultimate" infiltration capacity, is reached. If the water available is more than infiltration capacity, the excess runs off or fills ponds.

The infiltration capacity can be computed by comparing the differences between (1) the measured surface inflow and outflow for a given area, and (2) the measured differences in soil moisture and the measured rise in the ground water table.

Watershed Inventories

Watershed nearly always meant the drainage divide that separated the waters flowing into different rivers or oceans. Gradually, the term watershed came to mean drainage basin of a river or stream, so that, to most people watershed means the same as drainage basin. Watershed now implies a drainage area containing a few thousand or a few hundred thousand acres. It has become a social and economic unit for community development and conservation of water, soil, forests, and related resources. Drainage basin inventories are made by recording the various items of inflow, outflow, and storage change, and then balancing them on some periodic basis in accordance with the hydrologic equation. This provides a logical basis for planning future water supplies in accordance with a general inventory of supply, demand, and storage capacity.

Run-Off

Run-off occurs when precipitation, that does not have an opportunity to infiltrate into the soil, flows across the land surface and enters stream channels. A part of the precipitation that infiltrates the soil percolates downward to the ground water table and also enters stream channels through springs or seeps. Seepage includes flow into (influent seepage) and flow out of (effluent seepage) the ground water aquifers.

The amount and rate of precipitation affect the volume and peak flow of a stream. The physical characteristics of a watershed indicate what might be expected in the way of the total volume and the peak rate of run-off. A relatively impervious, steeply sloping watershed may shed most of the precipitation falling on it, but a watershed with good permeable soil may permit a high percentage of the precipitation to be infiltrated into the soil. Lakes, ponds, swamps, and reservoirs also act to level off peak rates of flow into the streams below. Generally, there is but little loss of flow from natural lakes and swamps to ground water since they usually exist because there is little or no percolation into the soil.

For all practical purposes, surface water means streamflow. Streamflow observations are made regularly, by the United States Geological Survey, at about 6,500 gaging stations located on all principal rivers and a large number of their tributaries. Streamflow data includes stream gaging to determine the height of the stream, called the gage-height record, and the current meter which records the velocity of the flow. The discharge of a stream is obtained by multiplying the cross sectional area of the stream by its mean velocity.

Analysis of run-off data includes data on the inflow and outflow for a reservoir or other body of water; the drainage basin characteristics; the topographic characteristics; the correlation of run-off with precipitation data, and data on evaporation and transpiration.

THE LIMITATIONS OF THE SCIENCE OF HYDROLOGY

As can be readily seen, for all practical purposes, the science of hydrology is concerned exclusively with the hydrologic cycle in all of its various aspects. Those who transport water laterally and those who find conventional ground water have much in common since they both have a technology that is based on physical factors only. One deals with the run-off of precipitation, whereas the other deals with its infiltration into porous rock materials. As far as water supplies are concerned, they both ignore the solid rock structures and the fissures which they must contain and the water that is available in some of these fissures. They also completely ignore the chemistry of the earth and the chemical reactions that are constantly taking place within the earth.

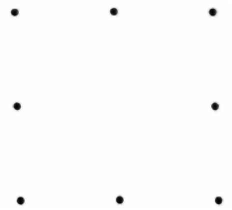
Even the various water supply research programs neglect both the solid rock fissure waters and the chemistry of the earth. Sea water conversion would short circuit the hydrologic cycle in that water would be obtained directly from the sea instead of sea water being evaporated into the atmosphere and then precipitated on the land. Cloud seeding attempts to aid the hydrologic cycle, to assure precipitation over certain areas of land. Reclamation of used water is simply taking the same available water supplies and attempting to use it over and over again before it either evaporates or makes its way back to the sea. Reducing evaporation from lakes and reservoirs is an attempt to modify that part of the hydrologic cycle with reference to retaining more of the surface stored water supply. There is no attempt to deprecate these research programs for they have their place in water research, inasmuch as the world's water problems are getting more and more acute. The thought that is being conveyed, however, is that they also neglect to take into account the chemistry of the earth.

If water is the product of chemical reaction, and the literature is replete with such illustrations, do these reactions take place within the earth, and if they do, why do hydrologists ignore them? If you were to hear the following story, how would you explain it?

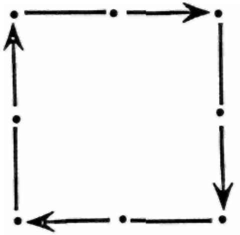
A young, unmarried girl, finding herself pregnant, visits a doctor and pleads with the doctor, begging that the doctor perform an abortion. The doctor, naturally, explains that this procedure is illegal, but faced with a desperate girl, suggests that she disclose the man responsible for her pregnancy, in which case the doctor might be able to help her in some way. At first, the girl refuses to reveal the man, but while standing near a window she notices a man walking on the other side of the street—in desperation, she points to him and says: "It was that man!" The doctor, observing to whom the girl was pointing, immediately goes to a desk drawer, extracts a gun and shoots the girl. The question is, why did the doctor shoot the girl? Without hesitation, quickly guess the reason, and after you've made several rapid guesses, turn to the appendix and read the answer. The chances are probably better than nine out of ten that your answer will disclose a mental block.

UNCONSCIOUS DELIMITING

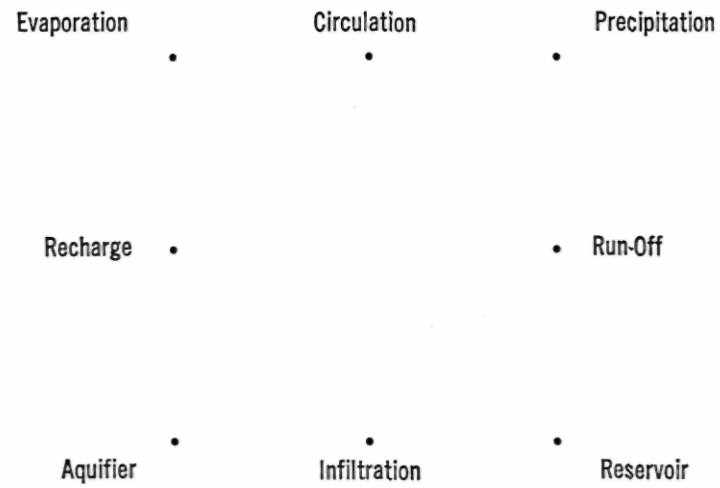
Another illustration would proceed as follows. Suppose you were asked to draw four straight lines so that, without lifting your pencil or retracing any lines, the four straight lines would go through and connect each of the following eight dots:



—none of you would have any difficulty, for the solution would simply be:

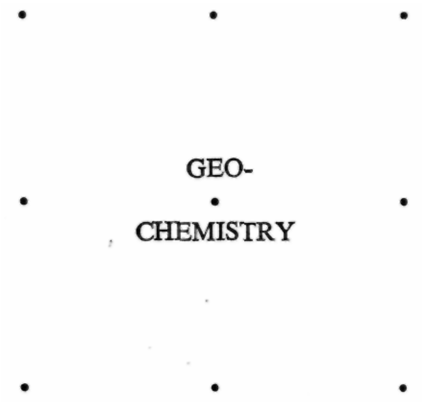


If the eight dots represent the hydrologic cycle, each of these eight dots might represent a factor of the hydrologic cycle, like this:



Hydrologists, also, can easily connect each of these factors.

But now, in the midst of these dots, we add another dot and call it geochemistry, the chemistry of the earth. With the same instructions given previously, draw four straight lines that will connect each of the following nine dots: [79]



How many of you can do it? How many hydrologists can do it? Try it, and if you are not successful turn to the appendix and find the answer.

Mental blocks exist because thinking processes follow along certain patterns that have been molded and shaped by training, and by the social, psychological, and economic environment of the individual. In essence, mental blocks are the result of self-imposed restrictions, which are unknowingly interposed and which sometimes prevent the solving of problems. For instance, in the problem of the nine dots, most people unknowingly impose a limiting factor which was not given in the instructions. That is, they limit themselves to keeping the lines they draw within the area bounded by the eight outside dots, although no such limitation is required by the instructions.

Most present day hydrologists, whether they work for a governmental agency or as consultants in private practice, whether their initial training has been in civil or hydraulic engineering or in ground water hydrology, have been so thoroughly indoctrinated and inculcated with the methodology and technology based on the applications of the hydrologic cycle theory that, when faced with a water shortage problem for a particular area, they seek a solution only in terms of their training and experience. Unfortunately, as shall be shown later, the only solution offered in such areas may be importation.

CONSCIOUS DELIMITING

It stands to reason, however, just as there are some people who can successfully solve the nine dot problem, that there must be some recognition, by at least some hydrologists, that geochemistry accounts for the addition of some water on the earth and that, therefore, it is a conscious delimiting among some, as well as a mental block among others, that excludes these waters from the science of hydrology.

Robert E. Horton said, in 1931, that if science is defined as correlated knowledge, "it is true that a statement of the field, scope, and status of hydrology at the present time may be little more than a birth certificate." [40J Although he recognized that in one sense the field of hydrology is the earth and therefore co-terminus with other geo-sciences, he continues: "More specifically the field of hydrology, treated as a pure science, is to trace out and account for the phenomena of the hydrologic cycle." [40] Horton also says that "hydrology is not concerned with waters which have been temporarily removed from circulation such as waters of crystallization or hydration in nature." [40] He implies, therefore, that both waters of crystallization and hydration are the results of the hydrologic cycle. It was previously shown that the great magnitude of waters of crystallization precluded an origin due to the hydrologic cycle.

Oscar E. Meinzer [80], who was formerly head of the Ground Water Division of the United States Geological Survey, writes that the central concept in the science of hydrology is the so-called hydrologic cycle and that it is especially concerned with the water after it is precipitated upon the land and until it is either evaporated back up to the atmosphere or discharged into the sea. In speaking of the comparatively great depths below the land surface, Meinzer [80 pp. 2-3] recognizes the abundant evidence that water or the dissociated elements of water occurs there in some sort of solution with other rock materials and that part of this internal water either reaches the surface or the rock openings near the surface.

Meinzer believes that these waters of internal origin are tangible additions to the water supply of the earth. Not only does he perceive that some waters in the earth are of internal origin, and hence not the result of the infiltration of precipitation, but Meinzer goes further and tells where he thinks the studies of these internal waters properly belong. "The critical studies of the water of internal origin," says Meinzer, "have been made chiefly in connection with volcanology and metalliferous geology and belong most properly to those branches of geology." [80 p. 3]*

A SERIOUS GAP

If people in the field of hydrology wish to delimit their science, exclusively to applications of the hydrologic cycle and hence to the exclusion of the water of internal origin, they may certainly do so. Unfortunately, however, governmental officials, legislators, and the general public are generally unaware of these internal waters and are therefore under the delusion that hydrologists are the water supply experts without realizing that these experts deal with only certain kinds of water, namely the run-off of precipitation or its infiltration in porous rock materials. It is indeed remarkable, as well as incongruous, that those to whom the world looks to for the solution of water shortages can be so disinterested as to relegate the study of the waters of internal origin to other branches of geology. Although it is true that geologists in the other branches of geology referred to, as well as in a few others, have done the critical studies, they are essentially geologic specialists who are concerned with these internal waters, not as water suppliers, but solely for the understanding of the role played by these waters in their particular specialties. It is, therefore, strange that ground water hydrologists have not developed research activities related to the location and procurement of these waters of internal origin for water supply purposes.

Here then is an hiatus, a gap created by the relinquishment of any interest by hydrologists and the non-acceptance by other geologic specialists for establishing both theory and technology for the location and use of these waters of internal origin for the water supply and service of mankind. In terms of the food and water limitations, that keep two-thirds of the population of the world in desperate need of a reasonable minimum food standard and in view of the expanding world population and the other factors that create a world

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*By permission from "Hydrology," by Oscar E. Meinzer. Copyright 1942. McGraw-Hill Book Company, Inc.

in increasing need of more water and food, this breech must be filled. Putting it very conservatively, the waters of internal origin constitute what might be termed, from the standpoint of water supply potential, a fruitful area of research.

Despite the fact that hydrologists profess, among themselves at least, of their non-interest in and their scant knowledge of the waters of internal origin they nonetheless persist in continuing to delude themselves and the public at large. This is accomplished by either a failure to mention the existence of these waters, or by minimizing the amount of such waters, or by deprecating the usefulness or the quality of these waters. Failure to mention are inherent in statements such as, "practically all ground water is derived ultimately from precipitation." Minimizing the amount of these waters is achieved directly by saying that, "most of the water below the ground is precipitation that has seeped downward from the surface." In those few cases where it has been admitted that there may be large quantities of such water, the quality is usually attacked, as in the following instance: "The quantity from these sources may be large in the aggregate, but the water is commonly too mineralized for most uses and is therefore avoided when encountered in wells. Essentially, all usable ground water is part of the circulatory pattern of the hydrologic cycle." [81]

The term ground water is frequently and exclusively defined to mean the water that is located in a conventional aquifer in unconsolidated rocks and hence undoubtedly a part of the circulatory pattern of the hydrologic cycle. But piddling with words does not solve the problem, it fights the problem. The use of the term ground water should encompass all waters that can be extracted from the earth.

It is rather interesting and perhaps of some significance that in the same issue of the Transactions of The American Geophysical Union, in which appeared Robert E. Horton's article discussing the science of hydrology, is an article by Roy W. Goranson entitled, "Solubility of Water in Granite Magmas." To quote Goranson briefly: "Geologists have been deeply concerned with the volatile constituents of magmas, for these constituents play important roles in volcanology, in ore-deposition, and in other igneous phenomena. Of these volatile constituents water is the most abundant." [82] It would seem that hydrologists, in the course of their work, would be exposed to situations that clearly indicate these new waters, that they would become quite interested in finding out more about them, and that knowledge about these internal waters would become quite commonplace among them. However, with respect to the geology of the earth and its chemistry, not only has the training of the ground water hydrologist been somewhat limited but their field experiences have likewise been somewhat confined.

GEOLOGIST v. HYDROLOGIST

Goranson has given evidence that water is the most abundant of the volatile constituents of magmas, and that geologists have been deeply concerned with these volatile constituents. The question which should naturally arise is: what is the difference between the work of the geologist and that of the hydrologist? Harold E. Thomas differentiates between the role of the geologist and that of the hydrologist as follows:

"A geologist's description of a rock generally includes all the features that can be observed by the naked eye as well as by microscopic examination. Inevitably some of these features will pertain to pore spaces, or the water-soluble constituents, or other characteristics of special interest to the ground-water hydrologist. On the other hand, the geologist and the ground-water hydrologist emphasize, respectively, the doughnut and the hole, and it is to be expected that their selection of the salient features concerning any specific rock will differ somewhat." [59 p. 10]

Of great significance, to those who are interested in solving the water problems of the world and who are also open-minded enough to realize the tremendous potential water supply that the waters of internal origin makes possible, is Thomas' continuing statement:

"Perhaps the greatest difference in emphasis is in the loose gravel, sand, and clay which mantles the surface of the earth nearly everywhere, and which may extend to depths of hundreds or even thousands of feet. These are the least likely places to look for economic deposits of most mineral resources. But they are far and away the most important producers of ground water. Probably more than ninety per cent of all wells do not reach bedrock, and a similar proportion of all water pumped comes from unconsolidated rocks, chiefly gravel and sand. Our knowledge of ground-water occurrence also is most comprehensive in these unconsolidated materials." [59]

When Thomas says that the loose gravel, sand, and clay are by far the most important producers of ground water, he, of course, is referring to waters of the hydrologic cycle. Inasmuch as very close relationships exist between the waters of internal origin and the deposition of the economically important metals and minerals, these very same areas are the least likely places to look for waters of internal origin just as they are the least likely places to look for economic deposits of most minerals.

The hydrologist's knowledge of ground water occurrence is essentially in the unconsolidated rocks. Tolman not only says that the study of water bodies in fractured but consolidated rocks has been neglected, but that it has also been erroneously assumed that: (1) the properties of the water in consolidated rock fractures are similar to the better known waters in the unconsolidated rocks, and (2) the water table in consolidated rock fractures is related to an underlying water body in the same way as the water table in unconsolidated rocks is related to its underlying water body. [37 pp. 291-2]

HYDRAULICS

A factor which necessitates defining hydraulics is not only the fact that many hydraulic engineers are employed in water supply endeavors, but also that they are thought by many people to be synnonomous with the hydrologist, and therefore a water expert in its broadest meaning. Horton has said that "hydraulics is concerned with the mechanics and physics of fluid motion whereas in hydrology the forces and the conditions of motion are natural and are intimately bound up with the activities of the hydrologic cycle." [40 p. 194] Hydraulics is the practical application of hydrodynamics, which is the mathematical study of motion, energy, and pressure of liquids in motion. For practical purposes, hydraulics treats of water in motion, its action in canals and rivers, its use in driving machinery, and the works and machinery used for conducting water or raising it.

One recent investigation by the California State Water Resources Board, for instance, was conducted under the direction of two principal hydraulic engineers, one senior hydraulic engineer, two assistant civil engineers, one assistant engineering geologist, three assistant hydraulic engineers, and one junior civil engineer. Assistance, according to the report, was also furnished by other hydraulic engineers, engineering geologists, civil engineers, a soil technologist, and an economist. The report of this investigation is published in Bulletin No. 12—Ventura County Investigation, October 1953, Revised April 1956.

From these job titles, unless these people have been improperly classified, one would not expect that they would have knowledge of the waters of internal origin. Furthermore, the preponderance of hydraulic engineers on this investigation would almost be enough to lead one to a fairly accurate guess as to what the final solution offered might be. The summary statement follows: [83]

> In common with many other portions of southern California, Ventura County has recently experienced an increase in water utilization during a period of severe drought, and as a result is confronted with the necessity of developing additional water supplies to meet its expanding needs. Water resources problems of Ventura County are manifested in perennial lowering of ground water levels, sea-water intrusion to pumped aquifiers, degradation of ground water quality, and general diminution of surface and ground water supplies during periods of drought to quantities inadequate to satisfy requirements. The initial alleviation of these problems will involve further regulation of the erratic local water supply, so that waste conserved during wet periods can be made available for beneficial use during periods of drought. Final solution of water problems of Ventura County will lie in importation of water supplies from outside sources.

NEW POINT OF VIEW

Modern hydrology, as a science, is considered to have begun with the work of Pierre Perrault (1608-1680) and of Edme Mariotte (1620-1684). These men had, for the first time, put hydrology on a quantitative basis.

Prior to Perrault, it was believed that the waters in rivers were more than could be accounted for by rainfall. Perrault measured the drainage area of part of the Seine River and then determined, by the use of a rain gage, the average rainfall for three consecutive years. He found that less than one-sixth of the water passed through the Seine Canal. Mariotte's investigation, a few years later, included the whole drainage basin of the Seine above Paris, and came to a conclusion similar to Perrault's. These early pioneer works became landmarks because it was thought that they conclusively proved that all waters, flowing on the surface of the earth, are the result of precipitation. Looking back from a present vantage point, it is realized that these early studies were concerned exclusively with rain gaging and with stream gaging, utilizing relatively crude equipment, and that their conclusions had not taken into account the interception by plant life, the losses due to evapo-transpiration, the losses by evaporation from bodies of water, and the rates of infiltration into soils and rocky materials.

The science of hydrology has progressed from these early beginnings, but it must be realized that it deals exclusively with surface water run-off and ground water run-off through pervious granular materials—the essential features of which are precipitation, infiltration, evaporation, transpiration, climate, and drainage basin characteristics—and that these ignore consolidated rock fissure waters for all practical purposes and the chemistry of the earth, the chemical reactions which produce the waters of internal origin.

In the face of these facts, it is obvious that a new point of view is needed if solutions to water problems are to be found. The following chapters are based on scientific evidence and knowledge, and although they may occasionally step out boldly into the unknown, where meager facts exist to support some conclusions, they do so only as underscoring the importance of the problem and the need for more research, which is coupled with an urgent need that many people be willing to examine new ideas. Only in this way, can an investigation proceed into a possible source of pure, clean, and abundant water supplies which have heretofore been almost universally neglected.

It is not who is right, but what
is right, that is of importance.
—THOMAS HUXLEY

CHAPTER V

THE DYNAMIC EARTH

Within the thin crust of the earth are temperatures that vaporize iron and pressures that keep molten rock a solid. Absorbed in everyday life problems, man is nonetheless periodically reminded of the deep mysteries that he beneath his feet when the elemental forces of pressure and high temperature breach a fracture in the earth's crust. On September 27, 1957, the world's newest volcano burst from the sea floor just a few hundred yards off the island of Fayal, in the Azores, belching forth flowing lava bombs, gases, and water vapor which billowed up some twenty thousand feet. In November of 1959 the spotlight turned to a volcanic eruption on the island of Hawaii and the lava was still flowing down to the sea in January, 1960.

In 1925, Henry Washington [84] hypothesized that the internal constitution of the earth was composed of six spheres of which the outermost—the one of least thickness—was a Granitic shell of about twelve and one-half miles corresponding to the composition of the average igneous rocks.

However, two seismic discontinuities of the first order are the basis by which the earth is currently thought to be divided into three main spheres, as follows:

1. The central core with a radius of about 2,175 miles, overlain with
2. A mantle having a thickness ranging from 1,770 to 1,780 miles, which in turn is overlain with

3. A crust having a thickness ranging from eighteen to thirty-one miles.

But within the core an additional discontinuity has been discovered at a depth of about 3,170 miles, subdividing the core into an inner and outer core. Daly [44] has explained this discontinuity by the theory that in the outer core occluded hydrogen and other gases occur.

Seismic and other data indicate that, within the crust of the earth, there exist three principal layers called the continental layers. The first, known as the intermediate layer, overlies the uppermost seismic discontinuity of the first order. This layer is thought to be intermediate between basalt and granite in chemical composition and its top is found at depths that vary from six to eighteen miles. Above the intermediate layer is the granitic layer that corresponds in composition to the average igneous rocks. The third layer, the sedimentary layer, is composed of sediments, and of sedimentary and metamorphic rocks, and has been found to extend to depths of about nine miles.

These continental layers vary in thickness. As the name implies, they are much thicker under the continents than under the oceans. For instance, they are considerably thinner under both the Atlantic and Indian Oceans and are virtually absent in the Pacific Basin area.

