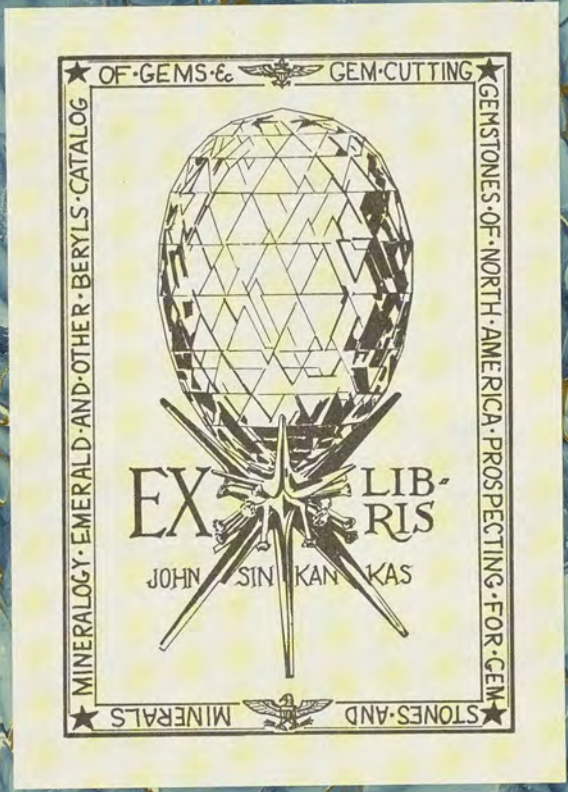

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The title to this vol. belongs in the
1st, and vice versa.

THE
MINERAL KINGDOM

BY

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WITH 91 PLATES (73 OF WHICH ARE COLOURED)
AND 275 TEXT-FIGURES

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The Precious Stones and related Minerals.*)

Precious Stones. The minerals included under this term are distinguished from others by the possession of certain special characters. They have a high degree of hardness, exceeding that of most other substances, which protects them from injury. They should be transparent and colourless or beautifully coloured; if cloudy or opaque, they should have a bright colour, as in turquoise, or some special optical effects, as in precious opal, cat's-eye and star-sapphire. Further, they must not be of widely distributed occurrence or found in very large masses. Minerals in which these characters are very prominent are the most valuable, as for example, diamond and ruby; while others in which they are less marked are of correspondingly smaller value, as in quartz and the other so-called semi-precious stones. No sharp line can, however, be drawn between precious stones and semi-precious stones, or between these and other minerals.

From the point of view of the practical jeweller, all minerals which are cut and polished for personal wear or for purposes of decoration may be regarded as precious stones; but the application of the term depends largely on the prevailing fashions; for instance, in recent years many cloudy and opaque stones, if of good colour, have been much worn. To the mineralogist, on the other hand, these special characters are of only secondary consideration, those of primary importance being the essential characters, such as chemical composition, crystalline form and physical properties, which serve to define the mineral species. The colour, on which the value of precious stones largely depends, is, as a rule, quite an accidental character of minerals, and different specimens of the same mineral species may be of very different colours. For instance, the mineral corundum when clear and of a rich red colour is more valued as a gem than diamond, while when grey and opaque it is if no value whatever as a precious stone. While the differently coloured varieties of corundum are regarded by the jeweller as separate gem-stones, each with its distinctive name, to the mineralogist they are identical, since they possess the same essential characters.

In this section we shall therefore describe those species of minerals of which certain specimens are suitable for use as gem-stones, describing at the same time also those varieties which are unsuitable for this purpose. We shall further, as a matter of convenience, include certain other minerals which are closely related to these. For instance, the description of diamond will be followed by that of graphite, since both of these minerals consist of the chemical element carbon; to that of beryl (including emerald) we shall append those of other minerals which contain beryllium. With the description of the numerous gem-varieties of the semi-precious stone quartz, we shall include an account of the other varieties, and so pass on to the next section dealing with rock-forming minerals, in which quartz might more properly be included. The minerals which we have thus more or less arbitrarily grouped together in this section will be described mainly from the mineralogical point of view as species, but mention will be made of their application as precious stones and of many of the points of interest in this connection.

Forms of cutting. In their natural form as crystals or as water-worn pebbles, precious stones do not display to advantage those characters on which their application

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*) Together with other works, use has been made of Professor Max Bauer's "Edelsteinkunde" (Leipzig, 1896), translated into English by L. J. Spencer, "Precious Stones" (London, 1904).

as gems depends; nor are they in a form suitable for wearing as personal ornaments. In order to bring out these characters, it is necessary to cut the stones into special shapes, and during this process a large proportion of the valuable material is sacrificed.

The actual form of cutting adopted must bear some relation to the optical characters of the stone, as well as to the natural form, such as the relative thickness and width, of the fragments. As a rule also, different forms are adopted for colourless and for coloured stones.

A colourless stone must be so cut that it displays to the full its strong refractive power and the prismatic play of colours; the form of cutting most suited for this purpose is the *brilliant* (figs. 158, a—c). The ground-form of the brilliant may be regarded as an octahedron with its upper corner cut off by a large facet, and its lower corner replaced by a small facet; the large facet is known as the table (fig. 158b), and the small facet as the culet (fig. 158c). Between the girdle, or margin, of the stone and each of these facets a number of other small facets are symmetrically arranged. A brilliant is mounted in an open, or claw, setting, also known as *à jour* setting, with the large table facet to the outside and the small culet below. Rays of light falling on the front of the brilliant are able to enter the stone, but they are unable to pass out at the back; they are totally reflected (p. 58) by the facets at the back, and thrown out again from the front, thus giving a brilliant reflection like that from polished silver.

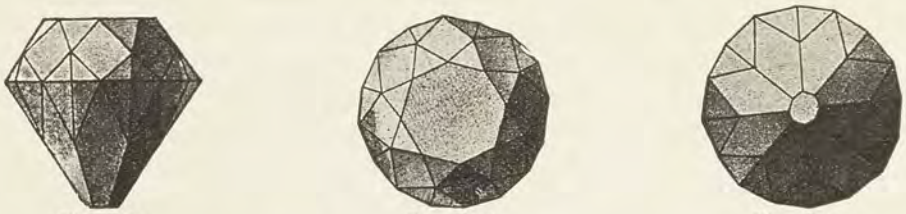
Fig. 158 a. Fig. 158 b. Fig. 158 c.

Brilliant form of cutting. a) viewed from the side, b) from above, c) from below. (After M. Bauer.)

With brilliants of the same size and form, but of different minerals, the amount of light so reflected back by the stone will depend on the index of refraction of the material; the higher this index, the more the light will be reflected, and the brighter and more lustrous will be the stone. The refractive index of air being unity, the values for some other substances are: water 1·33, quartz 1·55, topaz 1·62, corundum 1·76, zircon 1·97, and diamond 2·41. In quartz, all the rays of light which strike the surface at a less angle than 40° 10′ with the normal to the surface are able to pass out of the stone into air; but in diamond, with its much higher index of refraction, this angle is reduced to 24° 30′, so that much less light is able to pass out into air and more is totally reflected. A brilliant cut in quartz therefore shows but a poor reflection, as compared with the blaze of light from a diamond cut in the same form.

In addition to this reflection of light by the brilliant, there is also a splitting up of white light into it coloured components. The facets at the edges, through which the light enters and emerges, act as prisms, and prismatic colours are produced. Here again, diamond, owing to its very high dispersive power, surpasses all other colourless gems; the brilliant flashes of prismatic colours, red, green, blue, etc., often referred to as the "fire" of a stone, being especially characteristic of diamond.

For a brilliant to display these qualities to the best advantage, the facets must be inclined at certain angles, or, in other words, there must be a definite relation between the height and the breadth of the cut stone. In diamond, the height of the portion above the girdle must be one-third, and that of the portion below two-thirds, of the total height of the stone; and the diameter of the table facet must be five-ninths, and of the culet one-ninth, of the diameter of the girdle. In other colourless stones (e. g. topaz) these proportions will be different; and frequently the form of cutting may be quite different, the upper portion only being cut in the brilliant form while the lower portion may be given the star-cut. Since diamond is most frequently cut in the brilliant form, it is often customary to speak of diamonds so cut simply as brilliants; and conversely by the term brilliant a diamond is often understood. This may lead to some confusion, if, for instance, a colourless topaz cut in the brilliant form is sold as a brilliant. It must not be forgotten by a purchaser that the term can strictly be applied only to the form of cutting and not to the mineral.


Fig. 159 a. Fig. 159 b.
Rosette. a) viewed from the side, b) from above.

The *rosette* or *rose-cut* (fig. 159 a and b) is another form of cutting frequently adopted for the diamond, especially for flatter pieces of rough material, the cutting of which in the brilliant form would involve a considerable loss of material. Other colourless stones are also, but less frequently, cut in this form. Here there is a broad, flat face beneath, from which rises a low pyramid bounded by a number of small facets. The brilliancy and play of colours displayed by a diamond cut in this form are much less than with the brilliant form, and the value is correspondingly less. The brilliancy may be increased by placing a silver foil beneath the large flat face and hidden in the setting.

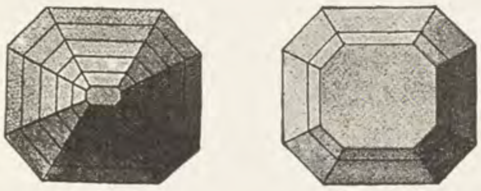
Fig. 160 a. Fig. 160 b.
Step-cut. a) viewed from below, b) from above.

Coloured stones are cut in a form which will display the colour to the best advantage, the most usual being the *step-cut* or trap-cut (fig. 160 a and b). Or there may be a mixed form of cutting, the upper portion of the stone being given the brilliant-cut and the lower portion the step-cut or the star-cut. For stones possessing a deep colour the form is made flatter than when the colour is paler. Those stones which differ in their colour or in the intensity of the colour in different directions, that is dichroic stones, must be cut in a certain direction if they are to show to the best advantage.

Opaque and translucent stones, the beauty of which depends solely on the colour or play of colours, are cut *en cabochon*, that is, with a rounded convex surface. This is the earliest form of cutting, having been used by the ancients for coloured stones, while at the present day it is adopted for turquoise, precious opal, star-sapphire, cat's-eye, etc.

Some precious and semi-precious stones, especially those with a uniform internal structure or with differently coloured bands are employed for engraving as *gems*. Two kinds of gems are to be distinguished; when the engraved figure is in relief we have the *cameo*, and when it is sunk below the surface the gem is called an *intaglio*.

The **process of cutting** and polishing precious stones varies somewhat according to the character and value of the material.

In the case of the valuable and extremely hard diamond no more material is removed than is quite necessary for the production of a finished stone, which should be as large as the rough material will allow, and at the same time free from flaws. The superfluous material is not removed by the usual process of grinding, since this would be an extremely lengthy operation, and furthermore this material would be lost. Advantage is taken of the perfect cleavage parallel to the octahedral faces of diamond, rough stones of unsuitable shape for cutting being first reduced to approximately the required form by cleaving. The larger facets of the brilliant form are then roughly shaped by the operation known as bruting or greying, which consists in vigorously rubbing two diamonds together, the stones being fixed to the ends of short sticks, or handles, with a hard cement or an easily fusible alloy. The facets are finished by grinding, as with other precious stones, but here the abrasive material must be the diamond powder itself.

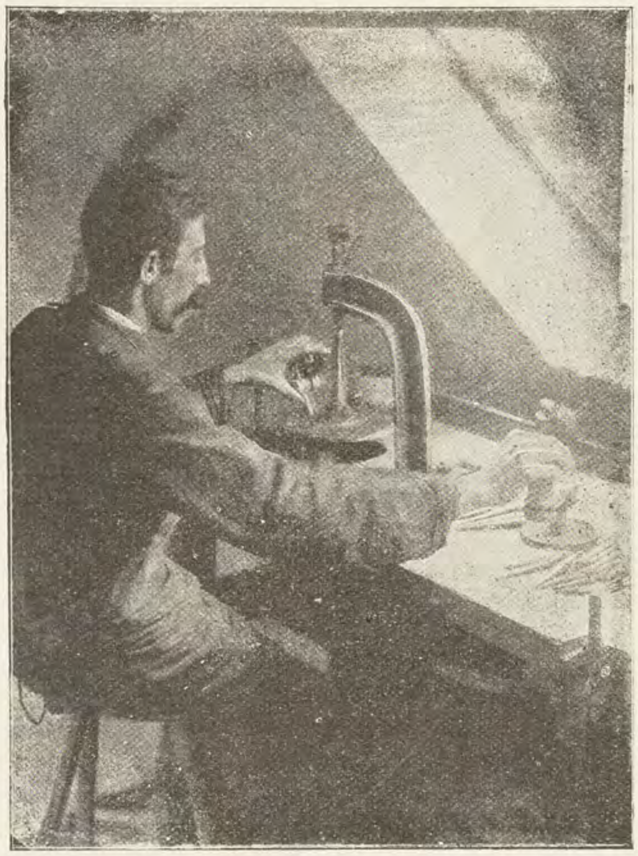

Fig. 161.
Gem-cutter at work.

The other precious stones, if in fragments of unsuitable shape, must be broken, or cut with the slitting disc — a thin disc of soft iron charged on its edge with diamond powder. For grinding, the stone is cemented to the end of a short holder or "dop", which is held in a clamp and pressed against the grinding disc. This is made of hard bronze or steel, and the grinding material consists of diamond powder in olive-oil for the harder stones, or corundum (emery) for the softer. In recent years the abrasive material almost exclusively used for all stones except diamond is carborundum, which is a compound of silicon and carbon produced artificially in the electric furnace.

In the accompanying illustration (fig. 161) the gem-cutter with his left hand presses the stone on the revolving disc, while with his right hand be regulates the speed of the disc, which is driven by water, electrical, or other power. On the table to the right are several of the short sticks to the ends of which the stones are cemented. In the operation of diamond grinding, the clamps are weighted with masses of lead, and several are placed on the disc at the same time, the grinding here proceeding much more slowly and the worker has time to attend to more than one stone. When one facet has been ground down to its proper shape, the stone has to be loosened from the cement and cemented again in another position. And when all the facets have been shaped by grinding with carborundum, they have then to be polished. This is done on discs of bronze or wooden cylinders with tripolite, putty powder or caput mortuum. A wooden cylinder used for polishing is to be seen on the left in fig. 162.

Larger stones such as agate and chalcedony are not cut in this manner, since the worker cannot press the stone against the disc with sufficient force and the disc will not withstand the pressure. These stones are ground against the edge of grindstones made of hard sandstone, which rotate on a horizontal axis and are kept moistened with water (fig. 162). The workman lies in a hollow bench, called a cuirass, and, having his feet against a bar fixed to the floor, he is able to press the agate firmly against the revolving grindstone. A special abrasive material is not employed, the grinding action of the grindstone being alone sufficient. For producing rounded surfaces the edge of the grindstone is grooved. After being roughly ground in this manner, the agates are polished on the wooden cylinders.

Such an agate-grinding workshop is shown in fig. 162. The hollowed out form of the cuirass is to be seen at the fifth place, which is vacant. The man on the left trims the stones with a hammer preparatory to grinding, and the boy before the wooden cylinder gives them their final polish. The man by the window in the background is cutting slices of chalcedony with a slitting disc charged with diamond powder.

Fig. 162.
Agate grinding at Oberstein, Germany.

Although the position of the worker appears to be inconvenient, recent attempts to introduce improvements with a sitting posture have not met with success; in the reclining position the worker is able to exert a greater pressure and is better able to watch the progress of his work.

The operation of boring spheres of agate to be worn as beads is still performed by the same primitive method that has been in use since early times. A steel point charged with diamond powder and held in a wooden cylinder is pressed by a lever against the sphere, and is caused to rotate by a to and fro movement of a bow with a string passing round the cylinder. With such a simple contrivance (fig. 163) the agate borer is able to perform his work at home. Much the same kind of apparatus was figured 130 years ago by Collini in his Diary of Travels, in which are recorded a variety of mineralogical observations, especially relating to agate and its working. And a figure given by Furtwängler in "Die antiken Gemmen" (vol. III, p. 399) suggests that a very similar form of apparatus was used by the ancient gem-cutters.

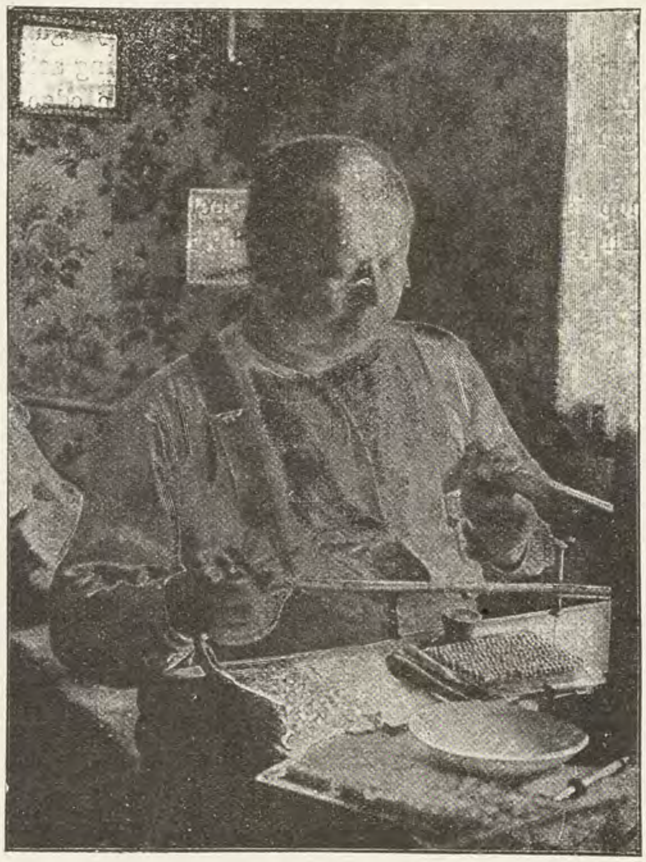
Fig. 163.
Agate borer.

The engraving of gems, seals and initials is an art requiring a considerable amount of skill. At the present time it is performed with small steel discs of various sizes, which are charged with diamond powder and oil and made to rotate rapidly about a horizontal axis (fig. 164).

The **unit of weight** adopted for precious stones has long been the *carat*. This is unfortunately not a fixed and definite unit of weight, but varies at the different centres of exchange. The average value of a carat is 205 milligrams, but different carats vary by as much as 18 milligrams. It would be an advantage if the value of a carat were universally accepted as 200 milligrams, that is one-fifth of a gram. Another curious usage in connection with this unit of weight is that the fractions are one-eighth, one-sixteenth, etc.

The **determination** of precious stones and the distinguishing of one kind of stone from another is in certain cases a matter of some difficulty, for in a faceted stone the external crystalline form has been obliterated and chemical tests involving the destruction of the material are not permissible. Colour, lustre and hardness afford some guide; to the lapidary an indication of the hardness of a stone is given by the time required to grind the facets. The specific gravity (p. 53), which may be determined by means of the Westphal's balance or with heavy liquids, will usually give a clue as to the identity of a doubtful stone, and this may be confirmed by an optical examination with the dichroscope (p. 62) and polariscope (p. 60). The determination of the refractive indices of the stone is also of great assistance, and this method has the advantage that the stone need not be taken out of its mount. Jewellers with a long experience are usually able to identify a stone at sight, but the only safe method in case of any doubt is to determine quantitatively some of the physical constants.

Counterfeiting of precious stones. Precious stones are natural products, and when we purchase one we take it for granted that the stone is a natural mineral. Artificial products do not possess the same charm, nor are they of equal value. The same is the case with wine; an artificial wine may closely approach a natural wine in composition and flavour, but it would be rejected by an expert. Up to the present time, only few precious stones have been made artificially in the laboratory of the requisite size and quality to pass as gems. The largest amount of success has been met with in the manufacture of ruby. These stones possess the same chemical composition, crystalline structure and physical characters as the natural ruby, and in their external appearance they are also identical; their only difference is that of origin. The artificial stones can, however, be recognized under the microscope, for they contain small, round air bubbles which are not present in the natural stones. Further, they are often more brittle, and their value is much less. Diamond has also been prepared artificially, but the crystals obtained are not sufficiently large and clear to be of use as gems.


Fig. 164.
Stone engraver.

Deception is practised by making only the upper portion of a faceted gem of a genuine precious stone, the lower portion, beneath the setting, being of glass of the same colour as the stone, and the two portions are neatly cemented together to form what is known as a *doublet*. Sometimes both the upper and lower portions, which are cemented together, consist of genuine stones, and by this means a larger and apparently more valuable stone is formed out of two smaller ones.

Glass imitations are the crudest and at the same time the earliest employed substitutes for precious stones. The glass used for this purpose is known as paste or strass; it is a highly refractive glass containing lead, and is suitably coloured by the addition of various metallic oxides. These imitations are sometimes very deceptive, but they can always be detected by their softness. When worn in jewellery their edges soon become rubbed and chipped, and they can readily be scratched with a knife. Glass being a much worse conductor of heat than crystallized gem-stones, these imitations feel warmer to the hand than genuine stones: for the same reason, moisture from the breath will remain on a glass imitation for a longer time than on a precious stone. The amorphous opal behaves in this respect like glass, while amber feels warmer than glass.

The artificial colouring of precious stones can in certain cases be performed with advantage. For example, yellow topaz when heated acquires a beautiful rose-red colour, and is then sold as rose-topaz or as burnt topaz. The common practice of colouring agates by artificial means is not done for purposes of deception, except, for instance, when a green coloured chalcedony is passed off as chrysoprase or jadeite. The coating of a yellowish diamond with a thin film of violet colouring matter, thereby giving the stone a white appearance, is a deception of the worst kind. Sometimes a stone when decolourized may be passed off as a stone of greater value, for instance when tiger-eye is sold as cat's-eye.

The **terminology** used by jewellers for precious stones is not only confusing, but also gives many opportunities for deception. Since the colour of gems is of prime importance, different minerals if of the same colour are often known by the same name, and these may be of widely different value. Thus the most valuable of gem-stones is the ruby, a red variety of the mineral corundum, but many of the stones sold as ruby are not true ruby, but red spinel, garnet, topaz or tourmaline. Although these red stones are distinguished from one another by certain prefixes, there still remains a confusion in terms: thus to the jeweller the true ruby is known as "oriental ruby", red spinel as "balas ruby", red garnet as "Cape ruby". Or again, yellow transparent stones may be known as topaz, but the "oriental topaz" is yellow corundum, whilst" occidental topaz" or "Spanish topaz" is quartz. It would be an advantage if the dealers in gems could be prevailed upon to use only mineralogical names for the stones, and these are now being adopted more and more by the larger firms; but the fault lies largely with the public, who would buy a stone under the name of ruby rather than one called spinel.

Historical.*) Like the precious metals, the precious stones have been highly prized since the earliest times. Originally they attracted attention by reason of their colour and lustre, and they were no doubt worn in the condition in which they were found. But even in very early times such stones were ground down into forms suited for specific purposes. They were worn as amulets, and a figure of some deity engraved on them in order to increase their charm: stones so cut were used as seals.

Even at the time of the ancient Babylonians, 4000 B. C., the glyptic art of engraving hard stones had reached a high state of development. The most ancient gems have the form of a pierced cylinder, and, being used for seals, their surface is deeply engraved with figures. Fig. 1 of plate 40a represents the impression made by rolling one of these Babylonian *cylinder-seals* on a plastic surface: as a rule, the figure is repeated twice around each cylinder. The material of which they are usually made is blood-stone; but other stones were also engraved, such as marble, lapis-lazuli, jasper, porphyry, serpentine and rock-crystal, and in later times also amethyst, chalcedony, sard and carnelian. The gems of the earlier period were engraved by hand, as shown by the angularity of the cuts; but those of the later period were engraved with a wheel, the cuts here being more rounded and all the lines have a round ending. The engraving wheel was caused to rotate by a string and bow held in the hand, and it is possible that later the treadle was used. The simple string and bow is used even to the present day for boring precious stones, though no longer for cutting (p. 199).

The art of engraving stones passed from the Babylonians to the ancient Egyptians, whose earliest gems likewise have the cylindrical form. This was soon replaced by the *scarab*, an oval-shaped gem with the form of the sacred beetle (fig. 3, plate 40a), which was later adopted by the Greeks and the ancient Etruscans. The figure of the beetle came to be omitted, though the general shape remained, and the name scarab was retained for oval gems on which various subjects were engraved. Most of the Egyptian scarabs were cut in a soft, blue or bluish-green material resembling faience, which is usually known as Egyptian porcelain; some in a dark blue, transparent glass; whilst seals in the harder precious stones are rare. In recent years many forgeries of the beetle-shaped scarabs have been made.

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*) Much of the matter here given has been taken from Adolf Furtwängler's work in three volumes on "Die antiken Gemmen", a work which from the excellence of its text and illustrations may be strongly recommended to gem-cutters.

PLATE 40a.

Antique Gems.

Fig.

1. **Babylonian Cylinder-seal,** represented on the flat. The original is engraved on a banded red and white jasper. A hero (Isdubar) in combat with a lion. The man clasps with one arm the body of the beast and presses his knee into its back; with the other arm he clasps its neck. The lion is worsted; its mouth gapes open, and its fore paws vainly beat the air. Isdubar is clothed with a scarf about the loins; his face is framed by six rolled locks and a long beard. The specimen is a masterpiece of ancient Babylonian glyptic art. It dates from the beginning of the fourth thousand before Christ, and belongs to the period of the Kings of Agadi and Erech.

   (After Furtwängler, 'Die antiken Gemmen', Plate I, fig. 1, vol. ii, p. 1.)

2. **Mycenian Gem,** a pierced fragment of blood-stone. A man wearing an apron holds up a large fish on an angling-line.

   (After Furtwängler, Plate II, fig. 49.)

3. **Scarab,** cut in beryl. The sacred bettle (*Ateuchus sacer*) of the ancient Egyptians was symbolical of the creation of the world, for life comes forth from the pellets of dung which the insect rolls around its eggs.

   (After Imhoff-Blumer and Otto Keller, 'Representations of Plants and Animals on Coins and Gems of Ancient Classical Times', Plate XXIII, fig. 16.)

4. **Ptolemaic Cameo,** in Vienna. Two-thirds actual size. Cut in a sardonyx of nine layers. Helmeted head of a youth and a female head. This famous example of Grecian glyptic art is unique amongst cameos in the boldness and freedom of the design and in the wonderful manner in which the different layers and inequalities of the stone are utilized. Only the hand of a genius could have achieved such perfection. The colouring of the whole is perfectly blended. The relief is low, and the several thin layers of the stone are not sharply separated but merge gradually into each other, an advantage which has been utilized to the full. The stone was probably engraved in Alexandria at the court of Ptolemy.

   (After Furtwängler, 'Die antiken Gemmen', Plate LIII, fig. 1, and vol. ii, p. 250; there figured in natural size, 11·5 × 11·3 centimetres.)

5. **Gem of the Augustan epoch.** Bust of Athena Parthenos of Phidias; the most perfect copy of this masterpiece now extant. On the left is the signature of the artist, Ἀσπασίου.

   (After Furtwängler, Plate XLIX, fig. 12, and vol. ii, p. 235.)

6*a* and *b*. **Bust in Chalcedony,** carved on all sides. Period, the first century after Christ. A life-like portrait, but of coarse and rough workmanship.

(After Furtwängler, vol. iii, p. 335, figs. 180 and 181.)

PLATE 40a.

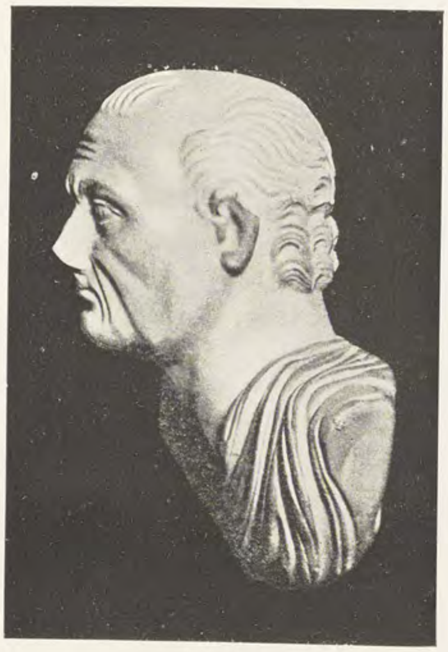
1.

2.

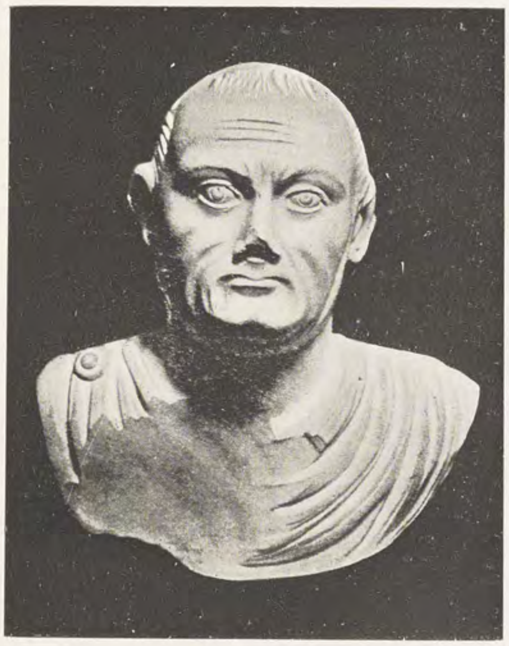
3.

4.

5.



6 a.



6 b.

In the earliest Grecian times of the Mycenaean period, cut stones were worn as ornaments, talismans and amulets, but they were not used as seals. Corresponding with this use, the stones were given a lenticular or orbicular shape, and were pierced, the surface being either smooth or engraved. Floral forms of ornamentation first came into use at that period. In the early Mycenaean period the material used for engraving was mainly the very soft stone steatite, which was worked by hand; but all later and better work was engraved with a wheel in harder stones. In the ruins of the city of Mycenae the work-room of a gem-cutter has been discovered by Tsundas; in a house of the acropolis he found a stock of unworked stones such as were employed for gems, namely chalcedony, agate, rock-crystal, and others; and in another room an unfinished lenticular agate which had been left unbored and without engraving.

In the ruins of ancient Troy of the first and second settlements, which date back to a period even earlier than the Mycenaean, numerous beads and discs of carnelian, lapis-lazuli and amber, and tops of columns and lenses of rock-crystal have been found. The tops of the columns are hemispherical in form with a hole for the column and a small hole at the side for a pin to fix the same.