The existence of separate shells of different mass composition means that among those shells the elements will be distributed in fixed proportions that depend on the chemical behavior of each element, the physico-chemical conditions present, and on the origin of the geospheres. It is necessary to recognize the fact that the geochemical evolution of the earth did not stop with the formation of a solid crust on the earth, or of either the hydrosphere or the atmosphere. Actually, the evolution has continued throughout the geological history of the earth—the earth is changeable chemically, and its geochemical evolution continues today.

The earth is, and throughout all geologic history has always been, an eruptive body, from within which molten rock has been uptruded, and on rising and cooling they have become igneous rocks, of which there are many varieties. It is now well established that granite has been intruded into the outer shell of the earth at many different times and that the latest intrusions of this kind are quite recent events, geologically speaking. In fact, granite is usually younger than the greater part of the rocks with which it is associated, and the light granitic magma, having a low temperature of crystallization, still rises upward through the crust.

ORIGIN OF THE EARTH'S HYDROSPHERE

In reviewing the origin of the earth, Adams, based upon the then current knowledge of the order of crystallization, states that the last stages of the solidification of the earth "produce a layer of basalt and then a layer of granite, at the same time releasing the greater part of the water and carbon dioxide to form the primeval ocean and atmosphere." [85]

Several recent authors [86] have posed the question of the origin of the earth's hydrosphere. In 1950, when William W. Rubey was President of the Geological Society of America and also Chairman of our National Research Council, he addressed our National Academy of Sciences regarding the geologic evidence of the source of the earth's hydrosphere and atmosphere. His conclusions were that both the ocean waters and the earth's atmosphere have come from the interior of the earth and, according to Rubey's calculations, in the years of the earth's existence hot springs alone have yielded over one hundred times as much water as exists in the present oceans.

In his presidential address before the Geological Society of America, Rubey assembled the critical evidence, formulated alternative hypotheses which he then examined for consequences that are testable by the actual geologic record. Five years later, Rubey writes that it seems evident that most of the major rock forming elements in sedimentary rocks and all the dissolved bases in sea water have been derived from the weathering of earlier rocks throughout the past. However, he points out that this is not an adequate source for a group of materials he calls "excess" volatiles (H_2O, CO_2, Cl, N, S, and several others), "all of which are much too abundant in the present atmosphere and hydrosphere and in ancient sedimentary rocks to be accounted for solely by rock weathering." [87] In seeking another source to account for these excess volatiles, the central problem of the origin of the hydrosphere and atmosphere are encountered head-on, says Rubey.

Rubey explains that there have been only two possible sources suggested for these "excess" materials: either the waters of the present oceans and all the other excess volatiles were inherited from a primitive ocean and atmosphere, or they have risen, during the course of geologic time, from the earth's interior to the surface. Rankama and Sahama [34 p. 304] conclude, however, that water vapor from the original atmosphere must have escaped from the earth and that the present water in the earth's hydrosphere is of juvenile origin.

The alternative hypotheses that the excess materials have risen to the surface from the earth's interior during the course of geologic time, says Rubey, "depends upon some complex and relatively unfamiliar process or processes of 'degassing' of the rocks of the earth's interior, and these complex processes get the hypothesis deep into the problems of physical chemistry and petrogenesis." [87] Rubey terminates his inquiry "with the conclusion that the hypothesis of gradual 'degassing' of the earth's interior leads to chemical consequences at the surface that appear entirely consistent with the observed geologic record." [87 p. 641]

Kulp [88] has calculated that 3400 x 10" tons of H_2O has escaped from the subcrust and core of the earth since its formation. Most of this amount, 2200 to 2600 x 10" tons of H_2O still remains in the crust and that the remainder, some 800 to 1200 x 10^{15} tons of H_2O has either dissociated into hydrogen and oxygen or escaped to the surface. These figures of Kulp, says Poldervaart, "would indicate an average of 2 1/2-4 1/2 per cent H_2O in the crystalline rocks of the earth's crust, which does not seem unreasonable." [39]

Mason [89] says that the suggestion has been made that primary magma is rich in hydrogen, which upon oxidation has produced the water. This process is quite improbable, says Mason, because the rocks that would crystallize out from such a primary magma would contain metallic iron and no ferric iron whereas no such rocks have been found. However, Urey quite pointedly says, "Both water and metallic iron are important constituents of the earth." [90]

Furthermore, Kennedy [91] has pointed out that in fresh igneous rocks the ferric to ferrous iron ratio yields pertinent information as to whether the magma was wet or dry. This relationship is based on the assumption that the partial pressure of O_2, in the rock melt at the time the iron-bearing minerals crystallize, was produced by the dissociation of water and that this pressure must equal the O_2 pressure produced by the dissociation of the iron oxides.

In applying thermodynamic data to the problem of the composition of magmatic gases, Ellis [92] shows that a primary magma containing H_2O, H_2S, and CO_2 explains the observed gas compositions.

ROCK SYSTEMS, ALTERATION, AND EARTH TIDES

Rocks have been analyzed and classified into various systems depending upon their age, their mode of origin, their subsequent alteration, their mineralogical content, etc. The earth is thought to be about four and one-half billion years old, and the oldest rock is dated at about three and three-tenths billions years. There are five eras of rock which are generally recognized, and each of these is subdivided, representing a different age in the geological history of the earth. Starting with the oldest first, they are:

Eras	Subdivisions	Approximate age (millions of yrs.)
PRE-CAMBRIAN	Archean	3,300 to
	Algonkian	520
PALEOZOIC	Cambrian	520 to 440
	Ordovician	440 to 360
	Silurian	360 to 320
	Devonian	320 to 265
	Carboniferous	265 to 210
	Mississippian	210 to 185
	Pennsylvanian	
	Permian	
MESOZOIC	Triassic	185 to 155
	Jurassic	155 to 130
	Cretaceous	130 to 60
TERTIARY	Eocene	60 to 40
	Oligocene	40 to 28
	Miocene	28 to 12
	Pliocene	12 to 1
QUATERNARY	Pleistocene	1 to .01
	Recent	.01 to present

The earth's physical history has been expressed in the widespread crustal disturbances which are termed revolutions. The Laurentian and Algoman revolutions occurred during the Pre-Cambrian era, followed later by the Killarney revolution at the close of the Pre-Cambrian era. Then the Appalachian revolution ending the Paleozoic era, the Laramide revolution ending the Mesozoic era, and the Cascadian revolution opening up the Quaternary era.

Rocks differ chemically, mineralogically, and structurally. By chemical composition, reference is made to the chemical elements that make up the minerals. For instance, two minerals like graphite and diamond, have the identical composition, consisting solely of crystallized carbon, yet they do not have the same properties nor the same uses. Two rocks may have the identical chemical composition but be different. Rhyolite, a volcanic rock, and granite, a plutonic rock, have the same chemical composition but the granular crystals of the granite are well formed and developed, visible to the naked eye, whereas the rhyolite is smooth surfaced. Minerals are assemblages of chemical elements, and they differ, from one another, both qualitatively and quantitiatively. Rocks, composed of minerals, also differ one from another, both qualitatively and quantitatively with respect to their mineralogical composition. It has therefore become necessary to name the rocks according to their mineral content, taking into consideration the qualitative mineral content, the relative proportions of the constituent minerals, and the mechanical and textural relations. Generally, rocks are classified into three broad groupings of igneous, metamorphic, and sedimentary, even though in some cases their characteristics are less sharply defined and sometimes there is even a merging of features. Chemicals make up minerals; minerals make up rocks, and rocks make the structure of the earth.

Turner and Verhoogen [93] have identified the chemical and physical processes that are responsible for the origin of rocks as:

1. The igneous processes of crystallization of minerals and the solidification of glass from magmas at high temperatures;
2. The metamorphic processes of recrystallization and mutual reaction of minerals in solid rocks at high temperatures;
3. The metasomatic processes whereby ions exchange between minerals of solid rocks and the migrating aqueous gases or

solutions, occurring over a wide range of temperatures and pressures, and

4. The sedimentary processes of weathering, deposition of suspended matter, and precipitation of dissolved material from solution in water.

The aim of petrology is the presentation of the origin and evolution of rocks based on the data of chemistry, field association, mineralogy, and the fabric of the rocks themselves. In rock masses, spontaneous changes occur such as the solidification of liquid magmas; the partial or total melting of solid rocks, and the sediments which undergo chemical or physical transformation. Inasmuch as the object of petrology is to study changes that occur spontaneously in rock masses, it is concerned essentially with a flow of whole crystals, molecules, atoms, ions or particles, and changes thereof while moving into, through, or out of rocks.

According to Dalton's hypothesis, formulated in the early years of the nineteenth century, the chemical atom was the ultimate particle of matter and hence indivisible. In 1815, Prout advanced the hypothesis that hydrogen is a primordial substance of which the other chemical elements are compounds. Lockyer, in 1876, advanced the idea that in some elements the atoms are dissociated when subjected to sufficiently high temperatures or high voltage excitation. After the discovery of isotopes, by positive ray analysis, Lockyer's hypothesis came to be accepted and was further reinforced as knowledge of the atom accumulated.

The atom consists of a positively charged central core, the nucleus, about which negatively charged electrons rotate in various orbits. Almost the whole mass of the atom resides in the nucleus, which is composed of positively charged protons and neutral neutrons. The removal or addition of outer electrons causes the atom to become an ion. Positively charged ions have fewer electrons than is necessary for the atom to be electrically neutral whereas negative ions have more.

Atoms and ions are the particles that constitute crystals. Crystal chemistry takes into account the size of these particles that make up the crystals. The space requirements of a particle are governed by the equilibrium established between the attractive and repulsive forces of the particle and a neighboring particle, with the distance so established between the two particles defined as the sum of the radii of the two particles. Since atoms and ions are the particles that constitute crystals, the effective size of an atom or an ion in a crystal structure is its atomic radius or its ionic radius.

The entire array of matter depends upon the properties of atoms and ions and upon the structural pattern that the atoms or ions, of a particular material, take on at certain temperatures. This structural pattern, known as a lattice, acts as a sorting mechanism admitting only those atoms or ions of the right size and shape into the assemblage of the mineral.

If all the atoms or ions of a crystal are at rest, in the equilibrium positions established by the different bonding forces acting between the particles, it becomes apparent that a certain amount of energy is needed to disintegrate the crystal into its individual constituents. When a rock is exposed to changes in temperature, pressure, or both, its mineral assemblage changes according to definite rules which are governed by the laws of physics and chemistry. This simple principle, which is the basis of metamorphism, explains the indisputable field observations that solid rocks, when exposed to the geological forces within the earth's crust, are continually being altered—chemically, mineralogically, and structurally.

The alteration is commonly accompanied by the loss and gain of some elements and is usually connected with considerable mechanical motion such as faulting, folding, plastic flow, or thrusting. When a rock is under stress within the limits of its elasticity it will spring back after the stress has been removed. This resilience is often called "elastic rebound" and is the stored energy equal to the work of the deforming forces. If a rock is stressed sufficiently it ruptures—some of the force is spent in permanently deforming the rock and in producing heat by friction, whereas the residual force is the resilience which brings the rock to a position of no strain. It is thought that earthquakes are caused by the elastic rebound of rocks to a position of no strain.

In Nordenskiold's article, "About Drilling for Water in Primary Rocks," which appeared earlier, he says that folding, in many instances, very likely results less from any violent revolution than from some almost imperceptible but nevertheless continually operating power. It is the periodic variations of temperature, Nordenskiold reasons, that cause slight dislocations of strata which accumulate over long periods of time to cause folds. A similar continuing operating power is the periodic tidal forces which change their direction every six hours. An observer in a boat on the ocean cannot notice the solar and lunar tidal effects which result in the periodic rise and fall of the ocean. Likewise, an observer on land notices the tidal effect on the sea but is unaware of the tidal effect on the land mass.

Pliny the Elder (23-79 A.D.) had said that at Cadiz there was a spring enclosed like a well, which would sometimes rise and fall with the ocean while, at other times, its rise and fall would be contrary to the ocean. Lambert [94] cites what he considers to be four clear-cut cases of the direct effects of the tide-producing forces inasmuch as they are remote from the coast and therefore the pressure of the load of tidal water must be unimportant. It is interesting to find that Lambert's first illustration is a whole series of lignite mines in Bohemia which were inundated in 1879, and that measurements, made over a period of five months, clearly marked lunar, solar, and declinational effects. His second illustration is of boreholes at about 2,700 feet above sea level and in the vicinity of natural springs. The third illustration is of an artesian well at an altitude of 2,955 feet, the fourth being a well drilled in limestone to a depth of 755 feet and containing water that is fresh instead of briny.

"It is remarkable that in all four cases cited, Duchov, Tarka Bridge, Carlsbad, and Iowa City," says Lambert, the lowest level of the water occurs at the time of the moon's transit." [94 p. 17] The most probable explanation of this, says Lambert [94 p. 18], is that the earth tide increases the spaces which the water occupies and therefore the water in the mineshaft, well, or borehole decreases. C. L. Pekeris of the Geology Department of the Massachusetts Institute of Technology, commenting in the same study said: "Since the apparent tidal forces of the moon pull outwards the portions of the earth that are facing the moon and those which are at its antipodes and tend to push inwards the intermediate regions, it is clear that at the time of the moon's transit, when the earth tide is high, the region underneath the station is under tension and is dilated, while 6 hours later, when the earth-tidal displacement is downwards, it is under compression." [94 p. 23]

Albert A, Michelson, in his study of microtides was able to compare the observed height of the tides with theoretical values, from which it was deduced that the tides in rocks are about one-fourth the magnitude of the tides in water. Thus, the crust of the earth is periodically being stretched in depth, and if the tension exceeds the elastic limits of the rock, horizontal fissures ought to occur.

Recrystallization usually takes place in metamorphism by rising temperature and pressure. In metamorphic rocks, the mineral assemblages correspond to approximate chemical equilibrium at certain pressure-temperature combinations which, of course, may vary from rock to rock, and from place to place.

Petrology, the study of the origin, structure, and composition of rocks, is the application of physical chemistry to rock making processes. Barth [95] points out that geologists in the past did not believe that the ordinary physico-chemical laws as determined in the laboratories could apply to the collossal forces in the interior of the earth, but that the extraordinary progress during the last fifty years in petrology has been achieved primarily by the theoretical and practical applications of these fundamental physico-chemical principles. Barth says that as is usual in the history of mankind, each new step has been bitterly opposed by conservative practitioners. But that, despite this opposition, the new school of thought gained momentum so that the need for exact physico-chemical studies of rock making processes is now generally recognized even though the curriculum lags behind in many schools.

IGNEOUS ROCKS AND MAGMATIC WATER

It was previously mentioned that igneous rocks are the solidification of the uptruded molten rock materials, termed magma. From the physical chemist's point of view a magma is regarded as a multicomponent system consisting of a liquid phase coexisting with solid phases, and at times including a gaseous phase.

A substance may have three distinct phases, a liquid phase, a gaseous phase, and a solid phase. Water is a liquid phase; water vapor or steam is a gaseous phase, and ice is a solid phase. If water, water vapor, and ice were to coexist in equilibrium, although there is only one component, the number of phases would be three. On the other hand, a solution of salt in water is a system of only one phase. In petrology and metallurgy, as well as in physical chemistry, phase diagrams are constructed in accordance with the phase rule of Gibbs and the revelation of its principles by Roozeboom.

The classic, Findlay's "Phase Rule," [96] is a comprehensive introduction to the subject. According to Rhines, the use of phase diagrams transfers the otherwise bewildering pattern of change that takes place into intelligible data as elemental substances are mixed together and are heated or cooled, compressed or expanded. [97] Eitel [98] points out that by changes in temperature, a compound, through physicial-chemical processes, undergoes a conversion of the atomic positions in its crystal structure which cannot be sufficiently described by the classical Gibbs phase rule.

In addition to the classification of the volcanic and plutonic rocks, there is another broad classification also applied to igneous rocks. That is whether they are acidic, intermediate, basic, or ultrabasic. The older classical definition of an acid terms it a compound containing hydrogen which is replaceable by a metal. The chemist thinks of acidity in terms of replaceable hydrogen, termed normality. Hydrogen makes for acidity; the hydroxyl group (OH) makes for alkalinity, which is basic and opposed to acidity, and therefore the two neutralize each other. Whenever an acid and a base are dissolved together, the hydrogen ion of the acid and the hydroxyl ion of the base combine to form water, and the other two ions combine to form a salt. The physiologist centers his interest on the ionized hydrogen because it is the hydrogen ion which determines acidity for the organism. The petrographic usage of the term acid is in the sense that rocks rich in silica are acidic.

When the silica (SiO_2) content is more than sixty-six per cent the igneous rocks are acid; when between fifty-two per cent and sixty-six per cent, they are intermediate; when between forty-five to fifty-two per cent, they are basic, and when the silica content is less than forty-five per cent, the igneous rocks are termed ultrabasic. [93 p. 51] Wahlstrom [99] says that the acid rocks are also rich in the alkalies and alumina, whereas the basic rocks, though poor in silica, are rich in lime, magnesia, and iron. For convenience in general description of igneous rocks, the light constituents are sometimes grouped together as felsic minerals as distinct from the mafic constituents which are dark, heavy, and rich in iron and magnesium.

All of the aforementioned usages, of the term acid, are correct in their respective fields despite the fact that in the newer definition an acid is defined as a hydrogen compound that can split off protons. The hydrogen ion is a proton.

Petrologists have noted for a long time that rocks intruded at a definite period in a given region maintain certain similarities of mineral and chemical composition. From this came the assumption that the rocks had been derived from a single common magma. Daly concluded that basaltic magma is the parental magma of all igneous rocks. Bowen, accepting Daly's conclusion as a fundamental thesis, states that other igneous rock types are developed principally by fractional crystallization, which is quite commonly referred to as magmatic differentiation or the process of differentiation.

As a magma cools through a certain temperature interval, it undergoes physical and chemical reactions which, according to the moderation theorem, must be exothermic. That is, chemical reactions which give off heat such as the condensation of water vapor and the crystallization of solids. This process may be extremely complicated and might involve a sequence of changes from condensation, crystallization, boiling, resorption of early formed crystals, to recondensation, and so on. The same magma evolving under different physical conditions must react differently, and of course, magmas of different composition, even under identical physical conditions, will have a somewhat different sequence of crystallization.

Bowen says that there is a considerable body of experimental results, on silicate systems, which furnish a reliable basis of the crystallization of rocks. Turner and Verhoogen believe that from forty years of laboratory investigation of silicate melts, comes the important generalization, that the reaction relation between igneous minerals and the melts from which they crystallize prevails. Solid-solution series exist in so many groups of igneous minerals, and the fact that they frequently develop reaction rims (coronas) of one mineral around central cores of another, are evidence of reaction. [93 p. 111]

As the temperature falls, the crystallization of a solid-solution series involves a continuous process, operating over considerable intervals of temperature, of reaction between the crystals and the melt from which they separate. Bowen [100] discusses a number of silicate systems that have been studied experimentally.

One of his illustrations is the system potassium metasilicate. At eight hundred degrees centigrade, crystallization begins with the separation of potassium metasilicate, and this continues to separate until the temperature has fallen to six hundred degrees. At this temperature, the liquid reacts with the crystals of potassium metasilicate (K_2SiO_3) and converts a part of them to $K_2SiO_3 \cdot 1/2\ H_2O$. The remaining liquid continues its crystallization with the separation indicated and the temperature falls to 380°. At this temperature, if there is any remaining liquid, it reacts with the crystals and converts a part of them to $K_2SiO_3 \cdot H_2O$. Any remaining liquid would continue to crystallize with the separation of $K_2SiO_3 \cdot H_2O$ until at least a temperature of two hundred degrees was reached.

Another illustration given by Bowen is that of the series, olivines — pyroxenes — amphiboles — biotites, which he says constitute a reaction series that is well attested to in many rock varieties. The liquid first reacts with olivines to produce pyroxenes, then it reacts with pyroxenes to produce amphiboles, and then with amphiboles to produce biotites. By the increasing water content of this series it is related to the series K_2SiO_3 — $K_2SiO_3 \cdot 1/2\ H_2O$ — $K_2SiO_3 \cdot H_2O$. [100 p. 56]

Kennedy [91] believes that water has a major role in determining the differentiation trend of basaltic magmas. The water content of the original melt determines the course of crystallization in calc-alkalic magmas, say Rankama and Sahama. They point out that if the water content is exceptionally low, there is one course of crystallization; if the water content is intermediate, there is the normal course of crystallization, and, if the water content is high, the crystallization follows still another course. In the water rich magmas the separation of biotite starts earlier, at a considerably higher temperature, and potash feldspar is either very scarce or absent. [34 p. 168]

By careful study of the textural interrelationship between the minerals in rocks, say Hatch, Wells, and Wells, it is possible to establish an order of crystallization. The first minerals to crystallize, they say, are those which can be precipitated from an almost anhydrous melt at high temperatures. These minerals include the majority of silicates found as constituents in the basic rocks — olivines, most pyroxenes, the calcic plagioclases, etc. The separation of these minerals, they say, leaves the liquid relatively enriched in H_2O and the other components of low atomic and molecular weights, known as the volatile, hyperfusible, or fugitive constituents. [63 p. 163] Several rock-forming minerals depend more on the concentration of volatiles than on high temperature for their formation, and in this category, Hatch, Wells, and Wells place most of the alkali-rich minerals and those containing hydroxyl.

All magmas contain volatile constituents, the most abundant being water, carbon dioxide, chlorine, fluorine, and probably others in small amount. [100 p. 282] Shepherd [101] notes that the volatiles which can be obtained from lavas have a water content of about eighty per cent of the total. Yet, lavas are magmas which have reached the surface, and inasmuch as the solubility of water in silicate melts appears to decrease with decreasing pressure, they may lose the largest part of their volatile content. [93 p. 49]

Granitic magma holds dissolved water but the solubility of water decreases with decreased pressure. Goranson [102] has shown that at nine hundred degrees centigrade and four thousand atmospheres pressure, which corresponds to a depth of about nine miles, granitic magma can hold nine per cent of dissolved water, whereas at the same temperature but at five hundred atmospheres pressure the same magma can hold less than four per cent water. "Granitic magmas containing water and other volatiles tend to concentrate these constituents in the liquid phase during crystallization if they are present in amounts greater than that taken up by hydrous phases (amphiboles and micas). Water so concentrated will dissolve in the silicate melt as crystallization proceeds unless critical phenomena intervene or unless the pressure generated exceeds the strength of the magma chamber." [103]

These volatile components of magmas play an important role in several respects:

1. Small amounts of water noticeably change the chemical potentials of the other components of the melt;

2. Such components as water, fluorine, and chlorine considerably decrease the viscosity of silicate melts, and

3. Water lowers the melting points of solids and the temperatures at which crystallization occurs.

Bowen [100 p. 288] notes that ten per cent water induces a lowering of the melting point somewhat more than five hundred degrees centigrade, an average of about fifty degrees for each unit per cent of water.

There are only eight main elemental constituents of igneous rocks and they comprise more than ninety-eight and one-half per cent of these rocks. These main elements, in descending order of their magnitude are: oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium. The chemical composition of the igneous rocks, however, only indicate the abundance of the constituent elements and not their manner of occurrence as would be characterized by the minerals in which they are incorporated. For convenience, minerals have been grouped so that they are sometimes referred to as mineral species or groups. For instance, feldspars are geochemically the most important mineral group for they occupy nearly sixty per cent of the mass of igneous rocks. The next in importance are the pyroxenes and the amphiboles which are essentially silicates of iron and magnesium, followed by crystalline silica such as quartz.

Volcanic rocks result from magmas that have erupted as lavas from volcanoes and from magmas that have cooled rapidly near the surface. Individual flows of volcanic rock occur as extrusions on the earth's surface, ranging from a few inches to several hundred feet in thickness and attaining lengths as great as seventy miles. The near surface intrusive volcanic rocks may sometimes take the shape of the volcanic vents in which they have solidified or may occur as tabular sheets known as dikes or sills.

The fabric, and in some cases the mineral composition, indicates that the crystallization of plutonic rocks took place under conditions of slow cooling, as compared with the rate at which volcanic rocks cool at the surface. It is thought that most of the plutonic rocks, now exposed at the earth's surface, crystallized at depths ranging from about two miles to twelve miles. In attempting to determine the depth at which melting will occur of rocks whose compositions approach that of the average granite, Tuttle and Bowen [103 p. 123] find the following:

1. Assuming that with depth, the temperature increases at the rate of thirty degrees centigrade per kilometer, then melting will begin at about thirteen miles. If the water content is on the order of nine per cent complete melting will ensue at this depth, but if the water content is less than nine per cent, melting will begin at thirteen miles but will not be completed until some higher temperature (greater depth) has been reached.

2. If the geothermal gradient is fifty degrees centigrade per

kilometer, then melting will begin at a depth of about seven and one-half miles.

3. Inasmuch as the geothermal gradients increase with depth, then the depth of complete melting with only two per cent water would be only about nine miles for an initial gradient of fifty degrees centigrade per kilometer and a little more than twelve miles for an initial gradient of thirty degrees centigrade per kilometer.

4. The temperature of completion of melting is extremely sensitive to slight changes in chemical composition, so that the only obstacle to complete melting is the amount of volatile materials. The amount of water and other volatiles available, to flux the silicates, determines the amount of liquid formed at any depth.

The cooling rate of the shallower plutonic masses is also affected by the size and shape of the magma body, as well as, by the existing temperature of the host rock into which the magma has intruded. Plutonic rocks appear in various forms and sizes, the smallest being dikes or veins only a few inches wide whereas larger masses may outcrop continuously over thousands of square miles. The normal sequence of magmatic evolution is generally the basic rocks, then the ultrabasic, the intermediate, and the acid rocks. The clan concept of rocks, wherein a clan is bound by resemblances in composition, was advocated by Wells and Daly and is followed by Williams, Turner, and Gilbert in their "Petrography." [104]

It has been noted that there is general acceptance of the fact that all magmas contain volatile constituents of which water is the most abundant. Such waters are referred to as magmatic water.

METAMORPHIC ROCKS AND METAMORPHIC WATER

The metamorphic processes that produce rock melts from sedimentary or igneous rocks are largely based on reactions which take place in the solid state and therefore they differ basically from the deposition of matter in agueous solutions and from the crystallization of melts. Metamorphism is the physical and chemical adjustment of solid rocks; a mineralogical and structural adjustment to the physical and chemical conditions which exist at depth and which differ from the conditions under which the rock in question originated.

The trend of reaction in rock metamorphism is toward the establishment of a stable mineral assemblage under prevailing temperature and pressure. A stable mineral assemblage is one which has minimal free energy under given temperature and pressure. All mineral assemblages which are in the same state have the same internal energy. The change in internal energy depends only on its initial and final states and is the total energy the assemblage gains or loses in the course of any process. The energy may be supplied to or taken from the assemblage in any form such as heat, mechanical work, radiation, etc. Turner says that all writers agree on the importance of water in rock metamorphism, and that it is generally believed that metamorphic adjustment of a mineral assemblage is very largely brought about by reactions through the medium of aqueous pore solutions or their gaseous equivalents. This water is partly supplied by the rock itself and partly derived from magmatic sources, the latter especially in contact metamorphism. [105] In contact metamorphism the changes are related to contacts with plutonic rocks.

Based on the recognition of field occurrences and the petrographic character of the rocks affected, Turner and Verhoogen [93 p. 371-2] erect a classification of metamorphic processes. Inasmuch as in metamorphic rocks the mineral assemblages correspond to approximate chemical equilibrium at certain pressure-temperature combinations, the exposure of the rocks to rising temperature and pressure changes its mineral assemblage according to definite rules and, at sufficiently high temperature, a silicate melt will form. When this melt cools, the changes occur in the opposite direction. First, a rock crystallizes, and then gradually, the rock, as well as the melt, changes in composition until the melt is completely solidified. Depending on the depth at which crystallization occurs, the melt will crystallize in the form of plutonic or volcanic rocks and hence is sometimes referred to as pseudo plutonic or pseudo volcanic rocks.

Ramberg [106], in a treatise on recrystallization and replacement in the earth's crust, has classified the metamorphic rocks themselves. The facies classification used by Ramberg is founded upon petrographic experience that mineral assemblages generally obey the laws of chemical equilibrium. In a metamorphic reaction, the mineral structures are gradually torn down ion by ion and are followed by the formation of new structures different from the old ones.

The kinetic energy of an ion depends on temperature, say Rankama and Sahama [34 p. 250], and as there are variations in their amplitude of vibration and in the number of collisions between ions, even the ions of the same element in a structure may have different amounts of kinetic energy. Furthermore, the number of free ions increases at elevated temperatures and may migrate into a new coordination. Ramberg [106] identifies many reactions which produce water when the temperature is increased, and as is evidenced by petrographic investigations the right hand sides of these reactions, at constant pressure, are stable at higher temperatures than the left hand side. The Green schist facies refers to those rocks recrystallized at the lowest temperatures of regional metamorphism, in the neighborhood of one hundred degrees centigrade or less. Metamorphic water is produced—with the following typical reactions:

potash feldspar + chlorite ⇌ biotite + carbon dioxide + water;

muscovite + calcite + silica ⇌ epidote + potash feldspar
+ carbon dioxide + water.

The Epidote amphibolite facies includes rocks recrystallized at a somewhat higher grade of metamorphism than the green schists. Metamorphic water is produced, and a typical reaction is:

kyanite + epidote ⇌ anorthite + water.

The rocks of the Amphibolite facies are formed at temperatures just above those of the epidote amphibolite facies. The temperature of amphibolite facies only rarely exceeds four hundred to five hundred degrees centigrade. Metamorphic water is produced.

The Granulite facies succeeds the amphibolite facies by rising temperature and rising pressure. The temperatures of the granulite facies is around 550 degrees to 650 degrees centigrade. Metamorphic water is produced—with the following typical reactions:

muscovite → sillimanite + potash feldspar + water

biotite + sillimanite → garnet + potash feldspar + water

biotite → hypersthene + potash feldspar + water.

The Pyroxene hornfels facies succeeds the amphibolite facies by rising temperature and decreasing pressure. The temperature of transition from amphibolite facies to pyroxene hornfels facies is about seven hundred to 750 degrees centrigrade. The pyroxene hornfels facies is the typical contact metamorphic facies. Metamorphic water is produced. Other facies also identified and discussed by Ramberg are Sanadinite facies, Eclogite facies, and Glaucophane schist facies.

Because igneous rocks themselves are of high temperature origin it might appear that they would be only slightly susceptible to thermal metamorphic changes. Harker reasons that the "genesis of an igneous rock, starting from a fluid magma and ending normally in a crystalline aggregate, covers a wide range of declining temperature, and the several constituent minerals, as we now see them, belong to different stages of the prolonged process of cooling. In many rocks, the latest-formed minerals have crystallized at temperatures which may be overtaken in metamorphism of quite moderate grade." [107] In addition, Harker points out that later minerals may be derived from a magma at the expense of earlier minerals, which had been crystallized at a higher temperature but ceased to be stable at a lower temperature in contact with the changed magma, and are therefore attacked by it.

VOLCANIC ACTIVITY AND VOLCANIC WATER

At the beginning of this chapter, the world's newest volcano was used as an illustration of a dynamic earth, and mention was made of gases and water vapor billowing up some twenty thousand feet. Where did the water vapor come from? Since most volcanoes are in or near bodies of water, it was formerly considered that the gaseous water contained in the magmas had been obtained from water that descended from the earth's surface. But this evidence when examined loses part of its force. [108]

There are several possible explanations for the origin of volcanic water. It may be part of the original substance entrapped at the time the earth was formed; or it may be magmatic water; or it may be metamorphic water; or it may be atmospheric water absorbed by the magma from the surrounding rocks, or it may have been formed by the union of primitive hydrogen and oxygen.

In the Hawaiian Islands, volcanic water has been collected, by means of tubes put into the molten lava, and analyzed. "It is plain that if atmospheric water is to reach a hot lava column at a temperature of one thousand degrees or higher it must do so as a gas, and therefore on the same terms as other atmospheric gases. Argon is invariably contained in the air in measurable quantity and forms no chemical compounds. Whence it follows that if the gases of the atmosphere had reached the liquid lava in any manner whatsoever the argon would be released with the others, but no trace of argon was found." [109] Another difficulty, say Day and Shepherd, "is to conceive a mechanism whereby atmospheric or surface water of whatever origin (for example, the sea) can make its way into a lava column or basin at a temperature of one thousand degrees or more." They conclude that the volcanic water "is entitled to be considered an original component of the lava with as much right as the sulphur or the carbon." [109 p. 305]

Magmatic gases are expelled at or near the surface of the earth as hot spring gases or through gas vents, the most violent of which are, of course, the volcanoes. The chief component of the magmatic gases, says Barth [95 p. 144], is water which makes up more than ninety per cent. There is also a surplus of HCl, HF, H_2S, CO_2, and other more or less volatile acid-forming substances, together with O_2, H_2, CO, N_2, etc., and such compounds as SiF_4, $SiCl_4$, metal chlorides, etc.

Kennedy believes that it is predominantly the decline in volatiles in the magma that brings a volcanic eruption to an end. "The first lavas that appear after the construction of a volcanic cone are generally relatively fluid, highly vesicular, and rich in water. Later lavas that may appear during an eruption are marked by higher viscosity and contain less and less volatiles." The last lava to emerge, says Kennedy, "is poor in volatiles and hence is of higher viscosity." [91 pp. 494-5]

According to Day and Shepherd, it has been shown that throughout molten lava, oxygen and hydrogen are uniting to form water, and that this chemical reaction is an important source of volcanic heat. They say: "The free hydrogen set free by the volcano reacts with sulphur dioxide at 1000° to give water and free sulphur directly." At this temperature, carbon dioxide and hydrogen undergo similar reaction. So that, "Neither CO_2 nor SO_2 can be associated with free hydrogen at temperatures in the vicinity of 1000° without the formation of water." [109 pp. 290-1]

What is now proved was once
only imagined.

—WILLIAM BLAKE

CHAPTER VI

THE DYNAMIC EARTH (continued)

Ample evidence has been given to show the existence of magmatic, metamorphic, and volcanic water. Indeed, the origin of the earth's water supply is thought to be derived from the interior of the earth. However, some of these processes must be looked at more closely for better understanding.

STAGES OF MAGNIATIC CRYSTALLIZATION

As a result of fractional crystallization, differentiation usually proceeds from ultrabasic rocks through basic and intermediate rocks to the acidic or silicic rocks. Several different stages of crystallization are generally identified, although the different stages are really part of a continuous process of magmatic differentiation by crystallization. Rankama and Sahama [34 p. 130] distinguish an early magmatic stage, a main stage of crystallization, and a late magmatic stage. During the early magmatic stage, silicates, sulfides, and oxides are formed; whereas the main stage produces gabbros, diorites, and granites; while the late magmatic stage results in pegmatites, pneumatolytic deposits, and hydrothermal deposits. [34 p. 161]

Fersman, according to Turner and Verhoogen [93 pp. 331-2], establishes four successive stages of crystallization which are governed by falling temperature as follows:

1. Magmatic stage—wherein equilibrium between the silicate melt (liquid phase) and the crystalline structure (solid phase) is maintained.

2. Pegmatitic stage, which is characterized by the coexistence of solid, liquid, and gas phases at temperatures ranging approximately from eight hundred degrees to six hundred degrees centigrade.
3. Pneumatolytic stage, in which equilibrium between solids and gases is maintained at temperatures from six hundred degrees to four hundred degrees centigrade.
4. Hydrothermal stage, wherein equilibrium between solids, aqueous solutions, and aqueous gas is maintained at temperatures from four hundred degrees to one hundred degrees centigrade.

The progressive abstraction of the early crystallizing rock minerals, from the magma, leaves a residual liquid which gradually becomes enriched in volatiles and gases containing metal compounds, and other valuable substances which were originally only sparsely distributed throughout the magma. The volatiles and the gases, along with their contents, tend to collect in the upper part of the magmatic chamber where they may escape into the enclosing wall rock and form metasomatic mineral deposits under certain circumstances.

Replacement or metasomatic replacement is defined as a process of simultaneous capillary solution and deposition wherein the replacing minerals are carried in solution and the replaced substances are carried away in solution. As Bateman emphasizes, it is an open circuit, not a closed one. Petrified wood illustrates how, by means of replacement, wood is transferred to silica. Similarly, one mineral may take the place of another, retaining both its original size and form, or says Bateman [110], a large body of solid ore may replace an equal volume of rock and thereby originate many mineral deposits. Even when traced with the highest magnifying power, says Lindgren [111], the typical metasomatic processes show no space between the metasome, the designation of the newly developed mineral, and the parent mineral. Lindgren illustrates that fibers of sericite are projected into quartz without even a minute break in the contact; that the crystal faces of rhombohedrons of siderite cut across the grains of quartzite without any interstices and that perfect prisms of tourmaline develop in primary feldspar or quartz.

Bateman [110 p. 54] indicates that the early withdrawals of the residual solutions yield simple pegmatite dikes that are varieties of igneous rocks, whereas latter withdrawals, of a more aqueous stage, yield pegmatites which are referred to as pegmatite veins. Generally, says Landes [112], pegmatites are more acidic than the plutonic bodies from which they are derived, and because acidic rocks are more common than basic rocks, pegmatites of acidic rocks are more common than pegmatites of intermediate or basic rocks. Based on the atomic abundance of sodium, potassium, and aluminum, Goldschmidt divided the pegmatities into two groups. His first group of pegmatites are composed of minerals wherein the atomic abundance of sodium plus the atomic abundance of potassium is higher than the atomic abundance of aluminum. In his second group, aluminum predominates over the sodium and potassium combined. A third group of pegmatite minerals would be those wherein the atomi.; abundance of sodium plus the atomic abundance of potassium is equal to the atomic abundance of aluminum.

Near the close of the solidification of the magma, some of the residual liquid may be withdrawn to form pegmatites; but aqueous solutions still remain which contain valuable mineral compounds from which economic minerals are deposited by replacement of the pegmatitic minerals. For instance, as the late residual liquid, the pegmatitic liquid, of a granite cools and crystallizes the earliest minerals formed, such as potash feldspar, quartz, and mica, will be those of latest formation in granite. This crystallization, says Bateman [110 p. 54], enriches the residual pegmatitic liquid in water, soda, lithium, and other substances.

The critical temperature of a gas is the temperature above which the gas cannot be liquified by pressure alone. Aqueous solutions may be either liquid or gaseous. When an aqueous solution crystallizes above the critical temperature of water vapor (374 1/2° C), minerals are deposited by a gas and is termed pneumatolytic deposition. If the crystallization occurs at a temperature below the critical temperature of water vapor, the minerals are deposited by water and is called hydrothermal deposition. Nearly all epigenetic mineral deposits, says Bateman [110 p. 301], are formed from mineralizing solutions composed of both liquid and gaseous aqueous solutions. Epigenetic refers to deposits which were formed later than the rocks that enclose them whereas syngenetic would refer to deposits formed at the same time as the rocks that enclose them.

Water, at temperatures above the critical point of water vapor, is a gas and therefore can be highly compressed. According to Barth

[95 p. 141], water vapor at four hundred degrees centigrade and one thousand atmospheres pressure has a density of 0.71, not greatly different from that of water under ordinary conditions. Near the surface of the earth, the pressure increases about five hundred atmospheres for each mile increase in depth. At greater depths, the pressure increases at a decreasing rate attaining a value of about three million atmospheres at the center of the earth. [85]

It has also been shown that very high pressures can be expected as a result of crystallization in systems containing volatile components. [113] Goranson conclusively proved that the pressure so generated could well exceed those required as a possible source of volcanic explosions. [102] Ramberg [106 p. 192] also points out that a rapid crystallization in a magma chamber with tight walls may, due to rapidly developing gas pressure, cause an explosion sufficient to overcome both the hydrostatic rock pressure and the strength of the chamber walls. Furthermore, crystallization can cause successive explosions by alternate relief of the pressure followed by further crystallization. [102] Kennedy explains that the somewhat rhythmic eruptions at a given volcanic structure is due to the cessation of eruption when the wet cap of the volcanic conduit has been discharged and dryer magma moves into place, and that the disturbance of the equilibrium relations among partial pressure of water, depth, and the total water content will cause diffusion of water into the magma at the lower confining pressure of the top of the magma column. "Thus the partial pressure of water in the top of the column will build up steadily until it is again high enough to blast aside the restraining rock and permit renewed eruption." [91 p. 495]

Upon final crystallization of the magma the residual liquid, or gaseous aqueous solutions, are ejected toward places of less pressure and therefore follow cracks, joints, bedding planes and other openings where they undergo chemical change by reaction with the wall rocks. The mineral substances in these solutions may replace the rock substances or they may be precipitated from solution.

HYDROTHERMAL DEPOSITION

As the term hydrothemal implies, they are hot waters that probably range in temperature from five hundred degrees down to fifty degrees centigrade and are closely associated with the deposition of metals and minerals. That most mineral deposits of igneous affiliations have come from hot waters of magmatic derivation is universally agreed upon says Bateman. [110 p. 57] Lindgren [111 p. 72] says that the majority of ore deposits were formed by large quantities of waters rich in carbon dioxide and hydrogen sulphide and heavily charged with alkaline salts, whereas in metamorphism there are small quantities of solutions that are free from large amounts of these gases. In fact, geologists attribute most of our useful metals and minerals to the metallic minerals deposited by hydrothermal processes. [110 p. 95]

The original water content of a magma that is granitic to dioritic in composition would perhaps be about one per cent. As crystallization proceeds, the water excluded from the earlier formed crystals becomes relatively concentrated in the remaining molten magma. In similar fashion, the sparse content of metals and other volatiles, which were originally dispersed throughout the magma, would become concentrated in this remaining liquid. [114] Continued crystallization results in still greater enrichment in water until the accumulation of water exceeds the amount that the remaining molten magma can dissolve. This saturation point, Goranson's investigations indicate, would be about nine per cent under certain pressure conditions. Three coexisting phases—the solid phase of rock minerals, a liquid phase of molten magma saturated with water, and a gas phase of excess water which may develop gradually into hydrothermal solutions—would result under such conditions. Thus further crystallization plus the growth of crystals encroaches upon the space left for the residual fluids and subjects the fluids to greater and greater pressure until the final act of crystallization expels, under great pressure, all excess water that does not enter into the rock minerals.

Ramberg [106 p. 269] notes that water not only functions as a catalyst in rock alteration, but that it is a significant rock building constituent. Hydrous minerals are abundant in low and medium grade rocks. They have HO in their lattices and cannot possibly form unless H_2O is available.

The hydrothermal solutions form cavity filling deposits when they lose their mineral content by precipitation within various openings in rocks, or they form replacement deposits by metasomatic replacement of the wall rocks. There may be a gradation between these two types of mineral deposits inasmuch as the cavity filling by precipitation may be accompanied by some replacement of the wall rocks. The filling of cavities, however, forms more mineral deposits than any other process. An ore filled fissure, called a fissure vein, is the most wide-spread and most important of the cavity fillings and yields a great variety of metals and minerals.

The essentials for the formation of hydrothermal deposits are enumerated by Bateman [110 p. 96] as: (1) mineralizing solutions capable of dissolving and transporting mineral matter; (2) openings in rocks through which solutions channel; (3) sites for the deposition of the mineral content; (4) chemical reactions that result in deposition, and (5) sufficient concentrations of deposited mineral matter. A similar description of hydrothermal deposition is made by Tarr, who says that the water vapor and numerous other gases contained in magmatic solutions become liquid when the temperature falls below their various critical temperatures. These gaseous solutions, being effective solvents, dissolve most metals and rare earths from the molten magma and retain them as they are concentrated into the residual liquors. The liquors are ejected from the magma, following lines of weakness in the surrounding rock, where they form larger openings in which they deposit their mineral content. The cooling of the solutions and their reactions with the wall rock and with other solutions bring about precipitation of the various mineral deposits. [114 p. 40]

There are two concepts as to the preliminary character of the hydrothermal solutions. One, that they left the magma chamber as hot liquids and remained as liquids. The other, that they left the magma as gaseous emanations and later condensed to hot liquids. However, in either case, cooling makes the later phase a liquid hydrothermal phase. It has been demonstrated that a vapor phase can and does collect, transport, and deposit metals. It is also known that hot liquids transport and deposit metals.