During the period following the Mycenaean there was a decline in culture and art, and soft stones were carved by hand with but little taste. Not until the end of the seventh century before Christ was the engraving, by means of the wheel, of harder stones, such as carnelian, chalcedony and quartz, again attempted. And it was not until the time of Alexander the Great that the art had again reached the high level at which it once stood in Mycenae. Up till then the designs were sunk into the stone, but now the cameo with a raised design began to be used. The most artistic and perfect of all cameos were cut in Alexandria at the time of Ptolemy. Use now began to be made of the different layers of banded stones. By the Grecian glyptic artists banded stones were so cut that the bands crossed obliquely over the face of the seal; but the cameos were so cut that the bands would be parallel to the face of the stone. The difference in colour and thickness of the several bands afforded the artist an opportunity of exercising his skill in the utilization of these features. The most perfect example of this Alexandrian art which is still preserved is the "Tazza Farnese" cameo. Two other famous stones are the so-called Ptolemy cameos, one of which is represented in plate 40a, fig. 4. These works of art mark the highest point ever reached in the engraving of cameos, and work of the same perfection has never since been achieved.

At the same period the transparent and harder precious stones possessing a beautiful colour and brilliant lustre were also employed. These came mainly from India at the time of its invasion by Alexander. A favourite stone was the hyacinth (identical with our hessonite), and next to this the Syrian garnet: beryl and topaz also came more into use. These harder coloured stones were ground down to a rounded convex surface, and the darker coloured Syrian garnet was made concave on the under side. They were worn as jewellery, especially in ear-rings, necklaces, and golden buckles. According to Strabo, precious stones were used in India for the ornamentation of metal tables, thrones, goblets and washing vessels. And it was from the Orient that the custom of decorating vessels with coloured stones came to the courts of the successors of Alexander the Great, and thence to Rome. In the time of the Roman emperors, stones cut with a rounded surface were used in luxurious profusion for the decoration of garments, shoes, vessels, weapons, chariots and ceremonial articles of all kinds. Constantine the Great bedecked his crown with jewels, and Julius Caesar appeared in the theatre with a wreath of gold and gems. This lavish use of precious stones was passed on to the middle ages — reliquaries, chalices, book-covers and other articles for religious ceremonies being ornamented with coloured stones cut with a rounded form.

With the decline of power in Greece and Alexandria, the Greek gem-cutters found occupation in Rome; their technical knowledge was developed to the utmost, and resulted in the production of the valuable works of art which have come down to us, more particularly from the time of Augustus. A small cameo of this period is represented in plate 40 a, fig. 5; the most perfect cameo belonging to the same period is the famous "Gemma Augustea" now in Vienna, a representation and description of which is given on plate 58 a. The smaller cameos served as jewels, and masks cut in stone were worn by the Roman officers like the orders of the present day.

The cutting of cameos in higher and still higher relief led, in Roman times, to the complete disappearance of the background, the resulting figure being usually a bust (plate 40a, figs. 6 *a* and *b*). In later Roman times, about the second century before Christ, the glyptic art began to lose favour and to decline. But as the art declined, the greater became the belief in the magic qualities of the stones; little value was attached to the artistic workmanship so long as some mystical symbol was engraved on the stone. This was the case with the abraxas gems, which in the first century of the Christian era were worked in Alexandria and widely distributed as amulets. On many of them was engraved the mystical word abraxas, from the Greek letters $\alpha = 1$, $\beta = 2$, $\rho = 100$, $\alpha = 1$, $\xi = 60$, $\alpha = 1$, $\sigma = 200$, the numerical value of which totals 365, and this, being the number of days in the year, was regarded as a holy number.

The Renaissance brought with it a revival of the gem-cutting industry, but neither the workers of that period nor of the present ever attained to the artistic merit and technical finish of the ancients. At the present day the cutting or grinding of gems, rather than their engraving, has reached a high stage of development.

The cutting of stones with facets was unknown to the ancients, but coloured precious stones have been cut *en cabochon* ever since the time of Alexander the Great. The *faceting* of stones is said to have been first practised in the thirteenth century, but it was not until the middle of the seventeenth century that the most perfect form, the brilliant, was devised by Cardinal Mazarin.

The cutting of facets on a stone is more of the nature of a craft than an art. Although an exact knowledge of the characters of stones is required to produce a good result, this depends largely on the running of the machine and the care of the worker rather than on any artistic qualities he may possess. In a well-cut brilliant we look for the correct proportions of height and breadth, we prize it according to the brilliancy of its fire, the purity of its water, and its size, but it cannot be accounted a work of art. On the other hand, an engraved gem, although cut in a stone with little intrinsic beauty, appeals to the imagination as a work of art, and as a document of the history of human culture it is of the greatest significance. A Ptolemaic cameo, for instance, possesses a far deeper interest and a higher value than the largest diamond.

*Curative charms of precious stones, and other superstitions.**) — There can be no doubt but that precious stones were originally worn and valued as ornaments. As they passed from one generation to another without any deterioration in their beauty and freshness they gradually came to be regarded as amulets by their possessors. The stone itself by reason of its imperishable nature came to be regarded as conferring on its wearer the same immunity from disease and the attack of evil spirits. In later

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*) H. Fühner, "Lithotherapie" (Berlin, 1902).

times the engraving of mystical symbols, such as the word abraxas, was believed to increase the magic power of the stone; and stones were then worn as health-bringing amulets rather than for any decorative purpose.

Different stones are supposed to possess powers of differents kinds, to bring certain virtues or repel certain evils. It is significant that the precious opal, a soft stone with an uncertain and changing play of colours, should very generally be regarded as unlucky, and will not be worn by many persons (for instance, the Empress Eugénie). On the other hand, it is said that the possessor of an opal will never be troubled with diseases of the eye. Again, the play of colours from an opal is supposed so to dazzle bystanders that the wearer becomes invisible; and on this account the opal is in favour with thieves. Amethyst is said to be a protection against drunkenness, to bring pleasant dreams, and good luck to the wearer. Beryl should be worn as a protection against soreness of the eyes, and to foster love. A beryl engraved as a scarab (plate 40a, fig. 3) brings with it the power of divination and oratory, providing the wearer leads a chaste life. The emerald brings liberty to the captured, and protects the mariner from violent storms. The chrysolite is regarded as a prophylactic against fevers, gastric pains, and kidney diseases. Red jasper is considered to be a styptic, while sapphire or lapis-lazuli is a cure for scorpion stings.

If precious stones confer all these wonderful benefits by simple contact with the body of the wearer, their action when powdered and taken internally must indeed be marvellous. In former times they were therefore believed to be of medicinal value, and it is probable that many fine stones were sacrificed to this superstition. This use of precious stones was brought into Europe by the Arabs, and held ground for many centuries, until with the advance of chemical knowledge it was held up to ridicule. Powdered blood-stone was used to stop bleeding and to cure watery and blood-shot eyes: this use being based on the belief that blood-stone was formed from dried-up blood.

In catholic countries stones are worn as amulets even to the present day; this being especially the case with chiastolite, a stone which in transverse section shows a black cross on a greyish ground. But the belief in the curative and protective properties of precious stones has long ago died out.

Diamond.

Amongst precious stones diamond is the best known and the one most extensively used in costly jewellery; it is distinguished from all others by its great hardness, high refractive power, brilliant fire, and its rarity.

The *hardness* of diamond is greater than that of all known substances, and is not even approached in this respect by any other mineral; it is 140 times harder than corundum, which after diamond is the next hardest mineral, and a thousand times harder than quartz (see p. 52). Owing to this great hardness a cut diamond never shows any signs of wear. That diamond is the hardest of all substances was known to the ancients, and Pliny wrote: "When struck upon an anvil it returns the blow and both hammer and anvil are shattered; it is also resistant to fire and cannot be made to glow. Its resistance to steel and fire may, however, be overcome by goat's blood, but only when this is warm and freshly bled, and only after several blows, the anvil and hammer being also always broken." That this was merely fable must have been recognized by Pliny, for a little farther on he says that diamond may be broken by blows into small splinters, which are used by the gem-cutters for embedding in iron and so boring hard stones with ease. Nevertheless, this fable of the indestructibility of the diamond — from which indeed its name, adamas, is derived — passed through the whole of the middle ages; it being also mentioned in the writings of that period that the power of the diamond is overcome by the use of goat's blood, especially if the goat has previously drunk wine or eaten parsley. As a matter of fact, diamond, in spite of its great hardness, can be readily pulverized, since it is a very brittle substance and further possesses perfect cleavages parallel to the faces of the octahedron. The brittleness of some crystals is indeed so great, that they of their own accord fly to pieces, like a quickly cooled and unannealed glass. Use is made of this brittleness, or frangibility, of the diamond in the preparation of diamond powder; this being largely used by the lapidary and gem-cutter, and it is the only material with which diamonds can be cut. Use is also made of the property of cleavage in reducing the stones to a more suitable shape preparatory to cutting. As already remarked, the ground-form of the brilliant is an octahedron, so that the octahedral cleavage enables this form to be readily obtained.

The brilliant lustre, or *fire*, and the play of prismatic colours are, to the eye, the most striking features of the diamond, but as already remarked they are only obvious when the stone is cut in a suitable form; they depend on the high refractive and dispersive powers of the substance. The refractive power is expressed by the following refractive indices (μ) for differently coloured rays of light, while the difference between these numbers is a measure of the dispersion: —

For red light (B line of the spectrum), $\mu = 2\cdot40735$
,, yellow ,, (D ,, ,, ,, ,, $\mu = 2\cdot41734$
,, green ,, (E ,, ,, ,, ,, $\mu = 2\cdot42694$
,, violet ,, (H ,, ,, ,, ,, $\mu = 2\cdot46476$.

The character of the lustre displayed by the surface of diamond, even when in the rough condition, is of a special kind and is known as adamantine lustre; on rough surfaces this may approach to metallic in character, and some rough diamonds have almost the appearance of metallic lead.

Owing to the high refractive index, most of the rays of light travelling inside a cut diamond will be totally reflected (p. 58); and owing to the high dispersion, the rays of white light are split up into red, green and blue rays. The fire and the play of colours are shown most prominently by stones which are perfectly colourless and free from flaws, that is, stones of the first water. The presence of even a slight coloration detracts from these effects; and for this reason the slightly yellowish Cape diamonds are of less value than the perfectly colourless stones from Brazil and India. An intense coloration, combined with perfect transparency, is very rare in diamond; the commonest colour is yellow, after which follow green, red and blue. In the collection of Mr. Tornow, of Frankfurt-on-Main, there are in addition to perfectly colourless faceted stones, others of a pale yellow, dark yellow, brown, rose-red, delicate violet, pale green, aquamarine-coloured, and black, all of faultless quality. The best example of a coloured diamond is the celebrated "Hope Blue" stone. Diamonds of a deep black colour and brillliant lustre are very rare; these are found in Borneo, and are used in the most expensive mourning jewellery.

Cloudy diamonds with a lead-grey colour and often traversed by fissures are known as *bort*; and the majority of stones which are found are of this poorer quality.

Diamond is perfectly transparent to the Röntgen rays, its transparency exceeding that of any other mineral. This affords a ready means of distinguishing a faceted diamond from any other stone or glass imitation which it may resemble in appearance. Under the influence of the rays emitted by radium it becomes strongly phosphorescent, and this also gives a means of distinguishing it from other precious stones (p. 181).

In its *crystalline form* diamond presents several points of interest. In the first place, the crystals are developed on all sides, so that they must have grown while freely suspended in some medium; attached crystals have not been observed. The crystals belong to the cubic system and are often octahedral in habit (plate 41, figs. 1, 2 and 3). Octahedra of diamond differ, however, from those of other minerals in the fact that their edges are not sharp but rounded, as represented diagrammatically in text-fig. 165. This rounding of the edges may possibly be a peculiarity of growth of the crystals, or it may be due to twinning. Other crystals have the form of the rhombic-dodecahedron (plate 41, fig. 5), but with rounded faces and edges, and as this curvature of the faces increases there may be a gradual transition to the hexakis-octahedron (fig. 6, and text-fig. 166). Another form is the four-faced cube with curved faces, which is usually combined with the cube. In addition to these holohedral cubic forms, tetrahedra have been found, indicating that diamond belongs to the tetrahedral-hemihedral class of the cubic system.

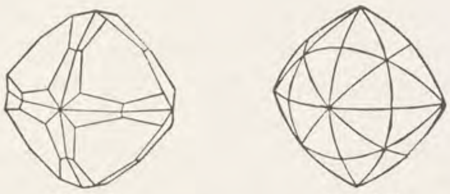

Fig. 165. Fig. 166.

Crystals of Diamond.

Octahedron with curved edges. Hexakis-octahedron with rounded faces.

The rounded octahedral form is well shown by the unusually large crystal represented in its natural form and size in fig. 167; this stone, known as the "Victoria" diamond, weighed in its rough state $457^{1}/_{2}$ carats, but by cutting was reduced to 180 carats. The largest known diamonds (the "Excelsior", fig. 169, and the "Cullinan") are only portions of crystals and their octahedral form is not so obvious.

Fig. 167.
The "Victoria" diamond. An octahedral crystal with rounded faces and edges. (Natural form and size).

Twinned crystals have an octahedron face as twin-plane, as in magnetite, and are usually flattened parallel to the twin-plane; twinned rhombic-dodecahedra are often lenticular (fig. 168), and can only be used for cutting as rosettes.

Fig. 168.
Twinned crystal of Diamond.

The faces of diamond crystals frequently show special markings: the octahedron faces being pitted with numbers of minute shallow depressions with a triangular outline, and the cube faces with depressions square in outline.

A special variety of diamond is that known as *carbonado* (also called "carbon" and "carbonate"), which has somewhat the appearance of coke. This is a black, finely granular and more or less porous aggregate of minute crystals of diamond. It is found in Brazil as pieces the size of a nut or at the most the size of a man's fist; the largest piece weighed 650 grams. It possesses the same hardness as crystals of diamond and at the same time is much tougher, and less frangible: the reason for this being that the mass as a whole is not cleavable, since it consists of small crystals aggregated irregularly. Owing to its extraordinary hardness, toughness and compactness, the unattractive-looking carbonado finds an important application in rock-boring: being set in the crowns of rock-drills it is indeed a crown jewel of some practical use, and without its aid the modern method of tunnelling would scarcely be possible.

That diamond consists of a combustible material was suspected by Newton, by reason of its high refractive index. That is consists of carbon and burns in the air to carbon dioxide was as good as proved by Lavoisier, but an exact demonstration of this fact was first given by Tennant in 1797 and more recently by Krause. Diamond consists in fact of *pure carbon*, and small splinters of it can be made to burn even in a gas flame, and still more readily when heated in oxygen. Traces of foreign substances are often present, and these remain behind as ash when the diamond is burnt. When heated under certain conditions to a high temperature, diamond becomes converted into the soft, black modification of carbon known as graphite.

The high *specific gravity* of 3·52 is a remarkable feature of diamond; in the porous carbonado it may, however, be as low as 3·14. This being much higher than the specific gravity of graphite, we can conclude that in diamond the molecules are very closely packed together. Amongst other colourless precious stones, topaz has almost exactly the same specific gravity as diamond, but the two are readily distinguished by the much stronger fire of diamond; further, diamond is singly refracting, or optically isotropic, whilst topaz is doubly refracting and optically biaxial. The other colourless precious stones (zircon, phenacite, rock-crystal) also differ from diamond in being doubly refracting, and further in their higher (zircon) or lower (phenacite and rock-crystal) specific gravity. A highly refracting glass cut in the form of a brilliant may closely resemble a diamond in fire and lustre, but this can always be distinguished from diamond by its softness, low conductivity for heat, and opacity to the Röntgen rays.

Enclosures of foreign substances are occasionally seen in diamond; these are always quite small, but they are of importance, since they detract from the value of the stone and they throw much light on the origin of the diamond. The following minerals have been observed as enclosures in diamond: haematite or ilmenite, quartz, rutile, iron-pyrites, topaz, and gold. On the other hand, diamond itself sometimes occurs enclosed in other minerals, for instance garnet.