It was mentioned earlier, that water at four hundred degrees centigrade and one thousand atmospheres pressure has a density of 0.71 which is not greatly different from that of water under ordinary conditions. However, water vapor so highly compressed has a significant solvent power on non-volatile mineral components such as sodium and silica for example. [95 p. 141] Increasing pressure increases the solubility of silicates in such a supercritical gas for the density of the gas increases so that the power of reaction between water molecules and "dissolved" silicate becomes more effective.

Under such circumstances, precipitation takes place along horizontal or upward isothermal flows automatically. [106 p. 195]

Lindgren has designated three groups of hydrothermal ore deposits based upon the temperatures, pressures, and geologic relations under which they were formed, as indicated by the contained minerals. The first group, known as hypothermal, refers to the high temperature deposits ranging from about three hundred degrees to five hundred degrees centigrade. These deposits are ordinarily, though not necessarily, formed at great depth under high pressure and are sometimes referred to as deep-seated deposits. These deposits are characterized by gangue minerals such as garnet, biotite, hornblende, pyroxene, specularite, magnetite, tourmaline, topaz, apatite, and scapolite, all of them being associated with quartz. The chief metals won from hydrothermal deposits are tin, tungsten, gold, molybdenum, copper, and lead, along with other ore minerals.

The second group, known as mesothermal deposits, is formed under intermediate temperatures and generally at depth under high pressure. The temperature range being from about two hundred degrees to three hundred degrees centigrade. The chief metals mined along with other ore minerals are gold, silver, copper, lead, and zinc. These deposits are characterized by gangue minerals in which quartz, calcite, dolomite, siderite, barite, sericite, chlorite, and albite occur.

Epithermal deposits constitute the third group which is formed at moderate temperatures, probably rarely exceeding 150° C. and in those instances by not more than 50° C, within a few thousand feet of the surface under medium pressure and many of them are developed close to the surface. The chief metals found in these deposits are gold, silver, and mercury along with other ore minerals. The gangue minerals that characterize these deposits are quartz, chalcedony, opal, calcite, dolomite, barite, fluorite, sericite, chlorite, and adularia.

"On the whole," says Lindgren, "it is evident that the great majority of ore deposits have been formed relatively near the surface and well within the zone of fracture, probably well within the upper fifteen thousand feet of the crust, and most of them within ten thousand feet of the surface." [111 p. 74] Lindgren explains that although certain kinds of mineral deposits have originated in the zone of weathering or at the surface, the largest number have been formed in the zone of fracture where circulation of solutions is comparatively easy. [111 p. 72] These solutions have an internal origin.

The zone of fracture, to which Lindgren refers, is based upon the conception of zones in the earth's crust developed by Van Hise. Van Hise [115] divided the outer part of the crust of the earth, depending upon the character of deformation when subjected to stresses, into three zones. Within an upper zone of fracture, deformation occurs mainly by rupture, faulting, jointing, differential movement between layers, fissibility, and brecciation. Beneath this zone of fracture there is an intermediate zone of combined rock flowage and rock fracture, below which is the zone of rock flowage wherein deformation is effected by granulation or recrystallization and wherein no openings other than those of microscopic size are produced.

Under the conditions which exist within the earth's crust, according to F. D. Adams [116], granite will sustain a much heavier load than that which will crush it at the surface of the earth. His experiments indicate that cavities may exist in granite to a depth of at least eleven miles. Even the sphere below the earth's crust is believed to be subject to fracturing. Benioff [117] believes that above 434 miles the mantle is sufficiently rigid to maintain fractures extending to that depth for time intervals of the order of a decade.

Openings in rocks have been classified into two major groupings. First, the original cavities and second, the induced cavities. Some of these openings must be interconnected to permit the movement of hydrothermal solutions from its source to the site of deposition. Large deposits of extraneous minerals require continuous supplies of new materials which means that through channelways must be available.

Ramberg considers a hydrous solution advancing up through a fissure and precipitating minerals due to the decreased temperature of about three-hundredths of one degree centigrade per meter. The solubility of calcite is 0.0018 grams per one hundred grams of water at seventy-five degrees centigrade, whereas at twenty-five degrees centigrade it is 0.0014 grams per one hundred grams of water. "The depth of 25° is close to 100 meters," says Ramberg, "and some 1,600 meters below, the temperature is 75° C. By the upward-flowing solution 0.0004 g of calcite will precipitate along the 1,600 meter-deep fissure for each 100 g of H_2O which passes through. That is to build up 4 tons of calcite as a thin layer along the fissure, 10^6 tons of water are needed." [106 p. 197] Ramberg points out that this calculation is artificial and uncertain because of the great effect of the carbon dioxide pressure upon the solubility of calcite. Nonetheless, it still stands as an excellent illustration that for the deposition of large bodies of extraneous minerals—many hydrothermal deposits contain hundred of tons of ore—tremendous quantities of water are required and through channelways are essential.

Boron is an element characteristic of the late stages of magmatic crystallization. Its small ionic size plus the volatility of many of its compounds, prevent its becoming totally trapped in the hydroxyl-bearing minerals during the magmatic crystallization. Although boron sometimes will crystallize as independent boron minerals during the last phase of the main stage of crystallization, boron minerals generally crystallize during the pegmatitic and hydrothermal stages.

It is generally recognized that all North American borates were deposited by fresh water rather than by ocean water. However, all boron deposits are not the result of evaporation. For instance, the Searles Lake brines from which borax is extracted contains about thirty-six per cent total salts, of which about 2.84 per cent is borax and the balance is mainly composed of chlorides, sulfates, and carbonates of potash and sodium. Through the process of weathering the igneous rocks of the surrounding area, the surface waters have brought the salines to the Lake where they have become concentrated through evaporation. But the purity of the kernite deposits, from which most borax is currently derived, and its manner of occurrence indicate that its precipitation had to occur from pure, fresh water other than that of meteoric surface water. Surface fresh water would also have deposited many of the commoner minerals that are associated with the Searles Lake deposits, but here, there is no evidence of such deposition. Riess [118] says:

> Taking this fact into account, that these commoner minerals are absent, and adding to it the fact that stibnite and realgar are present, can only suggest that the boron minerals here did not leach down from the surface, but, on the contrary, came through the underlying igneous rock.

Further evidence comes from studies of the isotopic constitution of hydrogen and oxygen in water which are based on the fact that the existence of heavy isotopes of hydrogen and oxygen in water affect the specific gravity of the water. Generally, the specific gravity is given in terms of the specific-gravity difference in parts per million, either lighter or heavier, when compared to a tap water of specific gravity. For instance, the various forms of atmospheric precipitation record with specific-gravity differences that are lighter, whereas juvenile water results in specific-gravity differences that are heavier. The role of isotope determination will be discussed more fully later, but it is desirable at this time to note the specific-gravity differences of some of the boron minerals.

The water of crystallization from tincal, a boron mineral which exists only as a coating on other borates and is formed by the hydration of kernite and by the dehydration of borax, and the water of crystallization from the minerals crystallized from the Searles Lake brine have specific-gravity differences that are heavier by from 2 to 2.94 ppm, while the water of crystallization from kernite has a specific-gravity difference that is heavier by from 4 to 6.8 ppm. [119]

One ton of kernite, when dissolved in water, will upon crystallization yield 1.39 tons of borax. The relatively low cost of producing borax from kernite has abruptly ended the use of colemanite and ulexite deposits in the Kramer District of the Mohave Desert. It has been estimated that 100 million tons of kernite and five million tons of borax existed in this district. One hundred million tons of kernite would be equivalent to 139 million tons of borax, and with the other five million tons of borax, would constitute a total deposit equivalent to 144 million tons of borax. Borax contains 47.2 per cent H_2O, so that 144 million tons of borax would be equal to 76 million tons of anhydrous borax. The solubility of borax indicates that 3.42 grams of anhydrous borax would precipitate from 100 grams of water during a temperature drop from 104° F. down to 68° F. This precipitation rate means that more than 2.22 billion tons of pure, fresh water would have been required to have precipitated 76 million tons of anhydrous borax.

However, of the 2.22 billion tons, 68 million tons of water would have become fixed in the crystallization of borax, bringing the 76 million tons of anhydrous borax up to 144 million tons of borax. More than 2.15 billion tons of water would have escaped being trapped in the crystallization of borax and inasmuch as kernite contains only 26.5 per cent H_2O an additional 39 million tons of water would have been released.

In other words, of the 2.22 billion tons of water necessary to have precipitated the estimated amount of kernite and borax only twenty-nine million tons of water became fixed in the crystallization of these minerals. Therefore, more than 2.189 billion tons, or 525 billion gallons of pure, fresh water escaped being fixed in the crystallization of either kernite or borax.

Fissures, channelways, and permeable beds serve as the main avenue for the movement of new mineral matter to the point of deposition. The brittle rocks consist mainly of minerals with low chemical mobility such as the calco-ferro-magnesium silicates. When these relatively brittle rocks are inclosed in more plastic rocks they more frequently contain cracks and fissures. [106 p. 219] Some cavities serve only as conduits for mineralizing solutions; some serve as conduits or receptacles for water, oil, and gas; but most cavities, under special circumstances, may become filled to form varied types of hydrothermal mineral deposits.

Having left their magmatic source, gases and hydrothermal solutions change in chemical composition as they travel along fissures, partly due to fractional precipitation and partly due to the reactions between the solutions and the wall rocks of the fissure. [95 p. 142] According to Kennedy [91 p. 497] there is much accumulated evidence which suggests that the sulfur-vapor pressure in a hydrothermal solution at a given point in a vein decreases fairly regularly from the beginning to the end of mineral introduction. He says that a higher sulfur-metal ratio exists in the earliest-deposited constituents than in the late deposited constituents.

Ramberg [106 p. 196] points out that the temperature will decrease along the flow of fluids that have just left a magma chamber and for fluids that propagate upward in the gravitational field, and that decreasing temperature will cause precipitation. Generally, decreases in temperature result in decreased solubility thereby causing precipitation. [110 p. 102] A decrease in pressure alone, however, can effect precipitation from a gas.

Hydrothermal deposition from solutions are principally promoted by changes in temperature and pressure, although reactions between advancing solution and the wall rock of the channelway, because of chemical incompatibility between the solution and the wall rock, also result in deposition. Bateman [110 p. 101] says that field evidence, in many cases throughout the world, indicates that when the wall rocks are not in equilibrium with the solutions they exert a profound effect upon hydrothermal mineral deposition.

A typical vein consists of a fissure which has been filled with mineral deposits from wall to wall and shows sharply defined boundaries. However, if the mineralizing waters that filled the fissure have acted upon the wall rocks and partially replaced them with the vein minerals an almost complete gradation from the unaltered rock to the pure vein filling may exist with no sharp line of division between them. [120] The nature and intensity of the alteration depends on the size of the fissure vein as well as upon the nature and kind of wall rock, and the chemical character, temperature, and pressure of the mineralizing solutions. Bateman [110 p. 105] has classified some of the alteration products for various wall rocks under epithermal, mesothermal, and hypothermal conditions.

The cause of the localization of hydrothermal deposits is controlled for the most part by the chemical and physical character of the host rock, by the depth of formation, by intrusives, by the structural features, or by changes in size of rock openings. No matter how favorable a host rock may be, ore deposition cannot occur unless rock openings are available for cavity filling or to permit solutions to enter for replacement.

Beginning their journey with heat from the magma, hydrothermal solutions gradually lose heat depending upon the rate of loss of heat to the wall rocks through which they pass. The rate of heat loss depends upon the capacity of the wall rock to conduct heat away, the amount of solution passing through, and whether any chemical reactions which take place are exothermic, that is, whether they generate heat. With cool wall rocks at the initial stages of hydrothermal solution circulation, the temperature drop will be relatively rapid, but the continuing flow of solution will heat the wall rocks to its own temperature and thereby slow down the heat loss. It will be recalled that, in the accidental occurrence of new water during the excavation for the Harlem Hospital addition, the temperature of the water held firm at sixty-four degrees fahrenheit during the months of February and March of 1956 but, then gradually, the temperature increased until in the middle of August, 1956, it reached sixty-eight degrees and there it remained until pumping was stopped seven months later in March, 1957. Rapid flow through intricate openings with large surfaces would result in more rapid initial heat loss than rapid flow through a straight walled open fissure.

Similarly, the solutions having originated under high pressure at great depths means that their upward movement is usually accompanied by a drop in pressure which promotes precipitation. However, in channelways, partial filling by mineral deposition, or constrictions, or other barriers may result in building up excess pressures. But solutions which once escape to more open areas with lower pressure are subject to precipitation. Even the ores of the near surface epithermal deposits were not formed by the ordinary circulation of surface waters. The best proof of this, says Lindgren [111 p. 442], is that the vein filling epochs were of short duration and followed closely after each considerable eruption.

The character of the hydrothermal solutions are interpreted largely by analogy with hot springs and laboratory experiments as well as from their visible action in minerals deposited from them and in the alteration of the wall rocks.

HOT SPRINGS

A report by Stearns, Stearns, and Waring in 1937, lists 1,059 thermal springs or spring localities. Of these fifty-two are in the East-Central region, three are in the Great Plains region, and all the rest (1,004) are in the Western Mountain region. The states having the largest number of thermal springs, according to the listing in the report, are Idaho with 203, California with 184, Nevada 174, Wyoming 116, and Oregon with 105. The curious thing is that these states having the largest number of thermal springs also have large areas that have but little rainfall.

The two main problems associated with the origin of thermal springs are the source of the water and the source of the heat. The water may be new water, derived from the magma itself, which has reached the surface for the first time; it may be ordinary ground water that has percolated downward where it is heated and then ascends to the surface; or it may be a mixture of these waters in any proportion. According to Meinzer [80 p. 422], the latest investigations reveal that thermal springs in the eastern part of the United

States discharge surface waters which have been heated by deep percolation, but that thermal springs in the western part of the United States derive part of their water and heat from magmatic sources.

Kirk Bryan [121] divided springs into: (1) springs due to gravitative pressure transmitted through a continuous body of water, and (2) springs of deep origin flowing as a result of agencies other than gravity, operative deep within the earth, largely the expulsion of water during the crystallization of igneous rocks, which he further subdivides into (a) springs associated with volcanism or volcanic rocks and (b) springs due to faults or fissures that extend deep into the earth. Nearly two-thirds of the recognized thermal springs issue from igneous rocks—chiefly from the large intrusive masses, which still retain some of their original heat—and many of the thermal springs issue along faults.

A fault is a structural feature consisting of a fracture and a dislocation of the rocks on one side of the fracture with reference to those on the other. Faults are of two kinds; normal faults and thrust faults. Faults differ greatly in their lateral extent, in the depth to which they reach, and in the amount of displacement. For instance, Hill and Dibblee [122] estimate the San Andreas displacement since the Pleistocene, which is the beginning of the Quaternary era, to be sixteen kilometers. Since the late Eocene, roughly some forty million years ago, a displacement of 370 kilometers. The total displacement along the San Andreas has been estimated by them to be about 580 kilometers. Inasmuch as the San Andreas earthquake of April, 1906 resulted in a maximum displacement of six meters there would have had to have been very many earthquakes to account for the great displacements which have been inferred from geological evidence. As Meinzer has written: [123]

> The large faults that can be traced over the surface for many miles, that extend down to great depths below the surface, and that have displacements of hundreds or thousands of feet are very important in their influence on the occurrence and circulation of ground water. Not only do they affect the distribution and position of aquifiers, but they may also act as subterranean dams, impounding ground water, or as conduits that reach into the bowels of the earth and allow the escape to the surface of deep-seated waters, often in large quantities and at high temperatures.

In some places, instead of a single sharply defined fault, there is a fault zone in which there are numerous small parallel faults or masses of broken rock called fault breccia which may afford good water passages.

Although some faults act as dams for ground water, others are important containers and conduits of ground water. Because the fracture surfaces are irregular, the opposite sides of many faults, especially normal faults in hard rocks, are not everywhere pressed together but form fissures through which the water may flow. After there has been displacement, the two sides no longer fit each other inasmuch as projections on opposite walls leave intervening openings. Again quoting from Meinzer: [123 pp. 185-7]

> Perhaps the most important function of faults in relation to ground water is that of conduits leading from deep sources of water up to the surface. Openings of no other kind probably extend so far below the surface, and no other structural features are so effective in allowing the ascent of deep-seated waters. Many springs owe their existence to the damming effect of faults, but many others are the outlets of waterways that follow faults. Many springs of the latter type have a large and relatively uniform discharge, and may yield water of high temperature, doubtless because it comes from great depths where the earth is hot.
>
> Excellent examples of springs produced by the rise of deep waters through fault openings are to be found along the edges of the mountain ranges of Nevada and western Utah. Many of these springs have large yields, some of them discharging several cubic feet a second. The abundance of these springs and the copious flow of some of them are the more impressive because of the aridity of the region in which they occur. The ranges of this region consist largely of tilted fault blocks, and in many places there are recent fault scarps in the alluvial slopes at the foot of the mountains. That many of the springs along these fault lines are not merely returning to the surface water that percolates into the sediments of the adjacent alluvial slopes but yield water that ascends from deep sources along faults seems to be shown by the following facts: (1) the springs are situated along the general courses of the fault scarps, some of the groups having a more or less linear arrangement; (2) the yield of many of the springs is larger than would be expected if they were supplied from local sources, and some with the largest yields occur along narrow dry ranges that supply but little water; (3) they have relatively uniform flow throughout the year, whereas ordinary springs in the region fluctuate more with the season; (4) many of these springs yield water whose temperature is above the mean annual temperature of the region, and hot springs that are not associated with volcanic rocks are abundant; (5) many of the springs issue from deep pools that are believed to be associated with fissures.

Some of these springs are described in U. S. Geological Survey Water Supply Papers 277, 365, 423, and 467.

The hot waters of Steamboat Springs, Nevada, deposit gold, silver, copper, lead, and zinc. Many hot springs like those of Steamboat Springs demonstrate beyond any question that the constituents of the hydrothermal deposits are taken into solution, transported, and deposited from hot waters. [110 p. 95] The hot gases, escaping from the underlying magma at Katmai, Alaska, are acid and yield vast quantities of hydrochloric and other acids. The fumaroles of the Valley of Ten Thousand Smokes in Alaska, according to Zies, discharged 1,250,000 tons of hydrochloric acid and two hundred tons of hydrofluoric acid in one year. [124] This confirms Bowen's concept that the gas phase that escapes from a magma chamber must be acid because it will contain an excess of hydrochloric, hydrofluoric, sulfuric, carbonic, and other volatile acids. Around the fumarole conduits, such minerals as magnetite, specularite, molybdenite, pyrite, galena, and others were found. Zies found that the magnetite also contained lead, copper, zinc, tin, molybdenum, nickel, cobalt, and manganese.

GEOLOGIC THERMOMETERS

Some minerals, yield only the maximum temperature of formation, others minimum, others exact temperature, and still others only approximate temperatures. The following are illustrative of the more important geologic thermometers: [125, 126]

Liquid inclusions in minerals. When one examines crystals of minerals from hydrothermal deposits, liquid inclusions can be seen within the crystal. These certainly indicate that the crystal grew in a liquid environment. In addition, drops of the liquids have been extracted, analyzed, and found to consist largely of water with magmatic constituents in solution. Heating the minerals, containing cavities partly filled by liquid, causes the liquid to expand, and the point at which the liquid just fills the cavity indicates the temperature of formation.

Melting points. The melting points give only the maximum temperatures at which the minerals can crystallize, although they may form at any temperature below the melting point. For instance, stibnite (antimony ore) at 546° C. and bismuth at 271° C.

Inversion points. Inversion is accompanied by a change in the internal crystal arrangement or symmetry of the atoms. There are many pairs of inversion minerals. For example, at 179° C. the mineral argentite changes over to acanthite, and at 573° C. high quartz changes over to low quartz.

Exsolution. There are many minerals for which the exsolution point has been determined. For instance, a solid solution of chalcopyrite and bornite unmixes into the individual minerals at 475° C.

Recrystallization. Native copper recrystallizes at 450° C.

Dissociation. At atmospheric pressure, pyrite dissociates into pyrrhotite and sulfur at temperatures over 615° C. Dolomite dissociates at five hundred degrees centigrade into magnesium oxide, calcite, and carbon dioxide, and at 890° C, the calcite dissociates into lime and carbon dioxide.

Changes in physical properties. At temperatures between 240° C. and 260° C, amethyst loses its color.

Decomposition. Malachite decomposes at 900° C, danburite decomposes at about one thousand degrees centigrade.

Certain minerals, because of their repeated association in deposits that contain one or more geologic thermometers, are ranked roughly as low, intermediate, or high temperature minerals. There are many such inferred rough geologic thermometers. Although it is true that one such mineral by itself may not be diagnostic, an association of two or more such minerals may be as good an indicator as an established geologic thermometer. The following are some of the common examples of such semi-diagnostic minerals arranged according to temperature:

HIGH	INTERMEDIATE	LOW	
Magnetite	Chalcopyrite	Stibnite	Ruby silver
Specularite	Arsenopyrite	Realgar	Marcasite
Pyrrhotite	Galena	Cinnebar	Adularia
Tourmaline	Sphalerite	Tellurides	Chalcedony
Cassiterite	Tetrahedrite	Selenides	Rhodochrosite
Garnet		Argentite	Siderite
Pyroxene			
Amphibole			
Topaz			

LABORATORY EXPERIMENTS

Most of the early interest in the study of hydrothermal systems stemmed from the desire to synthesize particular minerals rather than from any attempt to obtain any systematic data on the geochemistry of the earth's crust. It can now be said that virtually every common mineral known to man has been synthesized. It is common knowledge that synthetic diamonds are now being made. It is not as well known that our scientists have reversed the goal of the alchemists and are now changing gold into mercury for use in precision measurements.