The *artificial production* of diamond has been often attempted, owing to the high intrinsic value of the stone. A few of these attempts have resulted in the formation of minute crystals, but not of sufficient size to be of use as gems; nevertheless these results are of considerable scientific interest, and they indicate to us how diamond may have been formed in nature. It has long been known that carbon is dissolved in molten iron, and that on cooling it separates again as graphite. If, however, the molten mass be very quickly cooled under an enormous pressure a small portion of the carbon crystallizes as diamond, as was proved by the researches of the late Professor H. Moissan. This mode of formation of diamond helps to explain the occurrence of diamond in meteoric iron, and in steel and hard cast-iron. Diamond can also be produced artificially without the help of great pressures as proved by the experiments of J. Friedländer and Hasslinger, who obtained minute crystals by adding carbon to molten olivine. This mode of formation explains the occurrence of Cape diamond in an olivine-rock. Graphite together with diamond have been formed by the decomposition of acetylene at a very high temperature (2000—3000° C.); and recently A. Ludwig has described a method by which carbon may be directly converted into diamond.

The *occurrence and origin* of diamond in nature still present many problems to be cleared up. At most localities it is clear that the diamond is not found in the rock in which it was formed, being often met with in the sands and gravels of rivers.

In South Africa, however, it is found in an olivine-bearing rock of igneous origin and it is not unlikely that the crystals have been formed in such a rock while in a molten state in the earth's interior, and subsequently brought near the surface by volcanic forces.

Of the *localities* at which diamond is found, the earliest known are several places in *India*. It is from here that the fabulous treasure of Indian princes was obtained; and from the time of the Romans until the middle of the eighteenth century but few diamonds had been found in any other country. The diamond-yielding districts lie on the eastern side of the Deccan plateau, extending for a considerable distance from south to north in the basins of the rivers Penner, Kistna and Mahanadi, and in the neighbourhood of Panna in Bundelkhand. Throughout this wide area the diamond occurs in a thin bed of earthy material rich in pebbles; this bed is of sedimentary origin, but the original rock from which the diamonds were derived is not known. In places where this diamantiferous layer has become exposed by denudation the material has been removed by running water, and the diamonds are found amongst the pebbles in the beds of the present streams and rivers. Indian diamonds are noted for their purity of water, brilliant fire and play of prismatic colours, and in many cases their size. The majority of the famous historical diamonds are of Indian origin, and this is especially true of the few red and blue stones which are known. Since the discovery of diamonds in Brazil the production from India has fallen considerably, and still more so when the market became flooded with Cape diamonds.

In *Brazil*, diamonds were first found in the year 1725. The most important districts are situated in the neighbourhood of the town of Diamantina in the state of Minas Geraes, and in the state of Bahia. The minerals found in association with diamond in Minas Geraes are quartz, rutile, anatase, tourmaline, haematite, monazite, etc.; all of these are found also in the quartz-veins (in which, however, the diamond itself has not yet been found) which traverse the ancient rocks of the district, as well as in the sedimentary rocks formed of the débris of the quartz-veins and enclosing rocks. The oldest of these sedimentary rocks is a micaceous sandstone which possesses the pecularity of being flexible in thin slabs: this is known as flexible sandstone or as itacolumite (from Mount Itacolumi, one of the localities where it occurs). This rock in turn has also been subjected to weathering processes, and its débris, with diamond and the associated minerals, caps many of the hill tops in the neighbourhood of Diamantina. Some of the débris has been transported by running water and deposited as pebbles in the valleys, forming alluvial deposits on the sides of the valleys or on the present flood plains. The more frequently and the farther these material have been transported the rounder are the pebbles. The loose material of these alluvial deposits has in many cases been later bound together by a ferruginous cement; and it is in such material that the diamond represented in plate 41, fig. 7, is embedded. A clayey deposit mixed with pebbles and containing diamonds is known to the Brazilians as "cascalho". The diamonds of the Brazilian deposits have thus frequently changed their position, just as, after being cut as gems, they pass from one possessor to another.

The mode of occurrence of diamond in the state of Bahia is much the same as in Minas Geraes. Here a special rich find was made in the year 1844 in the Serra da Cincorá; it is at this place that most of the carbonado variety is found, very little coming from Minas Geraes and South Africa, and none from India.

On the average, Brazilian diamonds are much smaller than those from India and from South Africa: the majority of them weigh $^1/_4$ carat or less. The largest that has been found is the "Star of the South", which weighed $254^1/_2$ carats, and when cut as a brilliant 125 carats. The most frequent forms are the cube, the rhombic-dodecahedron and lenticular twin-crystals. In quality the stones approach those from India, and are better than the Cape diamonds.

From the time of the first discovery up to the year 1850 the production of diamonds in Brazil has been estimated at the value of £ 15,825,000, more than half of which was from Minas Geraes. At the present day the deposits are still not exhausted, and it is certain that other deposits remain to be discovered in this little-explored country.

In *South Africa* the first diamond was found in the year 1867. A shining stone picked up by some Boer children and used by them as a plaything was found to be a diamond; this crystal weighed $21^3/_{16}$ carats, and was shown at the Paris Exhibition of 1867. Other large stones were soon afterwards found, and then commenced the rush to the diamond diggings and a large population soon sprung up in a region which previously was only thinly inhabited. The first diggings were along the banks of the Vaal River in Griqualand West, Cape Colony; and in these "river diggings" diamonds were separated by the process of washing from the sand and pebbles. Very soon afterwards diamonds were also found on the arid plateau to the south of the Vaal River, at a spot where now stands the town of Kimberley, also in Griqualand West. Here, with an absence of water, the workings came to be known as "dry diggings"; they were the beginnings of the enormously rich and famous mines, the Kimberley mine, De Beer's mine, Du Toit's pan mine, and the Bultfontein mine, all in the immediate vicinity of Kimberley. The Jagersfontein mine and the Koffyfontein mine in Orange River Colony are also mines of the same character and discovered at about the same time.

The diamond-bearing rock of these mines is a kind of serpentine which has resulted by the weathering of an olivine-rock; it fills funnel-shaped depressions or pipes of unknown depth which penetrate the surrounding rocks. The latter consist of almost horizontal beds of shale, quartzite and sheets of diabase, and are sharply separated from the material in the pipes. The pipes are explosion-funnels formed by volcanic eruptions, and in their form are comparable with the crater-lakes (Maaren) of the Eifel. Their outline at the surface is approximately circular or elliptical; they measure from 200 to 300 metres across, and when first found they projected but slightly above the general surface of the ground. The rock is not slaggy and cellular like that of other volcanic necks, but is completely brecciated and fragmented, this structure being probably due to a series of steam explosions under a high pressure. With decreasing pressure and temperature the water condensed, forming a mud of the fragmented materials, which filled the funnel up to the top. The rock as we now find it is essentially a hydrated magnesium silicate, having much the composition of serpentine, and indicating that the original rock was largely composed of olivine, which is an anhydrous magnesium silicate. At greater depths in the pipes this material is dark blue or slate-grey in colour, and it is therefore known as the "blue ground": fragments of this "blue ground" with embedded diamonds are represented in plate 41, figs. 4 and 5. Nearer the surface, down to a depth of about 25 metres, the rock has been oxidized by atmospheric weathering and become yellow, being then known as "yellow ground" (fig. 6). Other minerals, besides diamond, found embedded in the "blue ground" are garnet (as transparent grains of a fine red colour, and known as "Cape ruby"), enstatite, chrome-diopside, ilmenite, etc.

Owing to the soft nature of the "blue ground" the winning of diamonds from it is a comparatively easy matter. Down to depths of 100—200 metres the material filling the pipes has been excavated in open workings; but at greater depths a regular system of underground mining has to be adopted, a vertical shaft being sunk and levels driven from this into the "blue ground". When raised from the mine, the material is spread out on "floors", and there watered and occasionally turned over; after being so

PLATE 41.

Diamond and Graphite.

Fig.

1. **Diamond,** limpid octahedron. Weight, 0·25 gram.
   South Africa.
2. **Diamond,** octahedron with faces slightly dull and rough. Weight, 0·33 gram.
   Vaal River, South Africa.
3. **Diamond,** octahedron with rounded edges; perfectly transparent and slightly yellowish in colour. Weight, 0·75 gram.
   Kimberley, South Africa.
4. **Diamond,** octahedron in "blue ground."
   Kimberley, South Africa.
5. **Diamond,** rhombic-dodecahedron with curved faces; transparent and slightly yellowish; in "blue ground".
   Kimberley, South Africa.
6. **Diamond,** crystal with curved faces, in "yellow ground". A rare and old occurrence.
   Kimberley, South Africa.
7. **Diamond,** small crystal in "cascalho".
   Minas Geraes, Brazil.
8. **Graphite,** lamellar.
   Ceylon.
9. **Graphite,** fibrous.
   Ceylon.

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left to the action of the weather for about a year it becomes crumbly, so that the diamonds and other heavy minerals can be readily separated by a simple process of washing. From the mixed lot of heavier stones so obtained, the diamond was formerly picked out by hand, but recently a mechanical sorting table has been devised. This depends on the fact that diamond adheres to a greasy surface more readily than do the other minerals.

Amongst the diamonds separated from the "blue ground" there are, besides perfect crystals, many splinters and fragments of crystals. This breaking up of the crystals is not a result of the operation of extraction, for the matrix has not been reduced by crushing; and moreover fragments which fit together are never found. It is without doubt a result of the volcanic eruptions by means of which the material was brought up from great depths in the earth's crust. As already mentioned, some of the crystals of diamond are in a state of strain, and burst of their own accord without any apparent cause; it is therefore likely that stones of this character, when suddenly brought up from great depths to regions of less pressure, would be fragmented. Stones of this kind are usually of a smoke-grey colour with a very bright lustre; they are known as "smoky stones", and are of no use for cutting. Such stones cannot always be recognized by the unaided eye, but when examined under the polariscope they are seen to be more or less strongly doubly refracting, like compressed or unannealed glass, while normal crystals of diamond are singly refracting

Although the diamond mines at Kimberley yield numerous stones, they are only very sparingly distributed through the "blue ground". A hundred wagon loads of "blue ground" from the De Beer's and Kimberley mines yield 70—80 carats of diamonds, while the same amount from the Premier mine yields only 30—40 carats. In other words, about six tons of the matrix from the richest mines must be washed in order to obtain one gram (5 carats) of diamond, and only a small proportion of this is suitable for cutting. Stones of comparatively large size are, however, often met with; stones up to 20 carats in weight, which are rare in Brazil, are here common.

The largest known diamond was found on January 25, 1905, in the Premier mine near Pretoria in the Transvaal, which is a mine of exactly the same type as the Kimberley mines: this stone, known as the "Cullinan" diamond weighed before cutting 3025$^3/_4$ carats (or 1$^1/_3$ lb. avoirdupois) and measured 4 by 2$^1/_2$ by 2 inches. It was a portion, probably not more than half, of a distorted octahedron. The next largest diamond, the "Excelsior" (fig. 169), was found in 1893 in the Jagersfontein mine in Orange River Colony: this weighed 971$^3/_4$ carats and was the size of a hen's egg. Other large South African diamonds are the "Victoria" of 457$^1/_2$ carats (fig. 167), and the "De Beers" of 428$^1/_2$ carats, the latter being a very regularly formed octahedron with rounded edges.

Fig. 169.
The "Excelsior" diamond. Actual size.

As a rule, the quality of South African diamonds is inferior to that of Indian and Brazilian, since they often show a faint yellowish tinge of colour. Although this yellowish colour is scarcely appreciable in itself, it is readily noticed when a Cape diamond is placed side by side with a Brazilian. The finest, and at the same time the rarest, stones are of a so-called "blue-whites"; the slightly yellowish stones are called "Cape whites".

Since the whole of the Kimberley mines were taken over and worked by the De Beers Consolidated Mines, the output has been regulated with a view of keeping the price of diamonds high and steady. The annual output amounts to $2^1/_2$—3 million carats, valued at about four million pounds sterling. Owing to the great value of such small objects as diamonds, special precautions have to be taken to guard against thieving. The native workers in the mines live entirely, during their time of contract, in a carefully guarded enclosure called a compound, and before they are allowed to leave they are exhaustively searched and dosed with purgatives. In spite of all precautions, however, it is estimated that something like a quarter of a million pounds' worth of diamonds are stolen every year.

As to the origin of the diamond in these pipes, it is certain that the mineral was brought up from great depths together with the rock in which it is now found, and that it must have been already formed before the eruption of this material. It is probable that the diamond crystallized out from a molten magma at some considerable depth, and that the magma had the composition of an olivine-rock and contained some carbon in solution. This view is supported by the experiments of Friedländer, which prove that carbon is capable of crystallizing as diamond from fused olivine; and it receives still further support in the experimental fact that diamond can be dissolved in molten "blue ground". It is thus probable that, in South Africa at least, diamond has originated as a separation from an igneous magma, and it is also probable that this has been its mode of origin in other countries, although it has not been elsewhere observed in its mother-rock. Bearing on the origin of the diamond, the recent discovery of crystals of diamond in blocks of a garnet-pyroxene rock (eclogite) in the "blue ground" is of some importance.

As compared with the three countries just mentioned, others in which diamond has been found are of little importance as regards production.

In *Australia*, diamonds have been found in some of the gold-fields and in deposits of stream-tin, particularly in New South Wales, but never as stones exceeding six carats in weight.

In *Borneo*, on the south and south-east sides of the island, not a few diamonds have been found. Most of them are, however, quite small, 95 per cent. weighing less than one carat. In the possession of the Prince of Landak and the Rajah of Mattan are stones weighing over 50 and 100 carats. Some of the stones are perfectly transparent and water-clear, but more frequently they are yellowish, or sometimes rose, red, bluish, smoky or black. Those of a red or blue colour are very rare and are therefore highly prized; black stones are still rarer, probably because they are in great demand by the natives, who wear them as amulets to guard against misfortune. Associates of the diamond in Borneo are gold, platinum, corundum, rutile, and other minerals.

In the *United States* of North America only a few scattered diamonds have been found; the largest, found in the surface soil in the village of Manchester, Virginia, weighed $23^3/_4$ carats.

In *British Guiana* the occurrences are of more importance, and in the valley of the Mazaruni river 3076 carats of diamonds were collected in the year 1901. The stones are usually small, none exceeding eight carats, but in quality they are comparable with the Brazilian.

In *Europe*, a few diamonds have been found in the Ural Mountains. On account of the similarity between the Brazilian and the Uralian gold and platinum occurrences it was predicted by Alexander von Humboldt that diamond would be found in the Urals. During his visit to the Urals in company with Professor Gustav Rose a special search was made, and the first European diamond was discovered in 1829 in some gold-washings near Bissersk, the actual discovery being made, however, by Count Polier, who had accompanied the expedition part of the way. Since that time other diamonds have been found, the largest weighing $2^1/_2$ carats.

The occurrence of *diamonds in meteorites* (see p. 165), though only as grains of microscopic size, is of considerable interest. Those found in meteoric iron must have had the same mode of origin as the crystals artificially crystallized from molten iron by Moissan (p. 208). The presence of graphite with cubic forms has also been detected in some meteorites, and it is probable that these cubic crystals were originally diamond which had later become altered to graphite.

Applications. — That diamond is used mainly as a precious stone is well known; we have already described how it is cut, and how it may be distinguished from other colourless stones. The most important centre of the diamond-cutting industry is in Amsterdam, and here all the larger and more valuable stones are sent to be cut. Smaller but not unimportant works are situated in Paris, London, Berlin, Hanau and Idar. Besides being used as a gem-stone, diamond finds certain important technical applications by reason of its great hardness. As bort and carbonado it is set in the crowns of rock-drills, and it is also used for boring cannon. It serves as a pivot-support in the more delicate classes of instruments and machines. Pierced diamonds are employed by wire drawers. Crystals with naturally rounded edges are extensively used for cutting glass, this being the well-known glazier's diamond; while sharp splinters are used for writing on glass. Diamond powder is much used by lapidaries and gem-cutters, and it is in fact the only material with which diamond itself can be ground.