Roy and Tuttle [127] say that most of the contributions to our knowledge of systems involving volatile materials comes from studies of problems in the earth sciences undertaken by laboratories that are primarily devoted to such studies. These studies have been undertaken in many instances because of a realization that the important role of the volatile materials in the genesis of the igneous and metamorphic rocks is only partially understood. It is certain, says Lacy, that "hydrothermal research will play an increasing and vital part in formulating petrogenetic theory." [128]

Subsolidus studies are concerned largely with equilibria conditions of crystals and vapor. Most of the hydrothermal studies conducted in the post-war period have utilized temperatures and pressures below that at which a melt appears but above the critical temperature of water. [127 p. 151] From these studies in hydrothermal systems information is obtained which has applications to geological problems. For instance, the temperatures and pressures at which compounds containing a volatile component breakdown; or the temperatures and pressures of certain reactions such as serpentine + brucite ⇆ forsterite + water vapor. For the stable coexistence of any mineral assemblage the required temperatures and pressures can be ascertained. From such studies knowledge is also gained concerning the changes that are brought about in the extent of solid solution as a function of pressure and temperature. [127 p. 175]

The effect of water vapor under pressure is remarkable in that it lowers the temperature at which a mineral will unfreeze and become a liquid. For instance, the liquidus of albite is lowered 300° C. at a water vapor pressure of 3000 kg/cm^2. [127 p. 171-3] The geologic thermometers previously mentioned were established by laboratory research, and the question of the origin of granite has recently had greater illumination as the result of experimental studies. [103]

Many of Riess' activities in locating water in areas facing water shortages have attracted widespread attention and grew to such intensity in localized areas that the Water Resources Division of the United States Geological Survey felt compelled to publish a five page tract, dated October 1954, taking exception to the availability of primary or juvenile water for ordinary uses.

The third supplement to the May 1953 edition of the "Publications of the Geological Survey," it is stated on its cover, is a complete listing of new publications issued from June 1953 to May 1956 inclusive, so that it covers the publication date of the above referred to tract. This tract, called, "Availability of Primary or Juvenile Water for Ordinary Uses," is not a professional paper, for it is not listed in that category of the third supplement. It is not a bulletin, for it is not listed in that classification. Nor is it a water-supply paper, being absent from that group. It is not listed as an investigation or as a miscellaneous paper, nor does it even rate to appear on the free list of circulars. It just isn't listed. Therefore, it fits the definition of a tract, a brief treatise that deals with some topic of the practical religion of ground water hydrology. If the reader is wondering whether it is, in fact, a publication of the Water Resources Division, the same thought revealed that it not only says so on the document, but was distributed by a local office of the Water Resources Division.

The arguments put forth obviate the necessity of a scientific rebuttal. Nonetheless, their position is being presented here in order to expose the type of thinking, not only of that of the authors, but common to many people currently engaged in trying to solve the water problems of our country. They are loyal, hard working, well meaning and able, but unfortunately their training and work does not leave them with an open mind.

It is probable that this five page document, in reality only four and one-quarter pages, was the direct result of requests for information about primary water stemming from a two part series which appeared in Fortnight magazine during the months of August and September of 1953. [129] This series is the only reference to primary water in the tract. Obviously, the reporters of Fortnight were more conscientious in trying to find out about the primary water concept than did the authors of what is purported to be a more learned article. It is equally obvious, that the series in Fortnight, written for mass consumption, could not provide the authors of the tract with much information of a scientific nature. It is also equally obvious, inasmuch as the U. S. Geological Survey does not list it, that the tract was designed as a throw-away, and perhaps, that is what is best for it.

The authors of the tract were not trying to learn nor even trying to find out if or how the primary water concept might differ from the almost classical description of juvenile water. They made no effort to communicate with Riess, nor did they give him the benefit of seeing the contents of their work either before or after publication. Water is a very serious business, and every and all leads that could possibly avert serious water shortages in many parts of our country should be followed up methodically. If this tract had been a regular publication of the U. S. Geological Survey it would have been indexed, knowledge of its existence would be had, and proper rebuttal could have been made. In this manner, differences of opinion could have been aired, the knowledge of each participant would have increased, and the country would have been closer to more permanent solutions of our water problem.

In lumping them together, in not distinguishing between primary water and the other juvenile waters, the tract commits its first blunder. Juvenile water has always been associated with and defined as being highly mineralized; and that is precisely the reason for utilizing another name like primary water to describe the pure, potable water that is available from the interior of the earth. The tract does not deny the existence of juvenile water for that would contradict too much field evidence. The authors say: "At present we are concerned not so much with the existence of juvenile water as with its availability in adequate quantities and of suitable quality for ordinary uses." [130] In their discussion, they atempt to treat quantity and quality separately, but this cannot be done until one knows what one is talking about and the constitution of juvenile water has been defined. Then, and only then, can a determination be made as to its quality or quantity. But, this they do not do! Their leading arguments are centered about the quality of juvenile water, and therefore, in order to avoid any possibility of distortion, they are quoted part by part, and comment is made therewith. They say:

> 1. Wherever water that can be assumed with confidence to be wholly or essentially juvenile has been collected for analysis (as in the form of vapor escaping from a volcano) it has been found to be so high in dissolved mineral constituents as to be entirely useless for ordinary purposes, and in so many cases highly corrosive. [130]

They do not indicate the criteria whereby an assumption with confidence can be made that certain waters are juvenile. Therefore, this argument, is in reality just a merry-go-round. If the waters are highly mineralized, they are juvenile, and therefore, all juvenile waters are highly mineralized. A first course in logic points up the fallacies of such an argument. This tells us nothing. In previous chapters, reference was made to the deposition of metals and minerals by magmatic springs and fumaroles thereby giving recognition to the high mineral content of many juvenile waters that reach the surface of the earth. Research work has been going on to find a clear-cut definition of the constitution of juvenile water. In the latest works, isotopes of hydrogen and of oxygen appear to hold the greatest promise.

> 2. That juvenile water should be highly mineralized is inevitable. Water is the universal solvent, capable of dissolving more different substances in larger quantity than any other. Reference to any textbook of chemistry shows, also, that water that is hot and under pressure dissolves larger quantities of most substances than does cool water under atmospheric or lower pressure. [130 p. 4]

Granted! This is just the point. It is a two way street, that as juvenile water cools and is subjected to less pressure, the substances dissolved therein are precipitated. In addition, the constitution of the host rock, through which the juvenile water passes, may precipitate minerals which otherwise, under lower temperature and lower pressure only, might not precipitate. This role of the host rock has been ignored by them, as has the fact that primary water has been found at temperatures which are not high.

> 3. Thus, juvenile water inevitably must dissolve large quantities of the chemical constituents making up the rocks. As the water rises toward the earth's surface and cools, the less soluble constituents like silica largely separate out, but even if the water cools to or nearly to atmospheric temperature as it comes near the surface it still contains large quantities of the more soluble constituents like sodium and chloride. [130 p. 4]

It will be recalled that primary water location is concerned with igneous rocks. Sodium, an alkali metal, does not form any simple compounds in igneous rocks. The alkali metals "are present only in complex compounds, formed together with other metals." [34 p. 429] The bulk of the sodium in igneous rocks must be found in the feldspars.

An interesting comparison, indicates that the content of sodium is less in igneous rocks than in the dissolved solids in lake and river water. The potassium content and the ratio of sodium to potassium is also given: [34 p. 432]

	Per Cent Sodium	Per Cent Potassium	Na:K
Igneous rocks	2.83	2.59	1.09
Dissolved solids in lake and river water	5.79	2.12	2.73
Dissolved solids in sea water	30.62	1.10	27.84

It was mentioned earlier that as crystallization proceeds the trend of formation is from the ultrabasic through the basic and intermediate to the acidic igneous rocks. It was also shown that the water content of the magma increases as crystallization proceeds and that the acidic rocks contain larger amounts of oxygen than do the basic rocks. Primary water location is more concerned with the acidic igneous rocks than with the basic igneous rocks, and during the main stage of crystallization, the content of sodium decreases in relation to potassium, as is shown by Rankama and Sahama in their calculations from Daly's averages, as follows: [34 p. 430]

Rock	Na:K
Gabbros	2.55
Diorites	1.43
Granodiorites	1.20
Granites	0.76

The waters of deep-seated magmatic origin are usually characterized by a notable content of heavy metals, whereas the concentration of such metals in waters of surface origin is low. [34 p. 279] It will be recalled that economic geology attributes to hydrothermal processes the deposition of the metallic mineral deposits that supply the major part of the useful metals and minerals. And, that one of the essentials for the formation of hydrothermal deposits, is the chemical reaction that results in deposition. By chemical reaction is meant the interaction of two or more substances which involve an alteration in their chemical composition due to an increase, decrease, or re-arrangement of atoms within their molecules. This fact has been ignored in the arguments presented. It will also be recalled that many of the authorities say that the chemical composition of gases and hydrothermal solutions change during their progress along fissures in the surrounding rocks; and that this is due partly to fractional precipitation and partly to reactions between solutions and the wall rocks. Hydrothermal mineral deposition is profoundly affected by reactive wall rocks not in equilibrium with solutions.

The solubilities of minerals are given in the tables of the "Handbook of Chemistry." [131] There are also tables of the solubilities of inorganic compounds in water at various temperatures. Merely for illustrative purposes, the chlorides are quoted at various degrees fahrenheit, however, it was shown that the primary water that was located was invariably below ninety-eight degrees fahrenheit and was potable. It will be noted that the solubility of sodium chloride does not decrease appreciably with lower temperature but it will be recalled that the content of sodium in igneous rocks is far less than the sodium content of lake and river waters.

The number of grams of anhydrous substance dissolved in one hundred grams of water at the following temperatures:

	Degrees Fahrenheit			
Substance	68	86	104	122
Ammonium chloride	37.2	41.4	45.8	50.4
Barium chloride	35.7	38.2	40.7	43.6
Calcium chloride	74.5	102.0	------	------
Cupric chloride	77.0	80.34	83.8	87.44
Lithium chloride	78.5	84.5	90.5	97.0
Manganese chloride	73.9	80.71	88.59	98.15
Nickel chloride	64.2	68.9	73.3	78.3
Potassium chloride	34.0	37.0	40.0	42.6
Sodium chloride	36.0	36.3	36.6	37.0
Strontium chloride	52.9	58.7	65.3	72.4

There are other complexities which are inherent in the formation of precipitates from solutions. Ramberg's illustration of the deposition of calcite was made difficult by the fact that the carbon dioxide pressure has a great effect upon the solubility of calcite. Another example would be the reaction between solutions of sodium chloride and silver nitrate. Both salt solutions consist of ions in water, so that, of the four possible products which may result from the ions in solution, one of them, silver chloride, being only slightly soluble, precipitates. It is also possible to select two salt solutions, which by interaction yield two insoluble salts, both of which precipitate, yielding almost pure water.

Another illustration is that of barium sulphate, an ionic substance, with its crystal lattice of barium ions and sulphate ions arranged alternatively. If solid barium sulphate comes into contact with a sodium sulphate solution, the lattice tries to grow by adding sulphate ions. As there are no barium ions in the solution, the sulphate ions are in excess on the surface of the solid resulting in a negative charge which attracts the sodium ions from the solution. [132]

In the discussion of plutonic igneous rocks, it was mentioned that the slow crystallization resulted in large crystals. This comes about because the ions or molecules have the time to arrange themselves in an orderly manner upon the faces of the crystals which are already there. Two related effects need to be mentioned. The first, known as "Ostwald ripening," is the disappearance of the smallest particles, by solution in the mother liquor, only to have their material redeposited on the larger particles—thereby resulting in the many precipitates that become coarser while in contact with their mother liquor. The other effect, known as "internal Ostwald ripening," is the dissolving of corners and edges of irregular particles and their redeposition in the hollow parts, thereby decreasing the surface area and resulting in a more solid particle. These particles may then become cemented together by the deposition of solid between them.

> 4. It is concluded, therefore, that true juvenile water may be expected to be highly mineralized under any and all circumstances. In any place where the proportions of the chemical constituents indicate juvenile rather than meteoric origin, if the water is dilute enough for ordinary uses it must have been mixed with meteoric water. Therefore, it cannot be considered to constitute an independent source that is immune to drought, nor can it be developed without regard to the effect of the development on other freshwater supplies in the same basin." [130 pp. 4-5]

Did the reader notice—"In any place where the proportions of the chemical constituents indicate juvenile rather than meteoric origin, . . ."—the other half of the merry-go-round. It would certainly seem that the entire tract could have been reduced down and simplified in its writing to: "All waters which are highly mineralized are juvenile water and therefore all juvenile water found must be highly mineralized and therefore not available for ordinary uses." Inasmuch as these conclusions are based on the preceding arguments, which have been rebutted, they may be disregarded.

Earlier, it was shown that hydrologists believed that the critical studies of juvenile water had been made in some of the other geologic specialties and that, therefore, the continued study of such water should be made in those special fields. The United States Geological Survey has some of the finest and most able scientists working in these other specialties. These are the people who have the training and experience to assay the value of primary water and its availability for ordinary uses. If the authors of the tract had been more fully aware of the complexities involved, the least they would have done would be to check their findings with some of these specialists.

ISOTOPE GEOLOGY

The investigation of stable and unstable isotopes of elements and of changes in their abundance has begun a period of more precise delineation of geological phenomena. For instance, up until fairly recent times it was heresy for anyone to doubt for just one moment that all graphite has its origin in organic matter. Wickman and von Ubisch [133] say that not only do most students of this subject nowadays agree that graphite may be formed from either organic or inorganic matter, but that it is possible in many instances to characterize the source of the graphite by its isotopic constitution. They show that the C^{12}/C^{13} ratio for the formation of graphite by: the metamorphism of organic matter is larger than 91.0; the reaction between a carbonate rock such as limestone and an intruding magma is less than 90.0; the pneumatolytic and hydrothermal processes give a provisionally adopted range from 89.0 to 91.5, and a mixture of two or all of the above mentioned sources would cover the ratio values already cited.

Likewise, it is heresy today to even suggest that supplies of fresh, potable water, of an origin other than that of local surface infiltration, exist within the earth. But the evidence is piling up and sooner or later there will be general acceptance of the fact that ground water has more than one origin.

It was shortly after the discovery of deuterium that slight differences in the density of water from different sources were first observed. These slight differences had not been noted before because in previous atomic weight determinations the experimental errors had been greater.

Rankama [119 pp. 243-52] cites the findings of many researchers with respect to the variations of specific gravity due to the different amounts of heavy isotopes of both hydrogen and oxygen contained in: atmospheric precipitation; ice; well and spring water; lake water; river water; sea water; connate water, and juvenile water. Briefly the current evidence indicates:

1. Atmospheric water vapor is lighter than either fresh water or sea water.
2. The heavier specific gravity differences increase as we go successively from water of ordinary wells and springs to water of mineral springs and then to water of thermal springs.
3. Water in thermal springs have a specific gravity indicative of the admixture of juvenile water and waters of vadose origin.
4. The higher the heavier specific gravity difference the greater the assumption of their deep-seated origin.

Isotope exchange, however, may further complicate a determination of the source of the water. For instance, Hall and Alexander [134] show that if most of the water-free oxysalts are dissolved in a known amount of water of known high specific density due to excess O^{18}, and the salt and water are completely separated later, a decrease in the density of the water occurs. Under such circumstances a lower specific gravity might be obtained and thereby mask the deep-seated origin of the water. Under these circumstances it is entirely possible that the 525 billion gallons of water, that it was calculated escaped being fixed in the crystallization of either kernite or borax, would have a lower specific gravity difference than the water that became bound in the kernite or borax. In such an instance the true origin of the pure, potable water might not be determined by isotope determination.

STRUCTURAL GEOLOGY

Earlier, reference was made to various aspects of structural geology such as: the role of faults, Nordenskiold's observations of the structures that were folded at Kings Bay and at Cape Staratschin, and the effect of earth tides. Earth movements determine the structure of the earth, and the terms tectonics and tectonic geology are synonymous with structural geology for structural geology endeavors to determine the structure, when it developed, and under what physical conditions it formed.

Strain is the deformation caused by stress, which in turn may be either compressive, tensile, or shear. If the stress is less than the elastic limit, the deformation is elastic inasmuch as the body returns to its original shape and size when the stress is removed. The deformation is plastic when the stress exceeds the elastic limit and the body only partially returns to its original shape when the stress is withdrawn. If there is a continued increase in the stress, the specimen eventually ruptures and develops one or more fractures. The rupture strength of rocks have been ascertained and compiled for compressive, tensile, and shearing stresses. However, geologists are more concerned with the stress that a rock can withstand without rupturing, irrespective of the time involved, and under specific temperature and pressure conditions with or without the presence of solutions. After long continued stress the rocks become much weaker and if the stress is applied slowly, less stress is required to cause rupture. Increases in temperature weaken rocks and the presence of reacting solutions also result in lowering their strength, but the elastic limit increases as the confining pressure increases.

The relationship of elastic quantities to electric quantities is apparently not described in structural geology books. However, Voigt has shown how the elastic quantities (stress and strain) and the electric quantities (field and polarization) are related by the piezoelectric coefficients or their inverse values, the piezoelectric moduli. [135] Piezoelectricity will be amplified very shortly.

Solid rocks are able to change their shape without visible signs of fracturing for individual grains of such minerals as calcite, quartz, feldspar, mica, and hornblende may be displaced when subjected to stress. Such intergranular movements take place entirely within the individual crystals, between the atoms, along glide planes. The glide direction, the position, as well as, the number of glide planes depend upon the mineral in question.

In the rocks of the crust of the earth, rupture is expressed by cleavage, joints, and faults. Many ruptures now occupied by dikes or veins are the concern of the petrologist or the economic geologist, whereas the origin of the rupture itself remains the concern of the structural geologist. Although petroleum geology is primarily concerned with sedimentary rock structures, oil production is obtained from fractures in igneous and metamorphic rocks in both California and Kansas. [136] Petroleum geologists have found that the extensive deposition of ore minerals along faults usually denotes poor prospects for oil production. [136 p. 119] These very same occurrences, however, may be favorable for primary water production.

Descriptive features and their interpretation are amply covered in the many good books that are readily available on structural geology. [137-141] Field observations do not always furnish conclusive evidence of structure, so that intensive microscopic study of rocks in thin section is frequently resorted to. Several excellent books on microscopic petrography exist. [104, 142, 143] Although such microscopic study may supply much valuable information about the composition of rocks any real clues to the problem of their history and structure may be lacking. In such cases, structural petrology may afford the key to solution. [144]

PIEZOELECTRICITY, ETC.

The attracting power of a tourmaline crystal has evidently been recognized in Ceylon and India since time long past. When tourmalines were brought to Europe its electrical character, that is, opposite polarities at the two ends of a heated tourmaline crystal, were noted by Aepinus in 1756. Brewster, having observed this same effect with various kinds of crystals, introduced the name "pyroelectricity" in 1824. The Curie brothers, Pierre and Jacques, were awarded the Plante prize in 1895 for their discovery, made in 1880, of a new method for the development of polar electricity by subjecting hemihedral crystals to variations of pressure. [145]

Piezoelectricity occurs when certain elastic deformations in a crystal, having no symmetry center, are accompanied by unequal vectorial displacements as the result of the lack of symmetry. When crystals, having no symmetry center, are compressed in particular directions they show positive and negative charges at certain portions of their surfaces, the charges not only being proportional to the pressure applied but even becoming reversed when the crystals are subjected to tension.

Applications of piezoelectricity include the use of piezoelectric crystals in filter circuits, in submarine signal and echo work, in intense ultrasonic beams for many scientific and industrial uses. [145 pp. 667-98] In fact man has not been able to produce means whereby the precise and regular frequencies of a piezoelectric crystal can be matched.

Specifically then, pyroelectricity is electricity or electric polarization produced on certain crystals by change of temperature, whereas piezoelectricity is electricity or electric polarization produced by mechanical strain in crystals of certain classes. The phenomenological theory of piezoelectricity, based on thermodynamic principles of Lord Kelvin, has been given by Woldemar Voight. [146] Despite the fact that atomic theories of piezoelectricity have been proposed ever since the Curies' discovery, a theoretically satisfactory treatment of the phenomenon is still at a very early stage, and it is hardly possible to give a rough estimation of the order of magnitude of the piezoelectric effect for even the simplest structures. [135, 145 p. 731]

Seignette electricity, also referred to as ferroelectricity, describes the fact that in the neighborhood of a certain characteristic temperature, the static dielectric constant of the crystal increases greatly with decreasing temperature. At this characteristic temperature, called the Curie temperature or point based on an analogy of ferromagnetism, polarization even occurs when the applied electric field is infinitely small. This means that at the Curie temperature spontaneous polarization begins and rapidly increases when the temperature is lowered below the Curie temperature. [135 p. 423]

The spontaneously polarized crystal has a structure of lower symmetry than the structure of the non-polarized crystal. Evidently spontaneous polarization is accompanied by a deformation of the unit cell so that a seignette electric crystal is always piezoelectric in the Curie temperature region, since in this region the crystal has no symmetry center. Spontaneous electric polarization and ferromagnetism, despite the resemblance of having a temperature region of spontaneous polarization, have essentially different causes.

Ferromagnetic Curie points also exist for metals other than iron. Microscopic spontaneous magnetism exists because a ferromagnetic body contains an excess specific heat when compared with normal metals. [147] Evidently a ferromagnet has an excess internal energy which does not depend upon the apparent magnetization but instead is a function of the temperature only. The occurrence of spontaneous ferromagnetism and spontaneous polarization, in conjunction with the heat from intruding magmas or from radioactive rocks may actually begin a process of electricity within the earth. Graham [148] has raised questions as to whether rock magnetism would be useful in describing the distortion rocks have undergone and whether rock magnetism would be valuable in the interpretation of complex structures of the crust.

In addition to spontaneous polarization and magnetization, piezoelectricity is caused by tensile or compressive stress and pyroelectricity is caused by changes in temperature.

Areas wherein both heat and deformation would occur simultaneously are the areas where the existing rocks are brought into contact with intruding magmas. Kemp [149] has shown that most of the granitic magma intrusions deform their walls whereas very few of the basaltic or gabbroic intrusions result in thorough deformation of their walls.