The *value* of faceted diamonds varies between wide limits according to the quality, colour, size and form of cutting. A one-carat brilliant of the first water was valued in the year 1878 (at the Paris exhibition) at 220 francs, one of ten carats at 3250 francs, and one of twenty carats at 11,400 francs. In 1903, for a one-carat brilliant of the best quality £25 was asked, and one of ten carats £600 to £700. The value of stones of the second water is about two thirds of that for stones of the first water. Rosettes fetch about four-fifths the price of brilliants. Specially large stones or those of a pronounced green, red or blue colour, being quite exceptional, commanded fancy prices, and no rule can be laid down.

Large and famous diamonds have in all times generally been used as crown jewels or in the possession of princes, but they have often changed hands. The "Regent", or "Pitt", now shown in the Louvre with the French crown jewels was found in 1701 in the Partial mines in India; it weighed in its rough state 410 carats and was cut to a brilliant of $136^{14}/_{16}$ carats; in 1791 it was valued at twelve million francs (£480,000). The celebrated "Koh-i-noor", now amongst the English crown jewels, formerly belonged to the Rajah of Lahore, from whom it was taken by the East India Company and in 1850 presented to Queen Victoria. In its Indian form of cutting it weighed $186^1/_{16}$ carats, and in 1852 it was re-cut as a brilliant weighing $106^1/_{16}$ carats; it has been valued at £100,000. The "Orloff" is the largest diamond in the Russian crown jewels; it weighs $194^3/_4$ carats, and has the form of a high and irregular rosette. The "Florentine", now in the state treasury at Vienna, weighs $133^1/_5$ carat; it is pale yellow, and is cut as an egg-shaped double rosette, or briolette. It is said to have once belonged to Charles the Bold, lost by him in the battle of Granson, and found again by a Swiss soldier. Similar adventures are related in connection with the "Sancy"

($53^{12}/_{16}$ carats), now the property of an Indian prince. All the celebrated gems so far mentioned are of Indian origin. Of Brazilian stones, the largest is the "Star of the South", which in the rough weighed $254^1/_2$ carats, and cut as a brilliant 125 carats; this also is in the possession of an Indian prince. The "Star of South Africa", a stone of the first water and weighing $83^1/_2$ carats, was found in 1869 in the Vaal River diggings; it was cut as an oval, three-sided brilliant of $46^1/_2$ carats, and was sold to the Countess of Dudley for nearly £25,000. Since that time still larger diamonds have been found in South Africa, the largest of which, the "Cullinan" and the "Excelsior", have already been referred to above. The "Cullinan", presented to King Edward VII by the Transvaal government, has recently (1908) been cut in Amsterdam into a large number of brilliants, the largest weighing $516^1/_2$ carats and another $309^3/_{16}$ carats.

Amongst coloured diamonds of large size, the following are especially noteworthy. The "Hope Blue", named after one of its former possessors, combines the blue colour of the sapphire with the fire and play of prismatic colours of the diamond; it is a brilliant of $44^1/_4$ carats and came from India. A pale blue diamond weighing 40 carats is preserved in the Bavarian state treasury. The best known green diamond, the "Dresden Green" kept in the "Green Vaults" of Dresden, is an almond-shaped brilliant of 40 carats.

Graphite.

Graphite, like diamond, consists simply of the chemical element carbon, and yet there is the most striking difference between these two minerals. Diamond is the hardest, and graphite the softest of minerals; diamond is colourless and perfectly transparent, while graphite is black and opaque; diamond is a non-conductor, and graphite a good conductor of electricity; diamond occurs as beautifully developed octahedral crystals, while graphite usually forms only lamellar and scaly masses. Similar cases of dimorphism, where two substances are identical in chemical composition but different in all their physical characters, are by no means uncommon, but it is not often that the two substances present such striking differences as do diamond and graphite. The present example may be compared with the two carbon compounds cellulose (woody fibre) and starch, which also are identical in their percentage chemical composition. Starch, which is largely present in grain and potatoes, is an important food-stuff and can be readily converted into other substances, such as sugar and alcohol; cellulose, on the other hand, is very stable and cannot be converted into sugar or alcohol, nor has it any nourishing properties. Attempts made by chemists to convert coal into diamond have at last been successful on a small scale, but not so with the conversion of cellulose into starch. We learn from chemists that, although cellulose and starch are found by quantitative analysis to be identical in composition, yet the chemical elements are combined in different ways in the two substances and that their chemical molecules are therefore different. In the same way, we must assume that the molecules of diamond and graphite are not identical; the molecules of one may contain a larger number of atoms than the molecules of the other, or the atoms may be linked together in a different manner in the two kinds of molecules. The two minerals are, in fact, not only different in their physical characters, but also in their chemical behaviour. Graphite, when heated with an oxidizing mixture of potassium chlorate and nitric acid, gives rise to a yellow powder of complex composition known as graphitic acid; but this substance cannot be prepared from diamond.

Graphite occurs in nature as lamellar, scaly or fibrous aggregates, or in almost compact masses. It is iron-black to dark steel-grey with a metallic lustre, and possesses a perfect cleavage in one direction. Platy and fibrous masses of this kind are represented in figs. 8 and 9 respectively of plate 41. Crystals are of rare occurrence and belong probably to the hexagonal system; they have the form of six-sided plates but are never very distinctly developed.

Owing to its very low degree of hardness (H. = 1—2) graphite is greasy to the touch and readily soils the fingers. Its specific gravity of 2·2 is much lower than that of diamond. Thin flakes of the pure mineral can be burnt in the flame of the Bunsen-burner. Usually, graphite contains an intermixture of incombustible materials, which when the material is burnt remain behind as ash: this may be present to the extent of 13 per cent. or even more, and the material may still be useful for certain technical purposes.

A liquid capable of dissolving graphite and other forms of carbon is molten iron. When the carbon in grey cast-iron exceeds a certain amount, it seperates again on cooling, usually in the form as graphite, and sometimes as quite good though small crystals.

In nature, graphite is found as a constituent of crystalline rocks; and in certain cases it may constitute the bulk of the rock, as in graphite-schist. When occurring under these conditions, graphite has usually been formed from coal or other carbonaceous material by the contact-action of intruded igneous masses. Another mode of occurrence is in veins; and here the mineral has probably been deposited by gases or vapours ascending through the earth's crust. In support of such a view we know that certain gases, such as acetylene and vapourized silicon carbide, deposit graphite when heated.

Some of the more important localities for graphite are the following. Borrowdale in Cumberland, Pfaffenreuth near Passau in Bavaria, Miask in the Ilmen Mountains in the Urals, on the rivers Kureika and Nishnaya in government Yeniseisk, and particularly in the Batugolskoi-Golez in government Irkutsk in Siberia. At the last named locality is the celebrated Mariinskoi graphite mine worked by Alibert and Faber; it is situated in the Tunkinsk mountains between the rivers Besimiannaia and Batugol and about 400 kilometres to the west of Irkutsk. In the United States, graphite is extensively mined at Ticonderoga on Lake George in the state of New York. The richest deposits are those in Ceylon, which yield not only the largest amount but also the best quality of graphite: the two specimens represented on plate 41 are both from here.

The best qualities of graphite are used in the manufacture of pencils, and the inferior qualities for crucibles, stove polish, oven plates, black pottery, dry lubricants, foundry facings, etc. Artificial graphite is now prepared on a large scale by means of electrical power at the Niagara Falls.

Corundum.

The species corundum includes several colour-varieties which are of considerable importance as gem-stones, and which were distinguished by special names long before it was known that they were identical in their chemical composition and other essential characters. The red variety is known as ruby, the blue as sapphire, the yellow as "oriental topaz" or yellow sapphire, and the violet as "oriental amethyst" or violet ruby, whilst cloudy specimens with no pronounced colour are distinguised as common corundum. Each of these varieties may be further described as "precious", when it is desirable to distinguish between a transparent stone and one of the same colour but cloudy and of little value. Stones of deeper and richer colour are sometimes described as "masculine," and those of a paler colour as "feminine". Finally the prefix "oriental" is employed to distinguish between corundum gems and other minerals possessing the same colour. Thus, "oriental ruby" is the true ruby, and the name ruby alone is on this account sometimes incorrectly applied to red spinel. "Oriental amethyst" is violet corundum, the true amethyst being a violet coloured variety of quartz. Before describing each of these varieties of corundum in detail, we shall outline the characters which they possess in common, that is, the general characters of the species corundum.

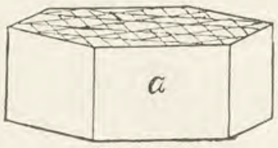

Fig. 170.

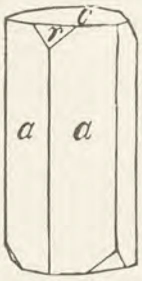

Fig. 171.

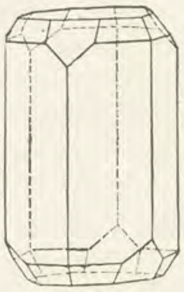

Fig. 172.

Crystals of Corundum (Ruby).

The mineral corundum consists of aluminium and oxygen in combination as alumina, Al_2O_3. It is never absolutely chemically pure, but always contains some iron oxide (1—2 per cent.) and frequently traces of chromium: these impurities give the colour to the material, since pure alumina is a colourless compound.

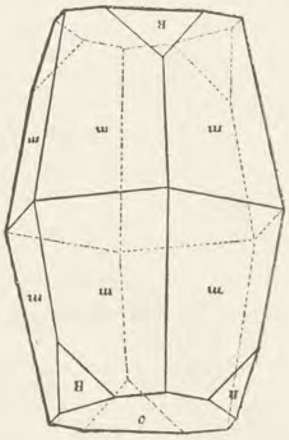

Fig. 173.
Crystal of Corundum (Sapphire).

Crystals of corundum belong to the rhombohedral division of the hexagonal system. The simplest form is a combination of a hexagonal prism with the basal pinacoid (text-fig. 170, and plate 42, figs. 2, 16 and 17). When faces of a rhombohedron are also present they truncate alternate corners between the prism and the base (*r* in text-fig. 171; plate 42, fig. 10), proving the prism to be that of the second order. Sometimes a hexagonal pyramid of the second order may also be present as faces truncating the edges between the prism and the base (text-fig. 172). The Naumannian symbols of these forms are respectively $\infty P2$, $0R$, R, $\frac{4}{3}P2$. When the prism is long the crystal has a prismatic habit (fig. 10), and when short a tabular habit (fig. 12). In other crystals the habit may be pyramidal, either with the pyramid alone (fig. 11), or in combination with the base (figs. 1, 15 and 18) or a rhombohedron (fig. 3, and text-fig. 173). The steep pyramid in figs. 11 and 6 has the symbol $\frac{8}{3}P2$. Whatever the habit of the crystals, they are always thick and lumpy, delicate forms of growth never occurring in corundum. In crystalline form, as well as in the type of chemical formula, there is a close similarity between corundum and haematite, the two minerals being isomorphous.

Well-developed twin-crystals of corundum are of rare occurrence; a specimen consisting of two individuals twinned on a face of the primary rhombohedron *R* is represented in plate 42, fig. 7. On the other hand, thin twin-lamellae parallel to the faces of the rhombohedron *R* are frequent both in crystals and compact masses, giving

PLATE 42.

Corundum.

Fig.

1. **Corundum,** blue crystal with steep pyramid faces and large basal plane.
   Miask, Ilmen Mountains, Urals.
2. **Corundum,** tabular parallel to the base; blue externally and greyish-brown inside.
   Miask, Ilmen Mountains, Urals.
3. **Corundum,** blue crystal. Hexagonal prism of the second order with rhombohedron and base.
   Ural Mountains (said to be from Kischtimsk, but more probably from Miask).
4. **Corundum,** with zonal structure.
   Ural Mountains (said to be from Novotagilsk, but more probably from Miask)
5. **Corundum,** blue crystals in rock.
   Miask, Ilmen Mountains, Urals.
6. **Corundum** ("Sapphire"), steep hexagonal pyramid of the second order with basal plane.
   Ceylon.
7. **Corundum** ("Sapphire"), twinned on a rhombohedral face.
   Ceylon.
8. **Corundum** ("Sapphire"), a greenish-blue, faceted stone. Weight, 0·69 gram.
   Australia.
9. **Corundum** ("Sapphire"), a blue, faceted stone. Weight, 0·46 gram.
10. **Corundum** ("Ruby"), hexagonal prism of the second order with rhombohedron and basal plane.
    Newton, New Jersey, U. S. A.
11. **Corundum** ("Ruby"), hexagonal pyramid of the second order.
12. **Corundum** ("Ruby"), crystal with the same forms as in fig. 10 but with shorter prism.
    Ceylon.
13. **Corundum** ("Ruby"), a deep red, faceted stone. Weight, 0·2 gram.
14. **Corundum** ("Ruby"), a brownish-red, faceted stone. Weight, 0·355 gram.
    Siam (?)
15. **Corundum,** rough, pale reddish crystal, pyramid with base.
    Lowndes Co., Georgia, U. S. A.
16. **Corundum,** reddish-grey, tabular parallel to the base.
    Siam.
17. **Corundum,** reddish-brown, hexagonal prism and base.
    Culsagee mine, Macon Co., North Carolina, U. S. A.
18. **Corundum** ("Yellow sapphire"), hexagonal pyramid with base.
    India.
19. **Corundum** ("Yellow sapphire"), faceted stone. Weight, 1·235 gram.
20. **Corundum,** dark brown, hexagonal pyramid with rhombohedron and base.
    Chantabun, Siam.
21. **Corundum,** massive, with striations.
    Macon Co., North Carolina, U. S. A.


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rise to planes of easy separation or false cleavage in these directions. Owing to this, corundum may sometimes be broken up into rhombohedral blocks (fig. 21) closely resembling cubes in form, the rhombohedral angle being 86° 4′. The twin-lamellae also give rise to striations on the faces of the crystals; on the basal plane these run in three directions (text-fig. 170), if the twinning is repeated on all three faces of the rhombobedron; and on a rhombohedral face or plane of separation in two directions. When, in cloudy corundum, the twin-lamellae are very fine the stone reflects from the basal plane a six-rayed star of light, which is shown to the best advantage if the stone be cut with a rounded surface and polished (*en cabochon*); this appearance is well shown in the variety known as star-sapphire.

The refractive power of corundum is high, but the double refraction feeble; the index for the ordinary ray being 1·769 and for the extraordinary 1·760. The dispersion also is not strong, so that in all these optical characters corundum does not approach the diamond. It, however, exceeds topaz, beryl and quartz in its refractive power, and therefore also in its lustre. When examined with the dichroscope, coloured stones are seen to be distinctly dichroic. The mineral is moderately transparent to the Röntgen rays.

Since the material is composed of the light elements aluminium and oxygen we should not expect it to be heavy; as a matter of fact, however, the specific gravity is unusually high, varying between 4·0 and 4·1. Corundum is thus one of the heaviest of precious stones, and in this respect is exceeded only by zircon and certain varieties of garnet.

Also in its hardness, corundum occupies a prominent position. Although the difference in hardness between diamond and corundum is very considerable, there is no other mineral with an intermediate hardness. The artificial product known as carborundum (carbon silicide) occupies such a position; and being harder than corundum, it is now largely used in place of this for grinding precious stones.

Ruby is a red coloured variety of corundum. The colour varies between delicate rose, carmine-red, brownish-red and bluish-red, and the shade most highly prized is the so-called pigeon's-blood red; some of these colours are represented in plate 42, figs. 10—16. When ruby is raised to a red-heat, its dark red colour changes first to a dirty red, then to a greenish-blue, and on cooling again the stone regains its original red colour and transparency. These changes in the colour may be readily observed by heating a ruby in a crucible of fused silica, especially if during the cooling a sheet of white paper be held beneath. From this behaviour we can conclude that the colouring matter is inorganic, since at a red-heat any organic colouring matter would be destroyed. No doubt the colour is due to the small amount of chromium oxide always present in ruby.

The dichroism of ruby can sometimes be observed by the unaided eye: a transparent crystal will be seen to be darker when we look through the basal plane and lighter through the prism planes. This is a point to be taken into account by the gem-cutter; if he wishes to get the deepest colour possible he must so cut the stone that the large table facet will be parallel to the base, while if he wishes to somewhat reduce the colour of a very dark stone the table facet should be perpendicular to the base. When examined with the dichroscope, the crystal will show the maximum difference in colour of the two images when it is viewed through the prism planes. The image corresponding to the extraordinary ray (*e*) will be pale red with a yellowish tinge, and the image corresponding to the ordinary ray (*o*) dark red with a violet tinge. The crystal represented in fig. 11 showed the two colours yellowish-pink (*e*) and dark violet (*o*) respectively, and the faceted stone in fig. 13 yellowish-red (*e*) and violet-red (*o*). On looking through the large table facet of a cut stone the two images seen in the dichroscope will, as a rule, be of the same colour, since, if the stone is properly cut, we are then looking along the principal axis and in this direction there is no dichroism. If such a stone be examined in the polariscope with the table facet resting on the stage, we will see a series of concentric coloured rings intersected by a black cross (i. e. a uniaxial interference-figure, plate 4, fig. 1): by placing a drop of oil on the stone the light will be better able to pass through, and the figure will be more distinct.

Crystals of ruby are usually bounded by faces of the hexagonal prism of the second order, the basal pinacoid, and a rhombohedron (fig. 10); a hexagonal pyramid of the second order may also be present, but only in rare cases does this predominate ($\frac{8}{3}P\,2$ in fig. 11).

Most of the best rubies used in jewellery come from Mogok in Upper Burma, where they occur with precious spinel in white marble; the weathering of this rock results in the formation of a clayey material, in which the rubies are also found, as well as in the sands of the neighbouring streams. Another very similar, but less important, occurrence in Upper Burma is in the Sagyin Hills near Mandalay. The stones are usually only quite small, seldom exceeding one carat in weight; clear stones exceeding ten carats are very rare and command a high price. The largest stones which have been found weigh over a thousand carats, but they are cloudy.

Other localities for ruby are situated in the provinces of Chantabun and Krat in the adjacent county of Siam. Most of the Siamese rubies (fig. 16) are of a brownish-red colour and are consequently much less valuable than the Burmese. Ruby mines have also been worked for a long period in Badakshan on the upper Oxus; the products of these mines passing mainly through Persia. In Ceylon (fig. 12) ruby is much less common than sapphire. Amongst American localities may be mentioned Newton in New Jersey (fig. 10), Lownes County in Georgia (fig. 15) and Macon County in North Carolina (fig. 17).

Ruby is generally cut in a flat brillant form or in the step-cut, and is set *à jour*. Its value depends on the clearness, shade of colour, and size of the stone. A faultless ruby of the best colour and weighing 3 to 5 carats fetches ten times the price of a diamond of the same weight; and for still larger stones no definite price can be stated. For a cut stone of $32^{5}/_{16}$ carats £ 10,000 has been paid, and for one of $38^{9}/_{16}$ carats twice this amount. Since the price varies widely with the clearness, colour and size of individual stones, it is difficult to state this exactly. On the average, a one-carat Burmese stone fetches from £ 2 10s. to £ 7 10s., while the dark coloured Siamese stones are worth about half of this amount. Paler stones are much more common and consequently cheaper. An idea of the size of a one-carat cut stone may be obtained from fig. 13 (weight, 0·2 gram = 1 carat): that represented in fig. 14 weighs 0·355 gram. Recently, cloudy ruby, which occurs as much larger crystals, has been cut and worn as necklaces.

Precious stones which may be mistaken for ruby are garnet (almandine and "Cape ruby"), spinel ("ruby-spinel" and "balas-ruby"), tourmaline (rubellite), and red topaz. Garnet and spinel being cubic minerals are singly refracting and are not dichroic, and the others differ from ruby in their specific gravity and refractive indices.

Owing to the rarity and high value of ruby, many attempts have naturally been made to prepare it in the laboratory, and recently with highly successful results. The methods employed will be mentioned further on at the end of our remarks on corundum. The stones of artificial origin can be distinguished from those of natural origin by the fact that under the microscope they show the presence of minute rounded cavities, or bubbles, and curved streaks; in the natural stones any minute cavities which may be present are angular in outline and the streaks are straight. Apart from these minute differences, however, there are no differences between the two, and many of the artificial stones are of even a better carmine-red or "pigeon's-blood" red than the natural stones. These artificial stones are produced in large quantities and quite cheaply; but, since they can always be distinguished as artificial products, the high price of the natural stones is not thereby lowered.

Sapphire is a blue colour-variety of corundum. Here the crystals are more frequently pyramidal in habit; a steep hexagonal pyramid is shown in plate 42, fig. 6, in combination with the base in figs. 15 and 18, and with the base and rhombohedron in fig. 3. Fig. 2 shows the prism and the base, and fig. 7 a twin-crystal.

The colour of sapphire ranges from pale blue or almost colourless to a deep inky blue, the colour most sought being an intense cornflower-blue. The same stone may be differently coloured in different parts, there being lighter milky patches in dark stones and darker patches in light stones, while less frequently blue bands alternate with those of another colour: such a banded stone is represented in plate 42, fig. 4, where the large face to the front is the basal plane. A yellow colour is often associated with the blue, as in figs. 6 and 7, and in that case the value of the stone is very low. Some bluish-green stones show patches of a more decided blue or green colour (fig. 8); these are strongly dichroic, showing in the dichroscope indigo-blue and green images. Stones of a pure blue colour are less distinctly dichroic; the crystal in fig. 6 gives for the ordinary ray a pure blue and for the extraordinary ray pale green; while other crystals show dark blue and pale blue respectively. Owing to this dichroism, stones show the purest and deepest blue colour when they are cut with the table facet parallel to the basal plane. The colour of a sapphire is not seen to advantage by lamplight.

The degree of transparency varies between wide limits: some crystals are perfectly transparent, and these are distinguished as precious sapphire, while others are only translucent or quite opaque (figs. 1—9).

Properly, the name sapphire should be limited to corundum of a blue colour, but it is also usual to speak of white sapphire, yellow sapphire, etc.

Yellow sapphire ("oriental topaz" or topaz-sapphire) is applied to those specimens of corundum in which some shade of yellow is pronounced. When specially clear these frequently exhibit small cloudy and milky patches, a peculiarity which enables "oriental topaz" to be at once distinguished from other yellow gem-stones. The dichroism is very feeble; but the brilliancy and fire is specially strong, and in lamplight there is no diminution in the beauty of the stone.

Amethyst-sapphire (or "oriental amethyst") is violet corundum with a distinct tinge of red. This is quite a rare stone, and can be readily distinguished from the true amethyst by its much higher specific gravity and by its strong pleochroism. With a deeply coloured violet stone the dichroscope shows for the ordinary ray a bluish-violet and for the extraordinary ray a yellowish-red image. In lamplight the colour appears redder, whilst the true amethyst becomes a dull grey.

Other gem-varieties of corundum may present colours resembling the aquamarine, chrysolite, emerald or hyacinth, and these are known by the corresponding names with the prefix oriental. These are, however, of rare occurrence, and their dichroism is usually only feeble.

Star-sapphire, or asteria, on the contrary, is commoner and of more importance. This is usually of an inconspicuous greyish-blue colour, though sometimes blue, violet or red (than properly a star-ruby), and is often quite cloudy. It characteristic feature is the six-rayed star of light which is reflected from the basal plane, due, as already explained, to the presence of numerous thin twin-lamellae in the stone. In order to show this star to the best advantage the stone should be cut and polished with a highly convex surface (*en cabochon*) with the flat base of the dome parallel to the basal plane. If the stone be cut in a direction at right angles to this it will show only one band of reflected light on the surface, and being then like a cat's-eye, it may be called a sapphire cat's-eye. At the present time good star-sapphires are held in high esteem, and the sharper the star the greater is their value.

Sapphire occurs in nature as a constituent of rocks of igneous origin. Several crystals embedded in the felspar of a granitic rock from the Urals are represented in plate 42, fig. 5. Small grains of sapphire are also sometimes found scattered through basalt. Usually, however, sapphire is found in deposits of clay and gravel, which have resulted from the breaking down of the mother-rock.

The most important localities are in Siam, and then follow Burma, India, Ceylon, Australia and the United States of North America; at other localities only cloudy stones of little value as gems are found. Sapphires of the best colour are found at Pailin and Battambang in Siam: those from Ceylon are usually pale and patchy (figs. 6 and 7); those from Australia (Emmaville and Tingha in New England) and from the United States (Eldorado Bar in Montana) are often dark greenish-blue. Recently, stones of a deep and pure blue colour have been found in the upper course of the Judith river and at Yogo Gulch in Fergus county in Montana. Sapphire sometimes of a good colour, but usually cloudy or only slightly transparent, is found near Miask in the Ilmen mountains in the Urals. Grains of sapphire are found in the Rhenish basalt at Unkel, Niedermendig and other places; cloudy prismatic crystals in granite at Wolfshau in Silesia; and with cloudy ruby in the dolomite of Campo longo on St. Gotthard.

Sapphire has been known since ancient times, and on rare occasions it is been engraved as a gem, though on account of its great hardness it is not well adapted for this purpose. At the present day it is much worn in jewellery, and its value depends mainly on the depth and purity of its colour. The most highly prized stones are of an intense cornflower-blue with uniformity of colouring and a velvety appearance combined with perfect transparency.

A ten-carat stone of the best quality would be worth £50 to £75, while paler stones with an irregular distribution of colour are worth much less (12—15 shillings per carat). Stones which are banded with blue and yellow may sometimes be so cut that the upper portion of the gem is in a blue layer, while the lower portion, which is hidden as far as possible in the setting, is yellow: such a stone when viewed from the front may show a good blue colour, but when viewed from the side it will appear distinctly yellow. The dark greenish-blue Australian sapphires are now largely in use, and cost from eight to ten shillings per carat. Stones of other colours are as a rule, cheaper: the yellowish stone weighing 1·235 gram (about 6 carats) represented in fig. 19 was bought for thirty shillings. Violet sapphire costs about 15s. per carat, and star-sapphire 6s. or more depending on the quality.

From other precious stones of similar colour sapphire and other varieties of corundum can always be readily distinguished by the specific gravity. The cut stone in fig. 8, which might be confused with tourmaline, was found to have a specific gravity of 4·1, proving it to be corundum.

Common corundum is cloudy and not attractive in colour; it may be grey, yellowish, bluish (plate 42, fig. 21), reddish-brown (fig. 17) to dark brown (fig. 20) or almost black. The crystals may be combinations of the prism and base (fig. 17) or a pyramid and the base (fig. 20), with or without a rhombohedron. It occurs embedded in granite, gneiss, serpentine, crystalline dolomite or other rocks at the localities mentioned above for ruby and sapphire. Large deposits of common corundum occur in the United States, a country which has also yielded some very large crystals, not only of corundum, but of many other minerals; the largest on record is a crystal weighing 312 pounds from the Culsagee mine in North Carolina. Massive corundum is sometimes known as admantine-spar, in reference to the hardness.

A fine grained mixture of sapphire with various iron ores constitutes the well-known *emery*. This is found especially in Asia Minor and the Island of Naxos, where it is interbedded in granular limestone or is met with in secondary deposits.

A mineral which frequently occurs in association with emery or common corundum is *diaspore*. This is usually found as greyish or yellowish foliated aggregates with a perfect cleavage and pearly lustre in one direction. In addition to alumina it contains some chemically combined water, the formula being $Al_2O_3 . H_2O$. It is a product of alteration of corundum and is found at the localities mentioned above for emery, and at Kossoibrod in the Urals and Chester in Massachusetts.

Artificial production of Corundum. — Crystallized corundum possessing all the characters of the natural mineral but of a dull grey or reddish colour is at the present day formed in large quantities as a by-product in the Goldschmidt process of preparing metallic chromium (p. 157) and in the electrolytic preparation of aluminium. Beautiful crystals of ruby were prepared in 1877 by Frémy and Feil; these are transparent and of a fine colour, but being in the form of thin hexagonal plates they are of little use for cutting as gems. One of the methods employed was to fuse at a high temperature (1500° C.) a mixture of amorphous alumina, potassium carbonate, calcium fluoride and potassium bichromate in a porous crucible. It is probable that under these conditions a series of reactions takes place: aluminium fluoride would first be formed, and this would be decomposed by the air and water vapour penetrating through the porous walls of the crucible from the source of heat. A still more successful process, by which fine rubies of almost any size and of good gem-quality are produced with ease, was devised in 1904 by Professor A. Verneuil of Paris. The material he uses is pure ammonium-alum, which, in a powdered form, is fed through the oxygen tube of an inverted oxy-hydrogen blowpipe. In the intensely hot flame the water, ammonium and sulphuric acid are volatalized and the alumina falls as a molten drop on a pedestal beneath and there crystallizes as corundum. As the operation is continued the corundum grows upwards as a pear-shaped drop or "boule". The material so obtained is colourless if the alum is quite pure and no colouring materials have been added: a ruby-red colour results by the addition of some chromium-alum to the ammonium-alum. Although these drops have a smooth rounded exterior with no external crystal-faces, they each consist of an individual crystal with an internal crystalline structure and identical in all their characters with naturally-occurring corundum.

Applications of Corundum. — Besides its use as a gem-stone, corundum has certain technical uses. Emery and massive corundum are powdered and sifted into grades of various fineness, the finest by washing in water, and used as an abrasive, either in the form of powder, as emery cloth, or as corundum wheels. In its use by lapidaries for grinding precious stones it has now largely been replaced by the harder carborundum. Corundum of the poorer gem-qualities are used for jewelling watches and other fine instruments, that is, as a hard bearing for steel pivots. The artificial corundum (known as corubin) produced in the Goldschmidt process exceeds emery in its hardness and abrasive power, and it is also used for the construction of refractory crucibles and moulds.

Appendix to Corundum.

Metallic aluminium was first prepared by Wöhler in 1827 by the reduction of aluminium chloride with potassium, and since then it had long been regarded as a metal of the future. At the present day it is obtained in large quantities from alumina directly. Corundum is, however, not formed in sufficiently large amount to be made use of, and the alumina employed is prepared from bauxite.

Bauxite is an earthy or clayey material of unattractive appearance, which when pure consists of alumina and water in approximately the proportions given by the formula $Al_2O_3.2H_2O$; it is, however, probably not a definite mineral species, but a mixture. It occurs as bedded deposits, and has been formed by a special kind of weathering process from basaltic and other rocks: and on this account it is frequently much intermixed with silica and iron oxide. With the percentage of iron the colour varies from white to yellow and brown. Extensive beds of this material are worked at Baux near Arles and other places in the south of France, and in County Antrim, and to a smaller extent at the foot of the Vogelsberg in Germany. The richest deposits are those of Georgia and Alabama in the United States, where in the year 1899 the output of bauxite amounted to upwards of 30,000 tons. Laterite, which is of wide distribution in tropical countries as a weathering product of granite, diorite, diabase and other rocks, also contains variable amounts of the bauxite substance.