Electric current, passing through solutions, decomposes them and results in the liberation of gases or metals, and is known as electrolysis. For instance, hydrogen is set free from solutions of salts of the alkali and alkaline earth metals, and also from solutions of acids. Oxygen is liberated from solutions of nitrates, sulfates, phosphates, etc. Metals are set free from solutions of salts of zinc, iron, nickel, cadmium, lead, copper, silver, and mercury. [150]

The alkali metals, called thus because their hydroxides are all soluble bases or alkalies, are lithium, sodium, potassium, rubidium, and cesium, which are found in varying amounts in nearly all silicates. The alkaline earth metals are normally broken into a main group and a subgroup. The main group consists of beryllium, magnesium, calcium, strontium, barium, and radium, whereas the subgroup consists of zinc, cadmium, and mercury.

If hydrogen and oxygen are present at certain specific temperatures, or in the presence of a catalyst, they unite to form water. From experimental work with electrical discharge, it has been found that an excess of hydrogen gave water only, whereas an excess of oxygen gave water and ozone, and that hydrogen peroxide is often a by-product of the union of hydrogen and oxygen. [151] In the catalytically promoted combination of hydrogen and oxygen, no one doubts that the influence of the metal is directed toward the hydrogen and not the oxygen. The hydrogen molecule undergoes a change and in this latter state is capable of adding to the unsaturated oxygen. Hydrogen peroxide is the initial product which is then reduced to water. [152]

SUMMARY

The evidence for the existence of primary water and its genesis in the interior of the earth was set forth in these chapters on the dynamic earth. The weaker crustal zones of the earth present the easiest areas for the location of primary water. Earthquakes and volcanoes are both connected with the weaker crustal zones of the earth. The annual average is about one great shock, approximately one hundred potentially destructive shocks, and about one million shocks that are potentially strong enough to be felt in a settled area. [153] In a 1,500 square mile area of India near the Tibetan border there have been almost daily tremors since December 28, 1958.

It can be seen that prospecting for primary water utilizes knowledge from geochemistry, petrology, mineralogy, crystallography, physical chemistry, as well as structural geology.

What man does not alter for the
better, time alters for the worse.
—FRANCIS BACON

CHAPTER VII

MAN'S-CHALLENGE

To meet man's water supply needs, all methods of supplying water must be used to supplement each other. An economic test must be applied to each, however, and the most economical way must be the choice in each specific instance, consistent, of course, with other factors which may weigh heavily when man's welfare is at stake.

Even by the most optimistic predictions, the cost of saline water conversion, some ten years hence, might be brought down to about fifty cents for one thousand gallons. Nonetheless, it would still represent a cost greatly in excess of present costs in many areas. Where saline water is a problem and water costs are high, such conversion is already at work. But, the costs of pipelines, pumps, and power to transport the converted water to inland areas distant from the source would make it no longer economically feasible for these inland areas.

The President's Materials Policy Commission, soon after World War II, foresaw a daily need of 341 billion gallons by 1975, while the New York Times survey of March, 1957, foretold a total usage in 1975 of 450 billion gallons. The anticipated water problem areas for the year 1970 have been compiled by the Population Reference Bureau, Washington, D.C., for the national health forum held in Philadelphia in March, 1958. The anticipated areas of deprivation are not restricted to the arid west but to many sections of our country. To meet these anticipated needs, many methods of supply are required. The time is long past due; solutions must be found if continued rational action is to be expected as water problems become even more acute. Primary water is not the only source for man's supply requirements, but in many cases it will be the most economical. Furthermore, there are several specific applications where primary water presents the only presently known solution, unfortunately however, known to but a few.

In an article by Julius Margolis, appearing in The American Economic Review, three recent books come under his critical review. He says that these volumes not only suggest procedures to evaluate the efficiency of water resources development projects, but that their objective is to analyze projects "so that the chosen set of projects will maximize national welfare." [154] Margolis' most incisive statement follows: [154 p. 100]

> Most disturbing in the analyses is the lack of attention paid to alternative programs by which the same goal might be achieved. This is, in turn, symptomatic of an even more general problem which is ignored. The volumes restrict themselves to projects and to procedures by which to evaluate projects which have already been proposed. To select the best from a known and restricted set of alternatives is far from maximizing. What are the procedures by which alternatives become known? Is there a best way to search out alternatives? In the perfectly competitive economy we assume that competition and the drive to maximize will generate all the best alternatives. Though this questionable hypothesis has never been tested, we do not even have a reasonable description of the process of search in the public sector which would permit judgments about its efficiency. The process by which alternatives are discovered and considered may be a major constraint on the possibility of maximizing a set of goals. ,

It would be difficult to assume that the work of Stephan Riess would have lain so long in limbo if water supplies were generally under the cognizance of private industry rather than governmental organizations. Private citizens and business organizations have been using his ability to locate water for many years.

SCIENCE AND OPERATIONALISM

There have been many instances where natural occurrences have for years not been explained. For example, Champion [155] quotes figures on the rate of transpiration by trees, and then says that in not a few cases the rate of transpiration exceeded the total recorded rainfall. Where did this excess water come from? Another is Lake

Chad. Situated in central Africa, it is 175 miles long and believed to be the last fragment of a sprawling inland sea estimated to have been roughly the size of the Caspian Sea. In 1953, the lake began to rise rapidly and for the first time since 1873 the waters were running in the Bahr el Ghazal, its outlet. There may be some conventional hydrological explanation, not yet made, that could account for the fact that Lake Chad is higher than it has been for eighty years, yet its rise has not been accompanied by any increase in rainfall.

Smithson, from whom the Smithsonian Institution got its name, said: "Every man is a valuable member of society who by his observations, researches, and experiments procures knowledge for men." Many of the great contributions in science were the result of chance observations. Chance provides the opportunity, but the scientist has to recognize and grasp it for it is the interpretation of the chance observation which counts. Pasteur's famous saying is certainly appropriate: "In the field of observation, chance favors only the prepared mind." A mind that is not open cannot be a prepared mind for all honest and intelligent observation must make a choice between given ideas. Or, in the words of Charles Darwin: "How odd it is that anyone would not see that all observation must be for or against some view, if it is to be of any service."

Many of our early great Americans formulated and published plans for a national system of education. The plans, says Adler [156], proposed the emphasis of scientific knowledge to equip the people for the responsibility of developing the resources of the country. Today, our schools are again being reminded to emphasize scientific knowledge. However, our concept of science trends toward technical application rather than theoretical science. Ruesch and Bateson say: [157]

> American men of science probably have among their members the largest number of creative engineers. However, there is a lack of scientific theoreticians, and those scientific thinkers who are American citizens are, by and large, of foreign birth. The pressure to conform does not produce original personalities, and therefore this field has been left almost entirely to Europeans.

This pressure to conform is not new to man, but has existed since the beginnings of society. Socrates, for example, believed that, regardless of the prejudices of other people and the possible consequences, the individual's course of action should be guided by knowledge, truth and the sovereignty of the intellect. Everyone knows Socrates' fate. It was Ralph Waldo Emerson who said: "Whoso would be a man must be a non-conformist."

The psychology of Americans, based upon the multiple premises of pioneer and puritan morality, is said to be governed by the premises of equality, sociality, success, and change. [157 p. 95] These four premises may account for our accent on technical application rather than on theoretical science. Equality and sociality require conformity and the conjured vision of the solitary scientist does not meet its requirements. Technical application brings change and the possibility of quick success whereas years of painstaking work in the theoretical sciences may or may not be recognized during one's lifetime.

In the field of hydrology, as well as in many other fields, operationalism—the doctrine that scientific concepts secure their meaning from the relevant set of operations involved—implies the abandonment of logical theorizing, which coupled with intuition and imagination, subsequently tested experimentally, have contributed the most concepts, theories, and hypotheses in the sciences. Beveridge recognizes the roles of intuition and imagination, and says: "Elaborate apparatus plays an important part in the science of today, but I sometimes wonder if we are not inclined to forget that the most important instrument in research must always be the mind of man." [158]

Even in physical "laws," says Sorokin [159], not all quantities are operationally measurable. He gives the illustration of the law of motion for a freely falling body wherein the value of G in the equation $S = 1/2\ GT^2$ gets its meaning not from any operational measurement, but solely because of its appearance in the equation. To calculate G the equation must be used—another indication of the importance of theory to every experimental operation. Sorokin sums it up neatly when he says: "To abandon intuitional insight and logical thought in favor of operational method would amount to castrating creative thought generally, and in science particularly. Without intuition and logic no real progress in science, religion, philosophy, ethics, and the fine arts has been or will be possible." [159 p. 36]

Julian Huxley recounts how he first came to realize the vast amount of scientific knowledge which he had at best been only dimly aware of. He became even more impressed with the fact that there was a lack of appreciation and understanding of science among business men, financiers, educational authorities, politicians, and administrators even though the existing structure of civilization and the hope of progress are based on science. "Almost equally serious, however," Huxley emphasizes, "is the absence of a broad scientific outlook on life, too often to be noted in the scientific specialist as well as in the layman." [160]

There is one other fact that needs to be examined. At one and the same time, there is a certain dogmatism that precludes new insights while a great reluctance to recognize contributions from the past also exists. Conant refers to Sir Archibald Geikie's summarization on the history of geology that "one important lesson to be learned from a review of the successive stages in the foundation and development of geology is the absolute necessity of avoiding dogmatism." [161] Gigantic presses, at Harvard University, capable of producing pressures up to six and a quarter million pounds, have shown that water, normally regarded as incompressible, can be halved in volume under a pressure of a million pounds per square inch. Other peculiar things have happened to solid substances under high pressure. Ice will not melt until its temperature is raised to 370° F. if subjected to 600,000 pounds pressure.

Brittain [162] says that actually most of the details in the construction of waterworks were discovered by man before they had the mechanical power to help with the physical labor. He cites many examples of this, one of which is the Grand Anicut, a dam 1,080 feet long built across the Coleroon River in Ancient India. Brittain quotes Hart as saying that in 1830 the Grand Anicut taught what no living engineer or treatise then affirmed, and that a British engineer, Captain Arthur Cotton, risked his reputation and his career on a revolutionary demonstration that the full force of the river at its mouth could be withstood by dams founded on pure sand rather than rock. Captain Cotton subsequently proved, when he built several such dams, that engineering science could duplicate this ancient feat. Hart says that those great barriers, resting safely on sand, are not only monuments to ancient engineering but also the modern ability to learn.

Nearly one-fifth of the surface of the earth is made up of deserts, supporting less than four per cent of the world's population. But approximately forty-four per cent of the land area presently thought to be hospitable to man, seven and one-half billion of the seventeen billion acres, is not usable for food production because of insufficient rainfall. Deserts usually have less rain, more wind, more sun, and higher temperatures than other regions of the earth. The most important factor about deserts is a low annual rainfall. Most geographers agree that if the rainfall is unevenly distributed throughout the year and the region receives less than ten inches of rainfall it may be termed a desert. However, the influence of the desert is felt in the areas around them so that these belts around the deserts, with an annual rainfall of from ten to twenty inches, are termed semi-arid regions.

Because of the high average temperature there is a more rapid evaporation of the little rain that does fall in arid areas. The prevailing winds generally blow into the desert from its peripheral areas; the cooler air rushing in to replace the desert warmed air which has risen.

Of the total land area in the United States, thirty-nine per cent has less than twenty inches of precipitation annually. This amounts to some 742 million acres, of which some 153 million acres receive less than ten inches of annual precipitation. The heart of our west is comprised of the desert states of Montana, Idaho, Wyoming, Nevada, Utah, Colorado, Arizona, and New Mexico. Sometimes known as the desert rim states, for they are partially under the influence of the desert, are the states of Texas, Kansas, Nebraska, South Dakota, North Dakota, Washington, Oregon, and California. In fact, most of our cultivated land is east of the one hundredth meridian.

The chief causes of our deserts are the mountain ranges which act as barriers forcing the moisture-laden clouds upward and thereby causing precipitation over the mountains that otherwise might precipitate over the deserts. There are other causes of deserts: sometimes a cold ocean current acts much as do mountains in robbing the rain clouds of their moisture; sometimes deserts are made by man and his animals. During droughts, the expansion of the arid areas is very great, an expansion that may become more or less permanent.

According to Bernard Frank [163], man-made or natural changes in the plant cover affect the relationship between soil and water. The effects, he says, are not always obvious but they exist just the same, and can be ignored only at man's peril. Says Frank: "Our struggle for existence is in part a continuous attempt to adjust ourselves to an unfavorable environment—often of our own making." [163] Stebbing gets very specific when he says: "The Man-made desert is a stern reality which so far has rarely been faced up to. Man has been the enemy of the forest and of vegetation ever since he learnt to grow crops for food and to pasture flocks and herds on the countryside." [164]

The most ancient type of cultivation known to man is called shifting cultivation. However, since its origin, this type of cultivation has been known by many different names in many different lands and even during the same historical period in the same country. The method is basically the same. Stebbing's description is worth reading: [164]

> A small piece of forest out of the surrounding mass was felled, the material as soon as dry enough fired, and the ashes roughly spread over the ground thus opened out and the seed of a crop sown. At the end of a few years, roughly three to five, a dense weed growth supervened, or the soil decreased in fertility, or both. The shifting cultivator then moved and repeated the operation in another piece of the forest. The eventual degradation of the forest from a fine dense high forest to a scrub, variously denoted as scrub, bush or savannah, took thousands of years and was in effect so imperceptible that it has passed unperceived—in fact was lost in the past histories of the earlier nations who lived in what are now deserts.

The Sierra Club Bulletin illustrates from current practices in Lebanon, the six steps of desert making as follows: [165]

1. An existing forest

2. A field is cleared in the forest and put into cultivation. Gradually, due to population pressure or exhaustion of the soil, the forest is completely destroyed and eventually cultivation is moved to the solpes where it starts the process of erosion

3. The abused flat lands are grazed and overgrazed

4. The livestock, like the cultivation, moves to the slopes, and the ravenous livestock eats the seedlings so that forest regeneration ceases

5. Goats finish off all traces of forest vegetation and nomads

with their flocks constantly move about in search of the raeagerest feed, and finally

6. Abandoned terraces, irrigation systems, and cities blend with the serene landscapes of the desert.

Stebbing [164] says that the cities of old time nations are known to us. It was the degradation of the forests and the drying up of the water supplies which resulted, in more than one instance, in the final disappearance of the peoples. Champion [155 p. 178] refers to the advance of deserts in Africa, Western India, and other places, and to the frequently given explanation of a possible drop in rainfall caused by denudation of the natural vegetation. He says, reliable evidence is difficult to obtain, but grazing and temporary cultivation are very important contributory factors if not the sole or even the main cause.

Libby's work with natural tritium may give some insight into the manner in which denudation may bring about decreased rainfall. Libby says that tritium is produced by cosmic radiation at an altitude of six or seven miles. The decay constant for tritium is 12.5 years half life and 18.0 years average life so that, says Libby, "it is clear that the tritium content of rain water will decrease with time elapsed after precipitation, since the cosmic ray source can introduce fresh tritium atoms only in the atmosphere where the new tritium atoms react with the atmospheric oxygen to form radioactive water." [166] Libby's measurements of tritium content in rainfall on Chicago indicated that this rain had probably fallen and risen five or six times in its travelling eastward from the Pacific Ocean. If rain falls on denuded areas it is subject to rapid run-off with little or no transpiration and less evaporation. However, vegetation, and especially forests can absorb tremendous quantities of water which becomes available to the atmosphere again through the processes of evapo-transpiration. Thornwaite mentions his experiments at Seabrook Farms, New Jersey, where very large amounts of water are used to process tons of vegetables.

The water, used to wash and process these vegetables becomes polluted with organic matter and the health authorities did not like the idea of releasing it into a stream. Says Thornwaite: [167]

> I thought some wasteland could be irrigated by it. Cultivated land took 2 in. of water and was then saturated. So I shifted the irrigation nozzle to a poor oak forest that had never been cleared

> or cultivated. It ran continuously at the rate of one inch an hour for 72 hours and then at an increased rate of five inches an hour for 72 hours and then at an increased rate of ten inches an hour for five hours—a total of 482 inches and none ran off. Later, we reserved 120 acres of that forest and irrigated it with the ten million gallons of water a day. (In one crop season we applied 1200 inches to a part of the forest). That makes it the rainiest forest in the world.

When an area is denuded of its forests and other vegetation, the water supplies, because of excess run-off, become unreliable or intermittent and therefore the water available for evaporation back into the atmosphere also becomes sporadic, resulting in rainfall that is unreliable or intermittent. Stebbing [164 p. 124] says that this is one of the greatest stumbling blocks in Africa to an appreciation of what is taking place in the upsetting of the balance of nature, thereby causing the rainfall to become unreliable or intermittent.

Other possible effects of denudation of forests on precipitation are covered in a subsequent section on afforestation.

Americans are and have been wasteful of the bountiful resources at their disposal. Higbee [168] says that it was already apparent in 1775 that Americans were deliberately wasteful. There was, of course, a minority of good husbandmen in every colony, but not enough to dissuade the majority from plundering their land. Despite all soil conservation efforts of recent years in the United States, erosion is still destroying the equivalent of 400,000 to 500,000 acres of good topsoil annually. The total farmland in the United States, including pasture and grazing land, is less than one and a quarter billion acres. [169] At the rate of soil erosion indicated, it would only take two thousand years and the United States would be completely pauperized.

Many other countries have greater yields per acre than we do. Our efforts, in the past, had been oriented toward getting greater production or yield per man engaged rather than obtaining the maximum per acre. This approach led to economy of production and hence lower prices. Later, both increases in yield per acre as well as yield per man engaged were achieved. But, for the future, still further increasing the yield per acre appears to be an inevitable task. Says Higbee: [168 p. 39]*

*Reprinted with permission from Edward Higbee, "The American Oasis," 1957, Alfred A. Knopf Inc.

> Running out of cheap land has forced re-evaluation of what we have. Today's 3 acres of arable land per capita is the lowest in our national history. True, we have crop surpluses, but the burden of these promises to be comparatively short lived. As we are reaching the end of unused arable land our population increases faster than ever. Yet the running out of acres need not alarm us so long as what we have produces more and more. Better management can compensate for shrinking area per man. It must if are to continue to eat well.

Higbee [168 p. 246] estimates that within less than fifty years the extent of our tillable fields will amount to about one and a half acres per capita compared with the present 3 acres per capita. One other possible approach is to get additional suitable acres. By this, is not meant the age old method of expansion of the cultivated areas to undeveloped countries. Many people have already given thought to the great areas of undeveloped soil which exist in Africa, South and Central America, and several of the larger tropical islands. According to Kellogg [170], twenty per cent of the unused tropical soils of the Americas, Africa, and the great islands, such as New Guinea, Madagascar and Borneo are cultivable. These areas would add one billion additional acres to the three to four hundred million additional acres available in the temperate zones. This is not the solution, it merely delays the day of reckoning, for how long will these additional acres last under conditions of rapid population growth? Another possible approach will be discussed shortly.

William Greeley adds to our indictment: "The standing saw-timber, supposed to have exceeded five trillion board feet in the primeval forests of the continental United States, has now shrunk to one and six tenths trillion feet." [171]* He points out that although the total drain, from every source, exceeds the growth rate by only two per cent the saw-timber drain is nearly fifty-four billion board feet against a saw-timber crop of thirty-five billion board feet. This total saw-timber drain includes about an eight per cent loss due to forest fires, bugs, and fungi. Greeley [171] charges the country with the deficit spending of timber, for in an average year nineteen billion feet of saw-timber are taken from our nation's capital assets. At this rate, the United States would exhaust its saw-timber supplies in less than eighty-five years. Saw-timber consists of timber large enough for saw logs, lumber.

*Reprinted with permission from William B. Greeley, "Forests and Men", 1956, Doubleday & Company, Inc.

Most desert soils are composed of weathered inorganic minerals deficient in what is known in soil science as cation exchange capacity; the capacity to adsorb nutrient elements when they are abundant and then release them to plants as they need them. Furthermore, some desert soils are porous enough so that water filters through them and leaches any nutrients that may have been near the surface to lower depths. However, the more common problem of dry deserts is that the "downward seepage of water through the sub-soil is so infrequent that salts tend to rise and accumulate at the surface in excess, through evaporation." [172] A good top-soil takes years to build, and over the long period of time required for soil formation secondary clay minerals and humic complexes, having special properties, are produced through chemical and biological modification. These special properties are the cation exchange capacity and the conditioning of the soil's physical structure which provides for a freer circulation of oxygen and a more complete absorption of rain water. [168 pp. 55-7]

Several vital problems face the nation: the need for more arable land; the need for more saw-timber, and the need for more water. Fortunately, the breakthrough that now permits the location and production of primary water may hold the answer to these problems, not only for the United States, but for the entire world. In the following sections are some possible solutions.

AFFORESTATION

An interesting commentary came out of the Fourth American Forest Congress, held in 1953: "Most forestry graduates are woefully ignorant of the soil and water aspects of forestry." [173] This recognition of inadequacies pertains to the relationships of soil, water, logging, erosion, floods, siltation, etc. The basic scientific principles are now fairly well known regarding these aspects and recognition of short-comings is more than half the battle in learning. Frank says: "We still have much to learn about how to maintain the soil and water resources of the timberlands and forest ranges, and we have a long distance to go in applying what we already know about these things." [163 p. 187] There is sufficient literature available on the aforementioned relationships and they are fairly well known, so that, the approach here can be on the relationships of afforestation and deserts.

In those areas where nutrients have been leached down to deeper soil layers, trees can draw on them and return them to the surface. Most herbaceous plants do not reach the deeper soil layers, but trees do draw on the deeper soil layers that are richer in mineral nutrients and ultimately return them to the surface. [155 p. 69] When the leaves, twigs, or dead flowers fall to the ground they are attacked by animals, bacteria, and fungi, and broken down so that they gradually release for further use the essential nutrients they formerly derived from greater depths and thereby enrich the topsoil. Vegetation also helps to stabilize the soil surface in arid areas. It shields the soil from the full force of rain and wind, and more of the rain water enters the soil covered with vegetation because the roots help to keep the soil open and pervious to water.

As for those desert soils with excess salts, there are two possible solutions. Kellogg gives us one solution when he says: [174]

> Some desert plants take up little salt; the leaves of others have as high as 10 per cent sodium chloride on a green-weight basis. The long growing of such a shrub has a great influence on the chemistry of the soil. Thus only a few short feet apart, the soil under one shrub may be rich in sodium salt and extremely alkaline and that under another may be relatively low in sodium and only mildly alkaline.

It was once thought that plants, wholly through the processes of selection and competition, adapted themselves to different kinds of soil. Kellogg [174] says that although such selection is very important, we now know that the different kinds of plants themselves strongly modify the soil on which they grow.

The other possible solution lies in increasing the amount of rainfall and thereby leaching out some of the excess salts. Most soils in arid regions are low in nitrogen, which increased rainfall would increase. But how does one grow trees and forests in the desert, and how does one increase the rainfall?

Desert areas, being at varying elevations, can support the growth of a variety of trees and vegetation. In many of these areas, the one thing lacking is adequate water. Through the location of new water in desert areas, new wealth in the form of timber can be created. Timber is one of the natural resources we know of that can constantly replenish itself, if managed properly. The timber stands, not only create wealth, but also, over the years, condition the soil so that more water will be retained and, under a planned program of cutting and extension of the forested area, additional land will become available to augment our decreasing supplies of arable land per capita.

It will be recalled that the orographic or mountain storm is the result of the mountain, acting as a barrier, forcing the warm, moist air driven toward it to lift and cool to the point where precipitation occurs. It should be noted that the mean annual precipitation is greatest on the western slopes of the mountain ranges west of and including the Rocky Mountains.

Through the process of transpiration, trees release tremendous volumes of water vapor into the atmosphere at a quite steady and reliable rate. Therefore, if forests are grown just east of the Sierra Nevadas and the Wasatch Mountains, the warm, moist air rising from the forests would be driven eastward by the prevailing winds and against the Wasatch and Rocky Mountains respectively, lifted and cooled so that the mean annual precipitation would be increased in these areas. It is also probable that precipitation would increase somewhat in the areas between the forests and the western slopes of the mountains. Under such a planned program, forests could mean: a timber money crop; conditioning the soil, and increased rainfall in arid and semi-arid areas. In the above instance, the forests do not create the rainfall; the forests merely put more water vapor into the air which has previously been wrung dry by the mountain range over which the air had to travel. The mountains bring about condensation and precipitation and hence create the rainfall. This process is incontrovertible.

Growth of forests on what is now arid or semi-arid land raises another question. That is, what effect will afforestation have on climate generally, and on rainfall or precipitation in particular? It has been shown what will happen where the prevailing winds blow moisture laden air to higher elevations or against mountains. But, here the question refers to the influence of the forest within the forest area itself and on adjacent areas. In addition to the transpiration process, foliage, and vegetation in general, intercept precipitation which is in turn evaporated directly therefrom. The mere process of putting more water vapor into the air does not, in and of itself, assure that condensation and precipitation will follow; therefore, concern is now focused on the influence of forests on the condensation of water vapor.

The evidence relating to the effect of the forest on rainfall is both inadequate and contradictory; the entire topic being one of controversy for many years. Some people believe that it is much easier to say that forests grow in areas where sufficient precipitation occurs and be done with it. But just as plants modify the soil on which they grow, forests modify the atmosphere. The question is an important one and therefore deserves closer scrutiny. The spread of desert and semi-desert conditions has frequently been attributed to the destruction of the forests in the Middle East and around the Sahara. [155 p. 59]

It was shown earlier that the dropping of dry ice in "rainmaking" produced precipitation where otherwise it might not occur, and that this process works only when the clouds are near the temperature at which ice crystals form naturally. It may be that in some manner, now unknown, the presence of forests also triggers precipitation. "It has been claimed," says Champion, "on fairly satisfactory evidence that under certain conditions, the presence of forests may just tilt the balance causing the fall of a shower of rain which would otherwise not fall in that locality." [155 p. 60] At any rate, with the tremendous amounts of water vapor that would be in the atmosphere above the deserts as the result of afforestation, artificial nucleation would prove to be more fruitful.

According to Geiger [175], H. F. Blanford published an article, in the year 1875, wherein he believed that he had established an increase in precipitation as a result of a large reforestation project in the central part of southern India. Blanford's investigations covered several decades; one decade before the reforestation and one decade after the reforestation was complete. Zon, a strong proponent, says: "Forests increase both the abundance and frequency of local precipitation over the areas they occupy, the excess of precipitation as compared with that over adjoining unforested areas, amounting in some cases to more than 25 per cent. The influence of mountains upon precipitation is increased by the presence of forests." [176] Schubert showed, by calculating the probable errors, that precipitation was more closely correlated to reforestation than were any of the other accidentally effective factors. Geiger says the conclusion of Schubert's work, which appeared in 1937, was twofold: "1. Of the year's precipitation on the Letzlinger heath, 6% can be ascribed to the influence of reforestation, and 2. The influence of the forest in dry years is demonstrably greater than in the wet years." [175 p. 311] Geiger also cites the work of M. Gusinde and F. Lauscher in the Congo. In 1934, they found that the annual rainfall of 1,979 mm. in the clearings within the virgin forest exceeded by almost thirty-three per cent the average rainfall of 1,491 mm. found in the eight surrounding stations outside the huge forest region. Geiger concludes "although these values ought to be considered with great caution because of the short time of observation, observations speak more for an increase of rainfall by forest than against it." [175 p. 311]

Hursh and Connaughton [177] report on the findings of the Appalachian Forest Experiment Station, which had established weather stations in the Copper Basin in eastern Tennessee, where the smelter fumes had denuded approximately eleven square miles, and in the adjacent forested area. The total of two years' precipitation was recorded as ninety-five inches for the denuded area and 115 inches for the adjacent forested area. Very frequently such differences are attributable to the fact that the gages, in a more sheltered area, out of the wind, catch more rain. However, in this study, the same relationship, twenty-one per cent more precipitation, in the forest area than in the denuded area, was obtained during storms in which there was no wind.

None of the aforementioned studies referred specifically to the effect of afforestation in arid and semi-arid regions. From what is known, what are the possibilities?

It is known that the leaves and branches of trees intercept rainfall and that evaporation occurs directly therefrom. It is also known that, through the process of transpiration, trees give up tremendous quantities of water in the form of vapor, and that this is part of a heat exchange process. Trees, along with other green plants, extract carbon dioxide from the atmosphere and evolve oxygen into the atmosphere. Some of the foregoing processes will now be examined only from the viewpoint of their possible effect on the condensation of water droplets large enough to precipitate.

It will be recalled that the convectional or thunderstorm is the result of uneven heating. When the air over a locality becomes warmer than the surrounding air it ascends, expands, and cools as it rises. If it cools sufficiently with enough moisture present, precipitation occurs. The air over a forest must be cooler than the air over an adjacent barren area in arid or semi-arid regions, inasmuch as the conversion of water into water vapor absorbs part of the heat. In this fashion, a great amount of heat is rendered latent by evaporation; to be given up only upon condensation. If forests are grown in such a way as to provide for large open areas, then the vapor laden air, when blown over the hot air region, will be heated and forced to rise so that upon rising and cooling, condensation and precipitation may occur. This type of convectional storm would occur, during the afternoons, when the surface is most heated. In addition, the tree crowns, which have absorbed and accumulated large amounts of heat during the day, give up the heat and thereby cause evening vertical convection of humid air.

An unexpected result of using too much dry ice, during cloud seeding operations, is the actual prevention of precipitation. Too many ice nuclei are formed, and there is insufficient water in the cloud to build all of them into flakes large enough to fall. The winds transport many desert particles for thousands of miles, and in the deserts themselves, the cooler air rushes in to replace the warm desert air which has risen. In the process it picks up many desert particles, is in turn warmed and rises into the air bringing with it tremendous numbers of particles. Such an excess of particles may actually prevent precipitation. The introduction of a forest in the desert area will decrease the number of particles. "The amount of dust," says Landsberg, "decreases very rapidly toward the interior of a forest and an air current travelling over wooded regions is effectively filtered." [178] Furthermore, the introduction of water vapor into the area may actually help many of these particles fall out, so that the moisture laden rising air is able to contribute its subsequent condensation to the fewer and fewer particles that exist thereafter. As a result of the continuous condensation, the droplets within a cloud can grow comparatively large; large enough to precipitate and fall back to earth. Junge [179] says that over land the condensation nuclei consists of particles larger than about .0001 mm., and that the important role in the formation of rain is probably by particles greater than .005 mm.

During the last fifty years there has been an apparent increase in carbon dioxide. "Because of the role of CO_2 in the heat budget of our atmosphere," says Junge, "this increase should raise the average temperature of the atmosphere by a small, though measurable, amount. Such a phenomenon has actually been observed in various parts of the world; the problem of a CO_2 increase, therefore, is of basic importance for meteorology." [179 p. 45] Plass, a physicist at The Johns Hopkins University, estimates that six billion tons of carbon dioxide are added to the atmosphere each year and that, at this rate, the amount of atmospheric carbon dioxide will double by the year 2080. The increased carbon dioxide, not only warms up the climate, but also cuts down on the amount of radiation reflected from the tops of clouds. The percentage of radiant energy reflected from a surface is called the albedo. According to Landsberg [178 p. 90), the albedo of clouds is sixty to seventy per cent. By blocking the loss of heat from the tops of clouds, reasons Plass [180], the temperature differential between the tops and bottoms of clouds are reduced and thereby weakens the atmospheric convection currents that are responsible for rainfall. Conversely, Plass [180 p. 46] believes, a decrease in atmospheric carbon dioxide would lead to a wetter and cooler climate. The contention that carbon dioxide should be less at higher altitudes because of its high specific gravity is refuted by Landsberg. [178 p. 78]

The most important factor for the elimination of carbon dioxide from the atmosphere is the process of photosynthesis. [181] This idea is supported by Junge [179 p. 47] when he says that the biological processes on land, about ninety per cent of which is attributable to the forests and cultivated areas, dominantly influence the carbon dioxide cycle. From this he concludes that the CO_2 concentration in air would be immediately affected by any upset in the biological cycle. Because of its long cycle, Junge believes, the ocean can only exert a damping effect on the variations in the CO_2 concentration in air.

The most variable compound in the normal composition of the Earth's atmosphere is carbon dioxide which may vary from 0.023 per cent to 0.050 per cent. [178 p. 78] Quinn and Jones [181 p. 19] say that the exact concentrations of carbon dioxide in air over wooded areas, desert land, in the atmosphere near the north and south poles, over the seas, lakes, etc., becomes of great importance to those working in the field of photosynthesis.

Quinn and Jones cite the work of N. T. de Saussure in 1830. They say: "His most remarkable observation concerned the difference in concentration of carbon dioxide during day and night. His values obtained at night were somewhat higher than those obtained during the day." [181 p. 19] This conforms to the recent writing of Hutchinson [182], who shows that the fixation of carbon dioxide by photosynthesis occurs during the day and that through the process of soil respiration, as well as by organic decomposition, carbon dioxide is released at night. Junge [179 pp. 45-6] says that the excess consumption of CO_2 during the day and the excess production during the night give rise to a vertical CO_2 gradient dependent also on the vertical distribution of the eddy diffusion. It will be recalled that there could be no plant growth if the amount of carbon dioxide fixed by photosynthesis did not exceed the amount of carbon dioxide released.

The particles that act as condensation nuclei may consist of solid material, droplets, or a mixture of both, and they grow in radius with relative humidity. There are many trace gases and their precise role in precipitation, although they are found in rain and some of them act as condensation nuclei, is not known. For instance, nitrous oxide [N_2O] is produced upon the decomposition of nitrogen compounds by soil bacteria. The amount of nitrous oxide produced is increased when the soil has a high water content and there is therefore poor aeration of the soil. Junge [179 p. 59] believes it to be highly significant that the soil can play a dominant role in the budget of an atmospheric trace substance of such fairly high concentration. Recent rain-water analyses indicate a similar importance for soil relative to the NH_3 and SO_2 content in the atmosphere. It has been observed that rain water collected under trees shows a substantially higher concentration of trace substances than normal rain water, primarily at the onset of rain. [179 p. 73]

The growth of forests in arid and semi-arid areas could have profound effects. The additional water vapor in the air acts as a blanket, as does any other large body of water, so that the desert areas should become more temperate; less heat in the daytime and more warmth at night. As for more definitive answers on the actual extent of the influence of the forest on climate generally, and on precipitation specifically, additional research is required. Research that will maintain close observation and measurement of all the possible factors involved, before, during, and after a desert afforestation program has been completed.

Supplying water to the large municipalities has become an increasingly difficult and herculean task. "In fact," says Fleming, "the business of supplying potable water to a big city is so elaborate a process that the finished product might almost be said to be manufactured." [60 p. 7] The following table is adapted from information cited by Fleming:

Minneapolis, Minnesota

Source of Water: Mississippi River

Treatment and annual usage		Purpose
Alum	6,000,000 lbs.	To remove color and materials. that will not dissolve.
Lime	18,000,000 lbs.	To soften the water.
Carbon dioxide	2,500,000 lbs.	To keep it soft.
Chlorine	700,000 lbs.	To kill bacteria.
Ammonium sulphate	500,000 lbs.	To keep the water pure until it reaches the faucet.
Carbon	500,000 lbs.	To control taste and odor.

Minneapolis is not the exception, either. Practically all muncipalities subject their water supplies, either all or part, to various treatments. A more inclusive list of treatments used by fifty cities is given as follows: [68] Activated carbon; alum; ammonia; chlorine; caustic soda; copper sulphate; ferrous sulphate; fluoride; ion exchanger; lime; phosphate; soda ash, and sodium silicate. The American Water Works Association [183] lists ten chemicals for coagulation treatment; twelve for disinfection; nine for taste and odor treatment; four for softening; four for prophylaxis, and eight for scale and corrosion control. In discussing the content, in potable waters, of ingredients having physiological value, the American Water Works Association [183 p. 377] raises an important question as to whether or not potable water should continue to be appraised solely on the basis that deleterious substances or microorganisms are absent.

In a recent scientific meeting held in Chicago, H. W. Poston, of the U. S. Public Health Service referred to the constant pollution of our drinking water by hundreds of new chemical products whose effects on human health are totally unknown. Some of these new chemicals such as plastics, detergents, and insecticides, he said, cannot be completely removed from water now by standard methods. Said Poston: "We don't know how to remove viruses from treated water. We don't know the effect on the human system of the constant accumulation of small increments of present-day chemicals." [184] Chronic disease, inasmuch as acute diseases have been increasingly controlled, have been steadily growing in importance. This is especially true in a population in which the proportion of older persons is growing. According to a recent study by the Metropolitan Life Insurance Company: "In 1901 only 46 per cent of the deaths in the United States were due to chronic diseases; by 1955 the proportion had risen to 81 per cent. The chronic disease category consists largely of the major cardiovascular-renal diseases and cancer, which currently account for 54 per cent and 16 per cent, respectively, of all deaths." [185] Each member of the population is a potential victim of chronic disease, and it has been estimated that, in 1950, twenty-eight million Americans were suffering from disabling and nondisabling chronic disease or impairment. [186]

A recent survey [187] indicated that, of the noninstitutional population of Baltimore, nearly 1,600 chronic conditions per thousand population, or 1.6 conditions per person, were diagnosed. The survey revealed that chronic conditions are no respectors of age, sex, color, or family income.

There were 407 diseases per thousand children aged under fifteen; 29.2 per cent of these children have one or more chronic conditions and 17.4 per cent have one or more substantial chronic conditions. A substantial chronic condition interferes with or limits activities or requires care, or is likely to do either of these in the future. There were 1,205 diseases per thousand people aged from fifteen to thirty-four; 63.5 per cent with one or more chronic conditions and 31.0 per cent with one or more substantial chronic conditions.

In the age group from thirty-five to sixty-four, there were 2,199 chronic conditions per thousand; 85.8 per cent with one or more chronic conditions and 65.9 per cent with one or more substantial chronic conditions. There were 4,042 chronic diseases per thousand in the age group over sixty-five; 95.4 per cent with one or more chronic conditions and 85.2 per cent with one or more substantial chronic conditions.

Adjusting for age differences, there were 1,671 chronic diseases per thousand females whereas among males there were 1,499 per thousand. Of the females, 68.0 per cent had one or more chronic conditions and 47.5 per cent had one or more substantial chronic conditions. Among the males, 61.5 per cent had one or more chronic conditions and 41.0 per cent had one or more substantial chronic conditions.

Among the white population, the rate was 1,635 per thousand; while among the nonwhite population, the rate was 1,387 per thousand. Of the white population, 66.7 per cent were chronic and 43.8 per cent were substantially chronic; whereas of the nonwhite population, 60.3 per cent were chronic and 46.1 per cent were substantially chronic.

Looking at annual family income and also adjusting for age differences, reveals the following: under $2,000 per annum, 1,807 chronic conditions per thousand; from $2,000 to $3,999, 1,592 conditions per thousand; from $4,000 to $5,999, 1,519 per thousand, and with family income over $6,000 the rate of chronic diseases was 1,419 per thousand.

A joint statement of recommendations by the American Hospital Association, American Medical Association, American Public Health Association, and the American Public Welfare Association included the following: "The basic approach to chronic disease must be preventive. Otherwise the problems created by chronic diseases will grow larger with time, and the hope of any substantial decline in their incidence and severity will be postponed for many years."[188] The Commission on Chronic Illnesses decided early in its history that "prevention, in its narrowest sense, means averting the development of a pathological state; more broadly it includes also all the measures which halt progression of disease to disability or death." [186 p. 4] In a discussion on preventability in the Baltimore study, the following statement is made: "The possibility of primary prevention—the prevention of the occurrence of chronic disease—was not considered. However, an attempt was made to measure the amount of chronic disease which could have been prevented from progressing to the state of causing illness, disability, and death, or could have been slowed in progress." [187]

It was noted in an earlier chapter, that the health related aspects of water pollution did not begin to receive attention in the United States until late in the nineteenth century. Thereafter, the acute diseases associated with polluted waters came under control. The importance of water and its role in the human body cannot be underestimated. It is time to look at water with respect to the chronic diseases. The United States Public Health Service has established the maximum amounts of various chemical substances in water that is to be used for drinking. This refers, for instance, to lead, copper, zinc, sulphates, magnesium, chlorides, and iron. In addition, they have established standards for bacteriological quality and for physical quality.

The Los Angeles County Hospital, after a study of 390 normal hearts, has established the average amounts of thirteen trace metals contained in tissue of the normal heart. The amounts of these trace metals, contained in heart tissue, were then studied in cases of hypertension, diabetes, and certain heart ailments. This research revealed that certain trace metal patterns exist in particular ailments. Dr. Blakrishna Hegde, of the Medical School of the University of Southern California, believes, as the result of his studies, that important alterations in the amounts of certain metals in heart tissue may be responsible for the causation of particular heart diseases, and that the alterations from normals of the metal values in the blood might help in diagnosis and treatment of heart disease.

Metals, and other inorganic as well as organic elements and compounds, are taken into the human body through the foods and liquids consumed. Theoretically, under one hundred per cent efficiency, the human kidneys, through its several million glomerular tufts and tubes, checks every drop of tissue fluid many times a day to assure that the soluble inorganic chemicals in the human body are kept in perfect balance. Therefore, a trace too much of one chemical is eliminated as part of the urine; in the event there is too little, it is accumulated until the proper proportions are maintained. As was noted earlier, one hundred per cent efficiency in man or his machines is rarely achieved. Continued ingestion of excess metals and other chemicals, over long periods of time, may result in bringing about greater tolerance on the part of the kidneys so that a gradual accumulation may be permitted. Or the continued excesses might bring about over-activity on the part of the kidneys thereby resulting in gradual deprivation over a long period of time.

The body fluids are composed principally of water, certain inorganic electrolytes, and proteins. A few definitions may be in order.

An electrolyte is a substance which, when dissolved in water, produces a medium capable of acting as a conductor. In other words, it is a compound which, in solution, conducts an electric current. The current is carried by ions rather than by electrons as in metals. An ion, it will be recalled, is a dissociated atom. A negatively charged ion is an anion whereas a cation is a positively charged ion. The cations in the body fluids, that is the positively charged electrolytes, are Na^+, K^+, Ca^+, Mg^+, H^+, and NH_4^+. The anions, or negatively charged electrolytes, consist of Cl^-, HCO_3^-, protein, phosphates, sulfates, and organic and other acids. These cations and anions are in all body fluids in greater or lesser concentration, as well as in tissues, although all of them need not necessarily be present in some tissues.

Elkinton and Danowski say that analysis for electrolyte content should preferably be by analysis of serum or plasma rather than of whole blood since the composition of electrolytes inside of blood cells is quite different from that in plasma. [189] Winkler, Hoff, and Smith summarize the experimental cardiovascular effects of potassium, calcium, magnesium, and barium, by slowly increasing the concentration of each ion. They say: [190]

> Dogs and cats under morphine and local anesthesia were employed. The chlorides or sulphates of these elements were injected at a slow uniform rate until death. Serial electrocardiograms were taken during the course of injection, and arterial blood pressure was continuously recorded. At intervals during injection the concentration in the serum of the ion being injected was measured. From these values the concentration in the serum of the ion corresponding to each effect could be obtained by interpolation. The only exception to this procedure was made with respect to barium, for which no suitable method was available.

Elkinton and Danowski note that the concentration of certain electrolytes varies with age and sex. [189 pp. 119-120] Inasmuch as the electrolyte concentrations are measured in the blood serum, they present a series of charts for the average values for serum sodium, serum potassium, serum calcium, serum CO_2, serum chloride, serum inorganic phosphorous, and for other serum concentrations. The serum concentrations given are for healthy individuals in the following age groups: newborn infants; children from five up to twenty; young adults from twenty to thirty, and older people from seventy to ninety. Since it is desirable to relate one ion to another in terms of its charge, valence, or combining power, and inasmuch as the masses of individual electrolytes differ, the values are given in milliequivalents per liter. Serum electrolytes which contribute but little to the bulk of the anion-cation balance, or because of other complexities, are expressed in milligrams per cent. The following table gives the average values and standard deviations for a few of the serum concentrations drawn from the aforementioned charts: [189 pp. 120-8]

AVERAGE SERUM CONCENTRATIONS IN HEALTH
(Mean value and standard deviation)

AGE GROUP	SODIUM (mEq.)	POTASSIUM (mEq.)	CHLORIDE (mEq.)	CALCIUM (mg.)
Infants	143±3.3	5.9±1.4	104.9±4.7	9.8±0.7
Children	144±3.0	4.3±0.4	103.3±3.0	9.8±0.4
Young Adults	146±2.6	4.4±0.3		10.0±0.6
Males			100.2±2.4	
Females			102.3 ±2.9	
Old People	144±3.2	4.6±0.4	105.4±3.0	10.3±0.7

The most important environment for man is not the air he breathes but is the body fluids which permeate and surround all of his tissue cells. Water will enter or leave any of the body fluid compartments in response to osmotic pressure changes. Extracellular water carries nutrients that diffuse into the cells and removes the wastes of tissue metabolism, and every cell depends, for its function, upon the relative concentration of water. Elkinton and Danowski [189 pp. 133-4] point out that homeostatic mechanisms tend to keep body water and solutes constant in health. In the early phase of the development of an excess or deficit, however, the concentrations are maintained only through changes in the volume of fluid, whereas concentrations are sacrificed for the sake of volume in the later phases.