The French bauxite, such as is used at Neuhausen on the Rhine for the manufacture of aluminium, contains alumina 60°/₀, iron oxide 20°/₀, silica 3—4°/₀, and water 16—17°/₀. From this mixture the iron oxide and silica are removed by chemical means, leaving a purified product containing on the average 99°/₀ of Al_2O_3. Metallic aluminium is extracted from this by electrolysis, the electrical energy being generated by water power, at Neuhausen on the Rhine, at Foyers in Inverness-shire, and at the Niagara Falls.

The electrolytic apparatus consists of an iron box thickly lined with blocks of carbon or better with fire-brick. A plate of copper or iron inside the box at the bottom, and connected to the exterior by a thick rod, forms the cathode, whilst the anode consists of a thick bundle of carbon rods. In order to start the process a mixture of alumina and cryolite is placed in the box and fused by the electric current of about 25,000 ampères per square metre of the cathode. Fusion takes place rapidly and metallic aluminium commences to separate on the cathode at the bottom of the vessel, which itself then forms the cathode. This is drawn off from time to time, but incompletely, sufficient molten aluminium being left behind in the box to continue to act as the cathode. The walls of the box are carefully cooled, otherwise the lining would be dissolved by the cryolite. More alumina is added from time to time, and the process proceeds continuously. The oxygen liberated at the anode combines with the carbon forming carbon dioxide, so that the anode has occasionally to be renewed. The temperature of the fused mass has to be carefully regulated, and the strength of the electric current must be kept as low as possible so long as the material remains fluid. During the continuation of the process the cryolite is decomposed to a slight extent and requires replenishing from time to time. The whole of the aluminium of commerce is now manufactured by this process.

Aluminium is remarkable amongst metals by reason of its very low specific gravity of 2·7. It can be cast in moulds, and being very ductile and not hard it is readily worked. If only it were resistant to saline solutions its applications would be still more extensive. It is largely used for the construction of vessels and pieces of apparatus in which a light weight is essential or desirable, for example, soldiers' flasks, boats of various kinds, parts of telescopes and photographic apparatus. It is also drawn into wire and rolled into sheets. Aluminium foil is used for "silvering" picture frames.

Since in the preparation of aluminium a very high temperature is necessary for the separation of the metal from the oxygen, a very high temperature (up to 3000° C.) is generated when the metal again combines with oxygen. On this depends the Goldschmidt process for the preparation of metallic chromium (p. 157) and other difficultly fusible metals. By the ignition of "thermite" (a mixture of powdered aluminium and magnetic oxide of iron) iron tyres, rails, etc., can be welded and hard steel softened; the method having the great advantage that the intense heat can be applied quite locally without affecting other portions of the structure. It has been used, for instance, by burglars for attacking iron safes.

Alloys of aluminium and copper have been already mentioned above under the latter metal. Recently an alloy of aluminium and metallic magnesium, known as "magnalium", has been used in the form of thin plates, it having certain advantages over pure aluminium. An alloy of aluminium and iron, ferroaluminium, is employed in the metallurgy of iron, especially in the re-melting of old iron, it producing a sound and uniform casting.

The amount of metallic aluminium produced in the years 1897 and 1907 is given below in metric tons (of 1000 kilograms):

	1897.	1907.
North America	1815	16329
Switzerland, Germany and Austria	800	8000
France	470	4500
Great Britain	310	3700
Total	3395	32529

While fifty years ago aluminium cost at the rate of £170 per kilogram, the present price is about two shillings, or about a shilling per pound.

Spinel.

Spinel contains the same constituents, aluminium and oxygen, as corundum with the addition of magnesia. Although the composition is so simple, the exact constitution of the mineral is still debatable. It may be regarded as a combination of two oxides, that is, a double oxide analogous to a double salt, when the formula would be written $MgO . Al_2O_3$. On the other hand, it is also often considered to be a simple salt in which alumina plays the part of an acid, and the formula written $MgAl_2O_4$, representing an aluminate of magnesium. Here we shall adopt the first of these alternative views.

Spinel may be taken as the type of a large group of minerals, the spinel group, all of which possess the same crystalline form and are analogous in chemical composition, being therefore isomorphous. Certain members of the group approximate to the ideal compositions stated below, while others consist of isomorphous mixtures of these and occupy intermediate positions; the more important members are:

Precious spinel, $MgO . Al_2O_3$.
Hercynite, $FeO . Al_2O_3$.
Pleonaste, $(Mg, Fe)O . (Al, Fe)_2O_3$.
Magnetite, $FeO . Fe_2O_3$.
Gahnite, $ZnO . Al_2O_3$.
Franklinite, $(Zn, Fe, Mn)O . (Fe, Mn)_2O_3$.
Chromite, $(Fe, Mg)O . (Cr, Al, Fe)_2O_3$.

Of these, magnetite, gahnite, franklinite and chromite have already been described; and of the others, precious spinel is the most important on account of its use as a precious stone.

Precious spinel is often very similar to ruby in colour, and when clear and transparent it is known as *balas-ruby* (plate 43, fig. 1) and *ruby-spinel* (fig. 2); the former of these names being applied to stones of a deeper red colour, and the latter to paler stones; but in the trade both are often loosely spoken of as ruby. When the colour has a brownish or yellowish tinge the name *rubicelle* is used; and a reddish-violet spinel is called *almandine-spinel*, or incorrectly almandine, for almandine is really a variety of garnet. These red colours may be of various shades, from pale red to deep ruby-red, delicate violet to dark violet, or violet-red and brownish-yellow. Blue, bluish-green and green colours may also occur, but these are much less common.

From ruby, red spinel differs not only in its chemical composition (which is not, however, readily determinable), but also in its crystalline form and physical characters. It crystallizes in the cubic system, and most crystals have the form of the simple octahedron (plate 43, figs. 1 and 2), the edges of which are sometimes truncated by narrow faces of the rhombic-dodecahedron. Twinned crystals with a face of the octahedron as twin-plane (text-fig. 142, p. 155) are of frequent occurrence; and they are so typical of spinel that twins of this kind are known as spinel-twins, even when they occur in other minerals; for instance, a spinel-twin of magnetite is shown on plate 29, fig. 9. Crystals of spinel are, as a rule, quite small; and the twinned crystals are often flattened parallel to the twin-plane.

When crystal-faces are present there is no difficulty in distinguishing between ruby and spinel by mere inspection; in the absence of these, as in a faceted gem, the two minerals can be readily distinguished by their optical characters. Spinel, being cubic, is optically isotropic, and when examined in the polariscope, in either parallel or convergent light, it remains dark. The refractive index, 1·72, of spinel, is rather lower than that of ruby, though still high enough for the stone to be of considerable brilliancy: while owing to its high degree of hardness (H. = 8) it takes a good polish. To the Röntgen rays spinel is much less transparent than ruby. The red colour of spinel is probably due to the presence of a small amount of iron or chromium: an analysis showed the presence of ferrous oxide 0·7 %, chromium oxide 1·1 %, together with 69·01 % alumina, 26·21 % magnesia, and 2 % silica. Under the action of heat the colour of spinel changes in much the same way as that of ruby, though at a low red-heat the stone is a dull grey instead of bluish-green; on cooling it regains its original red colour.

The specific gravity, 3·5—3·6, of spinel is rather high, though not so high as for ruby.

The size of spinel crystals is very variable; occasionally they may be as large as a walnut, while others are smaller than a pin's head, and between these two extremes they may be of any size. The two crystals represented on plate 43 show the average size. The larger crystals usually consist of a parallel aggregation of smaller individuals, and for this reason their faces are uneven and their edges rounded: only the smaller crystals are sharply developed.

Precious spinel is found as isolated crystals in the gem-gravels of Ceylon and Upper Burma; they are bounded by faces on all sides, but are often much rounded and water-worn. The crystals from Upper Burma are usually very dark in colour and those from Ceylon (plate 43, figs. 1 and 2) paler. In both these districts the mother-rock is a granular limestone, or marble, and the mineral, together with ruby, has probably been formed by the contact-action of an igneous rock-mass. Another important locality is Siam.

PLATE 43.

Spinel and Zircon.

Fig.

1. **Spinel** ("Balas ruby"), pale red octahedron.
Ceylon.
2. **Spinel** ("Ruby-spinel"), deep red octahedron.
Ceylon.
3. **Spinel,** blue, rhombic-dodecahedron with octahedron.
Ceylon.
4. **Spinel,** black octahedron.
Nikolaje-Maximilianovskoi mine, Zlatoust, Ural Mountains.
5. **Spinel,** bluish-grey, corroded octahedron in limestone.
Åker, Sweden.
6. **Spinel,** bluish-grey, fissured cube in limestone.
Wakefield, Ottawa Co., Quebec, Canada.
7. **Spinel** ("Pleonaste"), octahedron with icositetrahedron, on scapolite.
Warwick, Orange Co., New York, U. S. A.
8. **Spinel** ("Pleonaste"), octahedron.
Monroe, Orange Co., New York, U. S. A.
9. **Zircon,** tetragonal prism and pyramid; brown and cloudy.
Renfrew Co., Ontario, Canada.
10 and 11. **Zircon,** prism with pyramid; water-worn crystals.
Ceylon.
12. **Zircon,** prism with pyramid; a doubly-terminated crystal.
Buncombe Co., North Carolina, U. S. A.
13. **Zircon,** dark reddish-brown almost black; prism with eight-sided pyramid.
Ceylon.
14 and 15. **Zircon,** prism with two pyramids of the same order.
Mineville, Port Henry, Essex Co., New York, U. S. A.
16—19. **Zircon,** faceted stones. No. 16, weight 0·82 gram, specific gravity 4·71;
No. 17, weight 8·605 grams; No. 18, weight 1·16 gram, specific gravity 4·69;
No. 19, weight 0·79 gram, specific gravity 4·22.
Ceylon.
20. **Zircon,** prisms of the first and second orders with pyramid of the first order.
Ilmen Mountains, Urals.
21. **Zircon,** prism with several pyramids of the first order.
Caldas, Minas Geraes, Brazil.
22. **Zircon,** twinned crystal.
St. Jerome, Terrebonne Co., Quebec, Canada.
23. **Zircon,** in basaltic lava.
Niedermendig, Andernach, Rhine.
24. **Zircon,** large crystal in syenite.
Ilmen Mountains, Urals.


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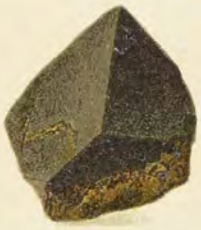
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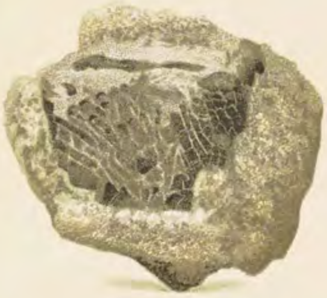
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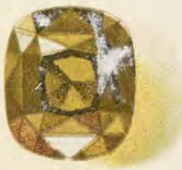
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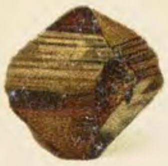
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Blue spinel is also to be regarded as a precious spinel when it is clear and transparent; usually, however, it occurs as cloudy crystals of unattractive appearance. Transparent crystals of a deep blue colour and of the size of a pea are found in Ceylon (plate 43, fig. 3); these have the form of the rhombic-dodecahedron with its faces striated parallel to their longer diagonal, as in magnetite (text-fig. 141, p. 155), and the three-edged corners truncated by faces of the octahedron. The close relation between spinel and magnetite is expressed not only by this similarity of crystalline form, but also by the fact that in blue spinel a portion of the magnesia is replaced isomorphously by ferrous oxide (up to $3^1/_2\,\%$ FeO). The blue spinel from other localities is cloudy, and its colour more of a bluish-grey, whilst the crystals are much corroded. Octahedra of this kind occur embedded in limestone at Åker in Sweden (fig. 5), and large cubes with curved and corroded faces are found at Wakefield in Ottawa Co., Quebec, Canada (fig. 6).

Spinel when clear and of a good colour is one of the more valuable of precious stones; a faultless ruby-spinel of 1—4 carats would cost £5—£20, while larger stones being of great rarity are much more expensive. A spinel-ruby of unusual size, weighing $133^1/_2$ carats, is one cut in the form of a knob, and on four plane facets it bears in Persian characters the names of four emperors of the Great Mogul dynasty. As already mentioned, red spinel is often known in the trade as ruby.

Blue spinel has only comparatively recently been cut and is not often met with in jewellery. Its colour usually shows a faint tinge of green and is somewhat dusky, a good sapphire-blue colour being quite rare. A blue spinel may readily be mistaken for blue tourmaline, from which it may be distinguished by its higher specific gravity, single refraction, and absence of dichroism. A good dark blue stone costs about eight shillings per carat. Recently blue spinels have been made artificially by the same method as that devised by Verneuil for the manufacture of rubies (p. 221), and have been sold as sapphires.

Green spinel. Whilst in blue spinel a part of the magnesia is replaced by ferrous oxide, in green spinel a portion of the alumina is replaced by ferric oxide (a specimen from the Urals containing $8{\cdot}7\,\%$ Fe_2O_3), so that the formula becomes $MgO.(Al, Fe)_2O_3$. It also contains a small amount of copper ($0{\cdot}17\,\%$), to which perhaps the green colour is due. It is of a grass-green colour, and known as chlorospinel, but it is not used as a gem-stone. It occurs in chlorite-schist near Zlatoust in the Ural Mountains.

Black spinel, ceylonite or pleonaste, differs from blue spinel in containing a still larger proportion of ferrous oxide, and also sometimes in the development of its crystals. It is greenish- or bluish-black, the colour being sometimes so deep that the crystals resemble magnetite in appearance, especially when the faces are bright and smooth. The octahedron always predominates, and is present either as a simple form (plate 43, figs. 4 and 8) or in combination with the icositetrahedron $3O3$ (fig. 7 and text-fig. 174). This is distinctly a mineral of contact-metamorphic origin, occurring usually in limestone which has been altered by contact with an igneous rock. Under these conditions it is found in blocks of limestone on Monte Somma, Vesuvius; in the Fassa valley in southern Tyrol; at Warwick (figs. 7 and 8), Amity and Monroe in the state of New York. Water-worn grains are also found in the gem-gravels near Kandy in Ceylon, hence the name ceylonite: the material from this locality is richer in iron than any other black spinel, containing $20{\cdot}5\,\%$ of ferrous oxide, together with $57{\cdot}2\,\%$ of alumina, $18{\cdot}25\,\%$ of mangnesia, and $3{\cdot}15\,\%$ of silica.

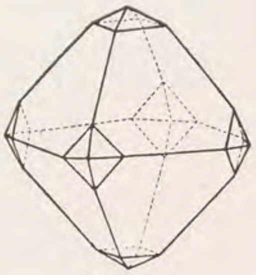

Fig. 174.
Crystal of Spinel
(Ceylonite).

Pure crystals free from enclosures, especially the water-worn crystals and pebbles from Ceylon, take a very good polish, and are used in mourning jewellery, though they are of little importance.

Hercynite is a member of the spinel group in which the magnesia is almost completely replaced by ferrous oxide. It occurs as a constitution of certain gabbros, but is of limited distribution. *Picotite*, another member of the group, is more common; it contains, besides magnesia (10·3 %), much ferrous oxide (25 %), together with alumina (56 %) and a considerable amount of chromium oxide (8 %). This occurs as a constituent of rocks rich in olivine, being enclosed in the olivine. The round black grains in plate 67, fig. 6, are picotite. With an increase in the amount of chromium picotite passes into chromite (p. 157).