Weisberg [191] gives the electrolyte concentrations of the various body compartments in terms of the cations and anions present in the cells, the spaces between the cells, and in the vessels and ducts. The concentrations of electrolytes do not indicate the total amount of the solute present, unless the measurements of volume are also known. Weisberg [191 p. 29] indicates the average total body content and daily exchange of both water and electrolytes, and Elkinton and Danowski [189 pp. 478-87] give diagnoses of specific abnormalities with regard to fluid constituents such as sodium, chloride, potassium, phosphorus, magnesium, and bicarbonate. Changes in the electrolyte concentrations bring about changes in the volume of the body fluid, and, it appears that over a long period of time, the body mechanisms may sacrifice the controls of these concentrations in an effort to maintain the volume of body fluid. Therefore, it is entirely possible, that the ingestion of excess amounts of chemicals, which act as electrolytes in the body fluids, over a long period of time may gradually accumulate and result in chronic illnesses and eventual death.

Through surveys such as the Baltimore study in conjunction with controlled experimentation, the existence of any correlation between the chronic diseases, the amounts of trace metals in heart tissue, and the electrolyte concentrations in body fluids, on the one hand, with the type, quality, and treatment, if any, of water that is supplied in various areas of the country, on the other hand, may be quite revealing.

MAN'S CHALLENGE

It should be apparent that man, throughout many civilizations, has made many changes, but the greatest change wrought by man has been the change from the original forest and grassland to cultivated or barren areas. It is time that man began to realize the mistakes of former civilizations, and begin to think in terms of the longer run. In the short run, the changes are imperceptible, but they exist nonetheless. If we are to avoid becoming a "have-not" nation, we must begin to turn the tide while there is still time. If we are concerned with the greatest good for the greatest number, we should heed Admiral Moreell's comment that the greatest number have not yet been born.

This phrase, the greatest good for the greatest number, has been used TOO OFTEN, sometimes to cover-up inadequate or poor planning or just ill-conceived planning. For instance, in "Water Facts for Californians," published by the State of California Department of Water Resources in 1958, the director of the Department, Harvey O. Banks implies that the state water plan is for the greatest good when he ends his foreword with: "The history of this Nation has proved conclusively that an informed and enlightened public, when free to make a choice, will make decisions leading to the greatest benefit for the greatest number."

The curious thing is that even the reference to an informed and enlightened public was also mere lip service for several reasons. First, in that very same year the administration attempted to have the 1958 legislature start the job of constructing a first unit of the Feather River project on the bold assumption that doing this with money out of the state treasury would commit the people of the state to a tremendously vast expenditure which even today is not realized by many. In November of 1960 the people of the state of California will be asked to vote on a bond issue of one and three-quarter billion dollars for the beginning of the state water program, but how many know that when the program was first offered in 1957 it was estimated to cost \$11.4 billion, then in 1958 it was up to \$13 billion, and then during October, 1959 in testimony before the U. S. Senate Select Committee on National Water Resources the figure became \$14 billion. If one peruses previous large scale programs, one generally finds that original estimates frequently fall short of the mark by about three-fold so that in reality we are probably talking about a total program of from \$30 to \$45 billion. All these billions, but not one cent for an objective investigation of the "new" water supplies that are available at a small fraction of the cost.

Second: Dewey Anderson, Executive Director of the Public Affairs Institute, wrote a pamphlet called "Meeting California's Water Needs" which was published by that nonpartisan, nonprofit research organization in 1958. Anderson's twelve specific illustrations challenge the so-called California Water Plan as: too general; vague; extravagant; inadequate; an artist's conception instead of workable blueprints, and a plan that avoids one vital problem after another.

Third: during January 1960 Adolph J. Ackerman, consulting engineer of Madison, Wisconsin, who was a member of the board of seven engineers investigating the water plan, presented an analysis before the Commonwealth Club in San Francisco. He said: "this is the time to face up to unpalatable truths, and to separate truth from promotional assertions." Ackerman declared that financial feasibility or project justification studies, as conventionally presented, had not been made, and that no clearly engineered concept which might be considered valid and in the public interest had been demonstrated.

The references to the state of California do not imply that its public officials are less honest or less intelligent than the officials of other states. What it does do, however, is to clearly demonstrate that tremendous population growth coupled with inadequate water supplies to keep up with the growth can bring about thinking and action that is not rational. If other states don't wake up soon, they will find themselves in the same untenable position.

In the field of economics, a commodity is never actually short in the absolute sense. If a particular commodity should become short in supply relative to the effective demand for that commodity, the commodity is not entirely unavailable; it only becomes unavailable at the former price. The fact that the demand exceeds the supply brings higher prices, which in turn can mean several things. Either the scarce commodities are enjoyed only by those having the financial resources, or the state institutes complete control of the supplies of the commodity and rations its distribution, or the higher prices encourage the development of means that will produce additional quantities of the scarce goods and thereby bring about a relative decrease in price. There are no known substitutes for water. Water is an economic resource, and like other resources and commodities is subject to the laws of supply and demand. Such reasoning, however, does not solve the water problem. It is the overriding importance of water that differentiates it from other resources; shortages of water not only stunt the economic growth of an area but keep its people destitute and in dire need of the basic human requirements. How can there be real peace and progress in a world with millions upon millions who are unable to enjoy the most basic and elemental requirements for life and sustenance.

For instance, it was reported in 1957 that, over twenty-one thousand villages in France lack running water. [192] A recent letter describes the central Anatolian Plateau in Turkey with existing 40,000 villages, "almost half are not yet supplied with either drinking water or irrigation water." [193]

Here at home for instance, the Colorado Indian Reservation, near Parker, Arizona, has been hampered by water shortages. Plans, having an ultimate objective of making its inhabitants independent and self-supporting with vastly higher living standards than they now enjoy, must first overcome the obstacle of the need for more water. Both California and Arizona, however, deny that the Indians are entitled to any more Colorado River water than is now being used to irrigate some 37,000 acres now under cultivation. It has been estimated that another 100,000 acres could be irrigated, if the water supply were available. [194]

What is in store when water supplies run out is well illustrated by an accidental occurrence in Kodiak, Alaska. The City Manager had to declare Kodiak to be in a state of emergency. "Residents boiled contaminated water and industries shut down today while an engineer hunted for the life-blood of the community—the water supply." What had happened to empty their sixty-one million gallon water reservoir on Christmas Eve? They didn't know but believed that a fissure caused by an earthquake drained away the water and left a muddy hole in the floor of the empty reservoir.

In 1958, the Census Bureau raised its estimate of the nation's population in 1975 by ten to fifteen million persons. The new estimates released by the Census Bureau on November 9, 1958 place the total for 1975 at between 215,800,000 and 243,900,000 depending on future trends in births, deaths, and immigration. At a symposium held in Oklahoma City during June of 1957, Vannever Bush warned of the threat of water shortage and urged that scientific groups find ways to assure an adequate supply. New water is one of the answers, and it is available, within reasonable limitations, wherever igneous rocks exist.

Complete state control of water and its distribution may seem like something in the public interest, however, how can assurances be given that such control might not be used only to assure such continued and complete control and to prevent the use of other possible alternatives. For instance, the State of California bulletin, "Water Facts for Californians," states that to satisfy the water needs of the state "requires the control and conservation of the state's water resources when and where they occur, and distribution of the conserved water to areas where it is needed at the time it is needed." But who makes the determinations as to need and the confiscatory action which would follow? How can people who have shown their closed minds be trusted with such life and death control? A UPI release, dateline Tokyo, January 9, 1960 says that the United Nations will shortly make recommendations to member nations to restrict the over-pumping of subterranean water. But are they aware of primary water and what it would mean for the world?

It is about time that new water was given an impartial, objective look-at. Nordenskiold's demonstrations have been ignored. Yet today we have need of the same kind of work he did. Anacapa Island, one of the channel islands off the California coast, has an important lighthouse high on its rocky shore. Friends Magazine says: "So rugged are the cliffs that boats bringing Coast Guard personnel and provisions (the island has no water) must be hoisted by crane from the sea to the platforms built on the rocks. In rough weather, landing is impossible." [195]

The unusually dry summer of 1959 saw water rationing at Hahn Air Force Base in the Moselle River area of Germany. Our Army Engineers found, at a distance of about 9,000 feet from the base, an old mine with its galleries filled with approximately 2,500,000 gallons of water and having its water level in the shaft only sixty-seven feet below ground. The emergency project was to draw the water from the mine and pump it to the base. [196] But no one seemed to consider how all this water managed to get into the mine during such an unusually dry summer.

Many federal agencies in the United States have varied interests in water, for instance: flood damage abatement; improvement to navigation; irrigation; drainage; water supply; pollution control; recreation; fish and wildlife; conservation; power generation; power transmission and distribution, and watershed treatment. This is to be expected. But when we think in terms of water supply, the myriad agencies that have activities in this area can only spell out disaster. There is no clear policy or program to assure the people of the United States of an economic solution to our water supply problems. The following federal agencies have activities in the field of water supply: Corps of Engineers; Bureau of Reclamation; Bureau of Indian Affairs; Bureau of Land Management; Geological Survey; Forest Service; Soil Conservation Service; Farmers Home Administration; Weather Bureau; Public Health Service; Tennessee Valley Authority; International Boundary and Water Commission, United States and Mexico, and the International Joint Commission, United States and Canada. [197] This, of course, is in addition to the states, the cities, and the water districts.

It is entirely possible that a scientist's complete work has been disregarded because a single aspect of his work was found to be unacceptable. If different parts are so mutually connected and dependent on each other then certainly all parts must either stand or fall together. But frequently the parts are wholly independent, and under such circumstances it is nonsensical that they fall together. For instance, Nordenskiold's reasoning that fissures exist due to small but periodic variations of temperature doesn't seem to have been accepted for it doesn't appear in any of the current volumes on structural geology. Yet this reasoning is certainly independent of his ability to find fresh water in the rock fissures. It seems that scientists should adopt what constitutional lawyers have learned to use in the event of partial invalidity, such as: "That if any section or theory shall be held to be invalid this shall not affect the validity of other sections or theories hereof."

As a patient investigator it is apparent that all the facts are not in and that they will never be in, as one travels a spiral in coming closer and closer to specific objectives one constantly finds that new doors keep opening new spiral pathways which in turn develop still new avenues to follow. As we gain additional knowledge some of our older beliefs get washed away, witness the number of Nobel prizes that have been awarded for new theories which have upset the older and long standing ones.

The reader will recall our earlier discussion about trying to fit irregular events into accepted theory. At the city of Medicine Hat, Canada, underground water estimated to easily produce ten million gallons daily was found running on the same approximate course as the South Saskatchewan River. The South Saskatchewan River and other ground water sources in the area average 1,500 to 2,000 chemical parts per million parts of water. The amazing thing is that despite the fact that the new underground water supply is of an extremely high degree of purity, only two hundred chemical parts per million parts of water, they attribute as its permanent recharge source the South Saskatchewan River with its 1,500 to 2,000 parts per million. [198] If this were only remotely possible, our dreams of an economic sea water conversion system would have been fulfilled.

One of our foremost investigators in the earth sciences, Wilhelm Eitel, voices his experience regarding the ever increasing trend toward specialization as follows: "The student will thus learn that

although specialization in the progress of research is a good thing, a broader knowledge of many disciplines will prove to be not only better but even indispensable for scientific achievement. The common efforts of chemists, physicists, metallurgists, mineralogists, and crystallographers in the investigation of structural conversions is one of the best illustrations of this experience." [98]
We should remember Geikie's statement: [1]

> From the beginning of its career, geology has owed its foundation and its advance to no select and privileged class of experts. It has been open to all who care to undergo the trial which its successful prosecution demands. And what it has been in the past, it remains today. No branch of natural knowledge lies more invitingly open to every student who, loving the fresh face of Nature, is willing to train his faculty of observation in the field, and to discipline his mind by the patient correlation of facts and the fearless dissection of theories.

With proper management, this earth can abundantly supply its inhabitants with all they require. But this is not the route we travel; to change our course requires meaningful education and understanding. "History is," as H. G. Wells describes it, "a race between education and catastrophe." What is your choice?

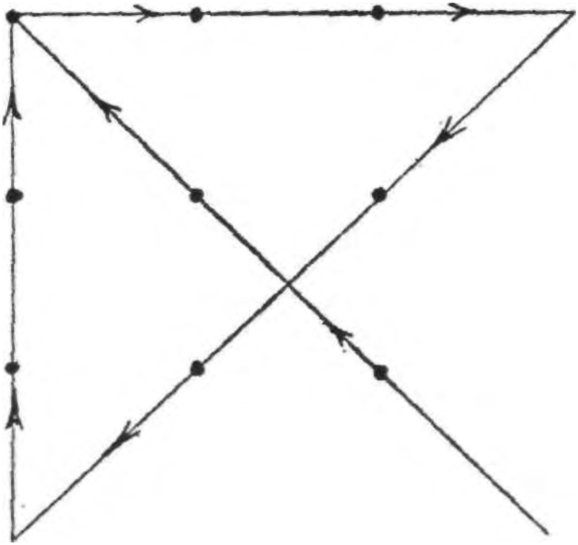
ANSWERS TO PROBLEMS

PREGNANT GIRL STORY

The immediate responses, of most people, will disclose that they use the word "he" or "his," or some other word that denotes masculinity, in referring to the doctor. The story meticulously avoided all references other than "doctor." The simple answer, in this story, is that the doctor is a woman and the pregnant girl had pointed out the doctor's husband. In our society, where most medical doctors are males, this is a natural assumption but not always true. In Soviet Russia, where currently most medical practitioners are females, the assumptions may be different.

NINE DOT PROBLEM

Answer:



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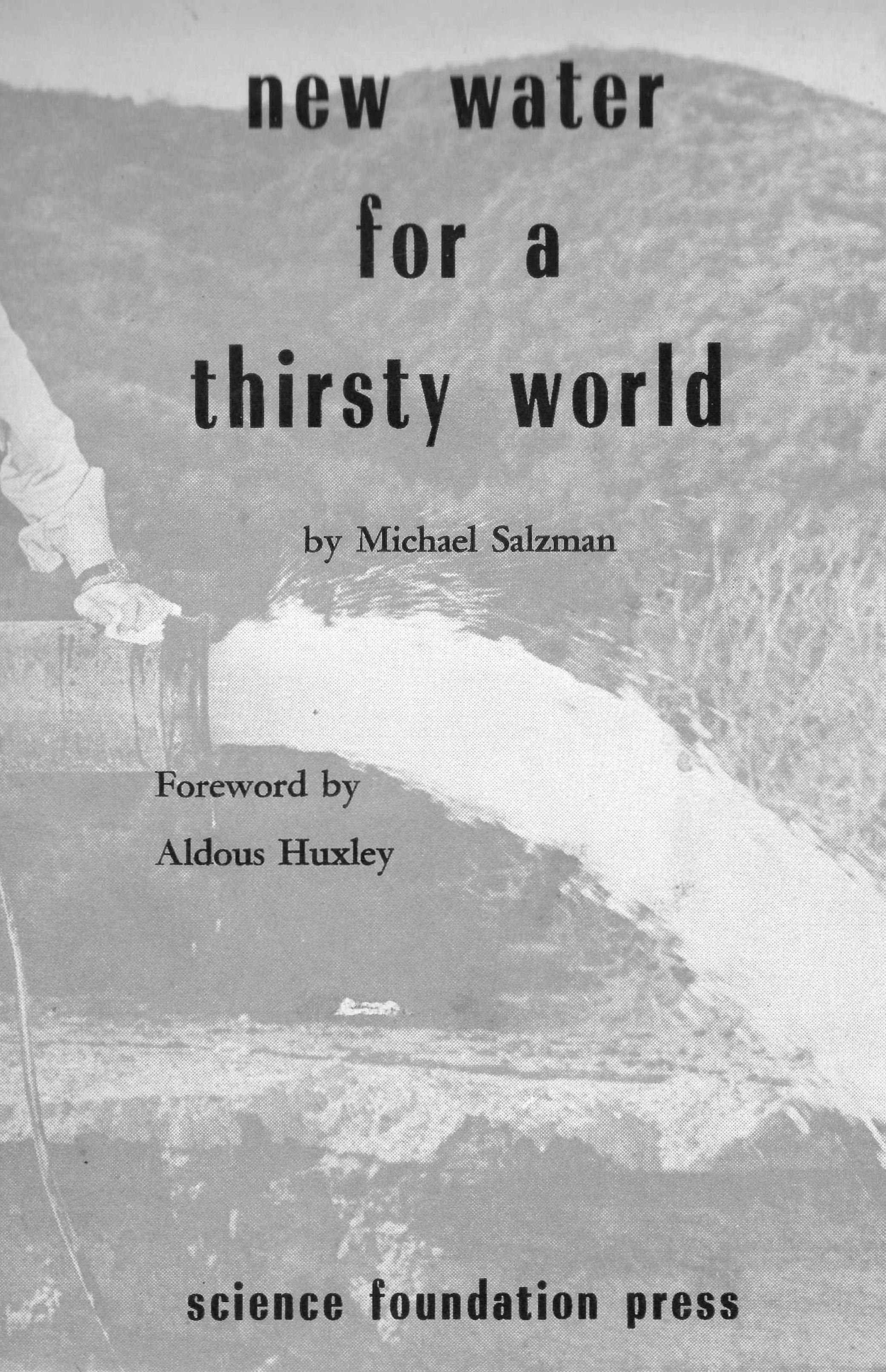

new water for a thirsty world

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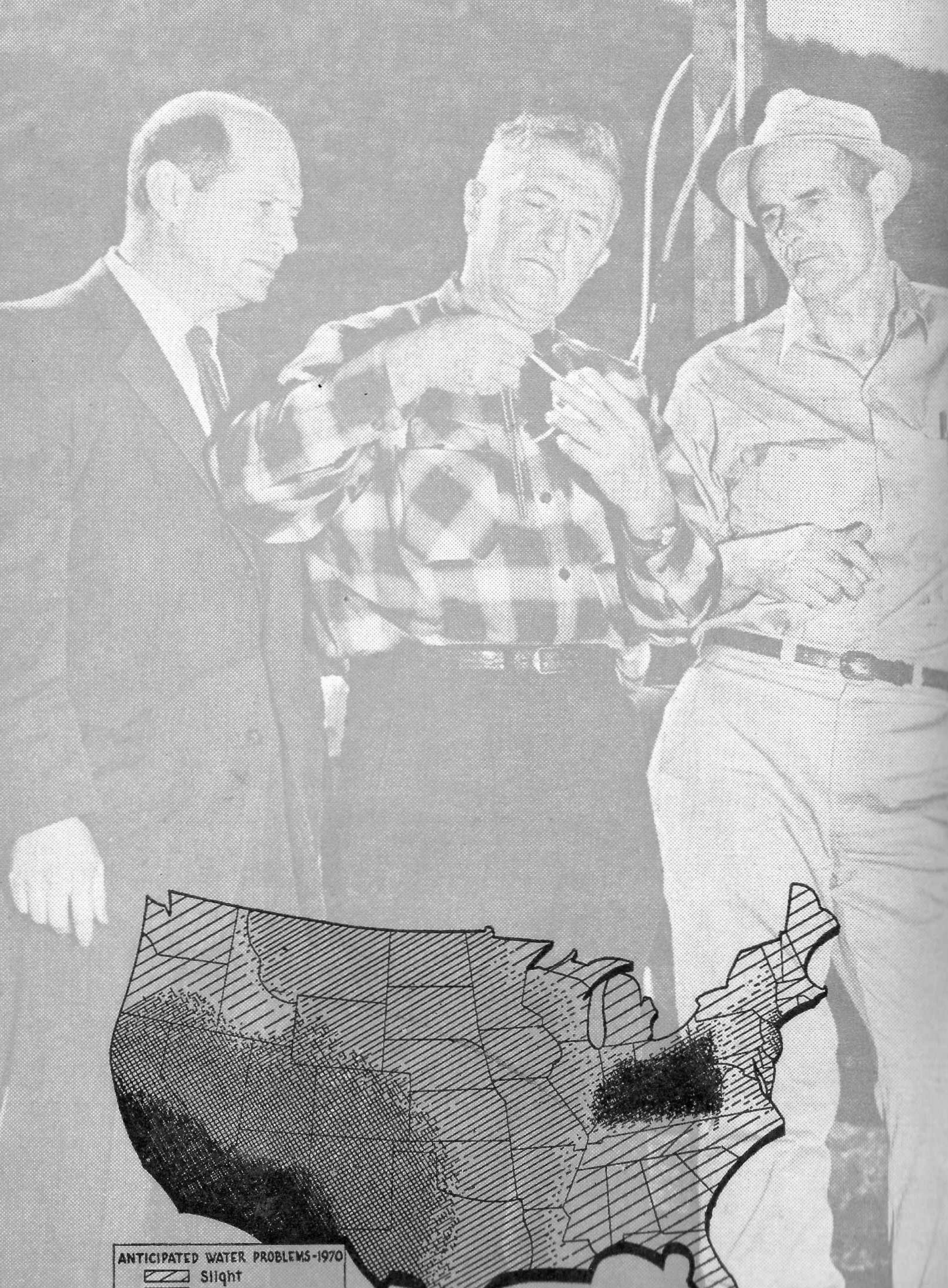

WATER SUPPLY — 1970

Intensities of water shortage areas, 1970, as compiled by Population Reference Bureau, Washington, D.C. for the national health forum held in Philadelphia, March