Zircon.

Zircon, like spinel, is a mineral the comparatively simple chemical composition of which can be interpreted in more ways than one. It contains oxide of zirconium and oxide of silicon in equal molecular proportions, and it can therefore, like spinel, be regarded as a double oxide $ZrO_2 . SiO_2$. According to another view, the compound is a salt, the zirconia being the base and the silica the acid portion; the formula is then written as $ZrSiO_4$, which express a silicate of zirconium. An analysis of a colourless zircon from Ceylon showed the presence of ZrO_2 66·71 % and SiO_2 33·05 %. Coloured zircon contains in addition from $^1/_2$ to 3 per cent. of iron oxide. Small amounts of thorium and other rare earths are also sometimes present.

The crystalline form is tetragonal, and the crystals, which are frequently bounded by faces on all sides, afford very good examples of this type of symmetry. The simplest form is a combination of a square prism and pyramid of the same order (text-fig. 175). This pyramid (*o*) has an angle of 123° 19′ between adjacent faces, and it is taken as the primary pyramid with the symbol *P*; the prism (*M*) is then also of the first order with the symbol ∞ *P*. The crystals in figs. 10 and 12 of plate 43 are of this form. A steeper pyramid of the first order with the symbol 3 *P* is lettered *s* in text-fig. 179, and is present in figs. 9 (on the right), 14 and 15, being in the last two larger than the pyramid *P*. Occasionally the prism faces may be very narrow or even quite absent, and we have then the simple bipyramid (fig. 21). On other crystals the prism of the second order may be present, either as narrow faces (*a* in text-fig. 176) or as the predominating form (text-fig. 177 and figs. 20 and 24); or again, it may be present to the exclusion of the first prism (text-fig. 178). Faces of an eight-sided pyramid may also sometimes occur (*x* in text-fig. 179, and fig. 13); a narrow face of the same form is seen in the lower part of

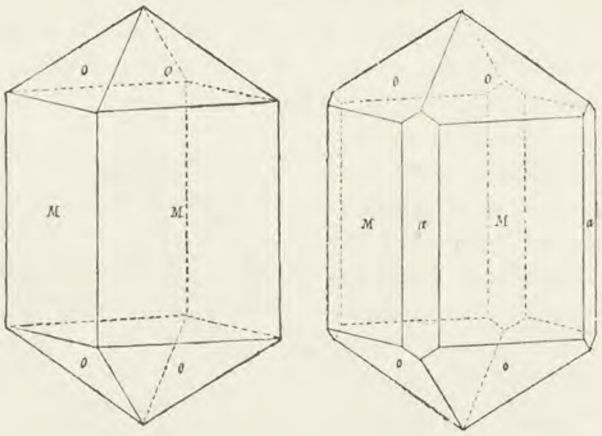

Fig. 175. Fig. 176.

Crystals of Zircon.

the crystal in fig. 24, where it truncates an edge between the pyramid of the first order and the prism of the second order.

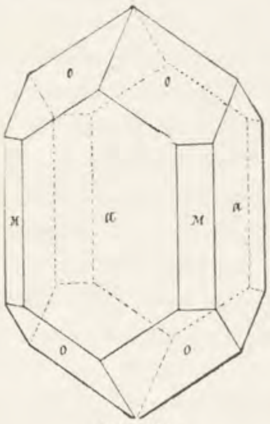

Fig. 177.

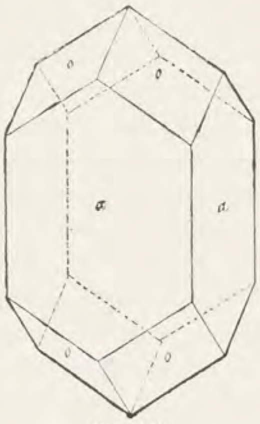

Fig. 178.

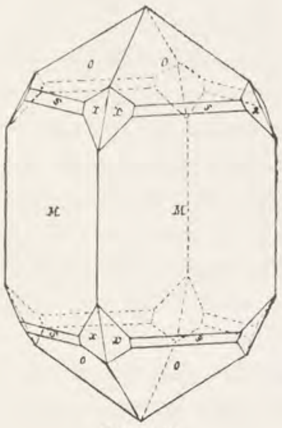

Fig. 179.

Crystals of Zircon.

Twinned crystals are rare, and they have a face of a pyramid of the second order $P\infty$ as twin-plane: in fig. 22 the forms present on the two individuals of the twin are the same as in text-fig. 175. In this mode of twinning, as well as in the habit of the crystals and the angles between the faces, there is a close similarity between zircon and rutile and cassiterite; and on this account these three minerals are often regarded as isomorphous.

Most crystals of zircon are cloudy and much fissured, being then almost opaque. Although quite hard ($H. = 7^{1}/_{2}$), such fissured crystals may readily be broken into fragments. On the other hand, clear crystals free from fissures are not so readily fractured, but these are usually rounded and with a rough surface (fig. 10 and 11). The colour is usually yellow, brownish-yellow, brown, or brownish-red to red; stones of a reddish colour being known as *hyacinth*. Other zircons may be colourless, green, rose-red, or violet, but stones of a pronounced blue colour are unknown. A few faceted stones of good colour are represented on plate 43; that in fig. 17 has much the same colour as the crystal in fig. 10, and the colour of fig. 18 is near that of fig. 11. The colour is sometimes of a very fiery hue, especially in certain brownish-red stones known as "hyacinth-topaz": in others it is more dusky, so that with a little practice it is possible to recognize zircon by means of its colour alone. The stones are not always uniformly coloured, as may be seen when they are viewed by transmitted light. The large stone shown in fig. 17 appears by reflected light to be uniformly coloured, but when it is held up in front of a window numerous very fine bands differing in colour are to be seen.

The colour of zircon is not always permanent when exposed to light and heat; for instance, zircon of a delicate rose-red from the Laacher See becomes colourless on exposure to light. Many coloured zircons are decolorized when subjected to a red-heat; and such decolorized stones may be mistaken for diamonds. A brown zircon (from Tasmania) when simply wrapped up in tinder and this ignited is decolorized, a colourless stone dropping out from the ash; it, however, does not remain colourless, and after a few months it becomes pale brownish-yellow.

The lustre of a clear zircon is adamantine in character, and approaches to that of diamond. The refractive index is high, being for the ordinary ray 1·9239 and for the extraordinary ray 1·9682, as determined on a zircon from Ceylon. The difference between these two values shows that the double refraction is also high. Dichroism can usually be distinctly recognized with the help of the dichroscope: the stones shown in figs. 16 and 18 give rose-red and yellow images, and the green stone in fig. 19 gives yellowish-green and colourless.

A remarkable feature of zircon is presented in the very wide variations in its specific gravity. For instance, the stone represented in fig. 16 has the value 4·71, that in fig. 18 being 4·69, while that in fig. 19 has a specific gravity of only 4·22: in other stones it may be as low as 4·0. Further, the specific gravity of some of the lighter crystals may be raised to the higher limit (4·7) by heating the crystals to redness, the change in specific gravity being usually accompanied by a change in colour. These variations suggest the existence of at least three polymorphic modifications of zirconium silicate, which differ not only in their specific gravity and behaviour when heated, but also in their optical characters. Zircon is the heaviest of all precious stones, and only in its lightest varieties it is equalled by almandine.

Zircon is very resistant to chemical reagents, most acids have no action on it, and only by sulphuric acid is it very slowly decomposed. It is thus not attacked by weathering processes; when the mother-rock is broken down the zircon it contains still remains fresh and unaltered, and in this condition it is often found in river-gravels. Indeed, microscopic crystals of zircon may be found in all sands and sedimentary rocks. Such crystals of zircon can readily be separated from any ordinary sample of sand by placing it in a heavy liquid, such as bromoform (sp. gr. 2·8), in which the quartz grains will float and the heavier minerals will sink. A further separation of the heavy minerals can be made with methylene iodide (sp. gr. 3·3). In the heavy residue so obtained zircon can be recognized under the microscope by its form, which is usually like that shown in fig. 13.

As to its mode of occurrence, zircon is found embedded in granite, syenite, basalt, and other igneous rocks, and in the sands and gravels which have resulted from the breaking down of these. Most crystals are only microscopic in size, and it is at only a few localities where they are found of any appreciable size, but then often in great numbers. Attached crystals are extremely rare.

In Germany, zircon is found in the Rhenish basaltic rocks, as in the millstone lava of Niedermendig (plate 43, fig. 23), in the basalt of Burgbrohl, Unkel and the Siebengebirge; small crystals of a delicate rose-red which fades on exposure to light are sometimes to be found in the sanidine blocks of the Laacher See. Colourless crystals occur attached to the walls of crevices in chlorite-schist in the Pfitsch-thal, Tyrol, but these are rare. Large crystals are embedded in the felspar of a syenitic rock near Miask in the Ilmen Mountains, southern Urals: fig. 24 shows such an embedded crystal, and fig. 20 one isolated from the matrix. These are characterized by the predominance of the prism of the second order, and by their brown or brownish-yellow colour combined with a certain degree of transparency. Zircon also occurs in a very similar rock in southern Norway; this rock is composed of felspar, elaeolite, mica and hornblende, and is known as a zircon-syenite, though it may perhaps be more correctly described as a nepheline-syenite containing some zircon.

The largest crystals of zircon, up to nearly six kilograms in weight, come from Renfrew in Ontario, Canada (fig. 9); and large twinned crystals are found at St. Jerome, Terrebonne Co., Quebec. In the United States, zircon is more abundant, especially in North Carolina, where in Henderson county it is extracted from a decomposed granite by the ton-load and used for technical purposes. The crystal shown in fig. 12 is from Buncombe Co., North Carolina; and the brownish-black crystals in figs. 14 and 15 from

Mineville near Port Henry in Essex Co., New York. Zircon is also found in the gem-gravels and gold-washings of Brazil (fig. 21).

Ceylon is rich in zircons of gem-quality, where they occur with other precious stones in the gem-gravels of the Matura and Saffragam districts. From here come the reddish-yellow variety known as hyacinth and several other coloured zircons. Hyacinth is usually found as quite small (about the size of the crystal in fig. 23) rounded grains, while crystals of other colours, though also water-worn, are larger (figs. 11—13). Although these water-worn crystals and pebbles of zircon are rough and dull on their exterior, they yield fine stones when cut. Recently, hyacinth, similar to that from Ceylon, has been found in Tasmania; and zircon of gem-quality is also fairly abundant in New South Wales.

As to the applications of zircon, it may be remarked that the brownish-yellow hyacinth has long been used as a gem-stone, but that those of other colours have only comparatively recently been placed on the market. The stones are nearly always cut in Ceylon and India, and it is therefore difficult to obtain the rough material. Brownish stones are often decolorized by the application of heat, and are then known as "cerkonier" or "Matura diamonds", or simply as colourless zircon. These are, amongst colourless precious stones, exceeded only by diamond in their high refractive index: they may be distinguished from diamond by their higher specific gravity and by their double refraction. Coloured zircons are also readily to be distinguished from other stones of similar colour by the higher specific gravity, or if this does not suffice, as in certain garnets, by their double refraction and dichroism. The brilliant or a mixed-cut is the form of cutting usually adopted; and the stones are often cut with a considerable depth, especially in India. Owing to its brilliant lustre and rich colours, this stone in coming more and more into favour. In the trade, deep brownish-red stones with much fire are known as "hyacinth-topaz", and the green, rose-red and yellow usually by their correct name, zircon.

The price is fairly moderate. Thus, the stone from Ceylon shown in fig. 17 with a weight of 8·605 grams (42 carats) was bought for a little more than £5 (109 marks); it is, however, not quite clear by transmitted light, but it is of an unusually large size. Smaller stones are considerably cheaper, the green stone in fig. 19 costing ten shillings, and the yellowish rose-red stone in fig. 18 sixteen shillings.

Besides being used as a precious stone, zircon has certain technical applications. On account of its hardness, it is used as pivot-supports for balances. The zirconia prepared from it possesses the property of becoming incandescent when ignited; advantage of this is taken in lighting, especially for projection lanterns where a brilliant light is required. Recently, zirconia has been much used in electric arc-lamps, it giving a more steady and more brilliant light. Some samples of zircon contain thorium, which is extracted for making the mantles of the Welsbach incandescent gas-lights; the bulk of the thoria used for this purpose is, however, obtained from monazite.

Beryl.

The species beryl includes several precious stones, which, though identical in chemical composition, crystalline form, and other essential characters, are markedly different in colour; and since colour is one of the first considerations in precious stones, these colour-varieties are distingnished by special names — emerald, aquamarine, golden beryl and common beryl. To the jeweller these are different stones, differing widely in their value. Chemically, this mineral is a silicate of beryllium and aluminium with the formula

$Al_2O_3 . 3\,BeO . 6\,SiO_2$; corresponding with the percentage composition: alumina 19%, beryllia 14·1%, and silica 66·9%. A small part of the beryllia is frequently replaced by an equivalent amount of magnesia, and small quantities of alkalis and water are sometimes present, while emerald contains a little (0·3%) chromic oxide.

Crystals of beryl belong to the holohedral class of the hexagonal system, and almost without exception they are prismatic in habit. The faces of the hexagonal prism are either smooth or striated vertically, and sometimes these striations may be so deep and frequently repeated that the column approaches a cylindrical form (plate 44, fig. 11). Many crystals are bounded simply by the hexagonal prism and the basal plane perpendicular thereto (figs. 4 and 14). Pyramid planes, when present, are usually small, and they belong to hexagonal pyramids of the first and the second orders. In fig. 9 is seen a face of a pyramid of the second order (*r* in text-fig. 180) set over the edge of the prism of the first order. The forms and symbols represented in the accompanying text-figures (180 and 181) have already been given on p. 32 (in these figures the corresponding faces do not bear the same letters: $a = m$, $p = o$, $r = q$). Frequently the crystals show rounded or corroded terminations (figs. 6 and 8), as if they had been attacked by some solution while still in the earth's crust. Fig. 7 shows a similar appearance, but here in the central portion of the crystal.

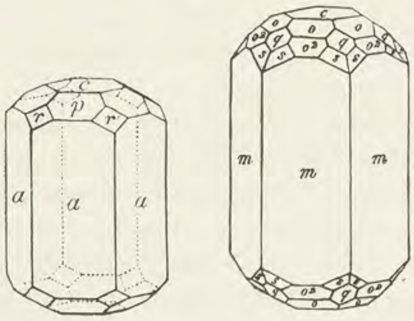

Fig. 180. Fig. 181.

Crystals of Beryl.

There is an imperfect cleavage parallel to the base, and this is sometimes shown by a series of horizontal fissures in the crystals (fig. 14). Usually, however, this cleavage is not to be seen, and the fracture of the mineral is typically conchoidal. It is said that the ancients used fragments of beryl with their curved fractured surfaces as eye-glasses, and it has been suggested that the German word 'Brille' for spectacles is derived from the Greek name 'beryllos' for this mineral. In the interior of clear crystals of beryl there may often be seen numbers of straight striae or bands which are so delicate and fine that in a cut stone they are only visible when placed at a certain inclination to the rays of light. If these striae are present in a cut stone, we can distinguish at once between a beryl and a similarly coloured topaz. The specific gravity of beryl varies between 2·67 and 2·76, being on the average slightly higher for emerald than for aquamarine. The hardness (H. = $7^1/_2$) lies between that of quartz and topaz.

Being a hexagonal mineral, beryl is doubly refracting. A chip taken off a crystal parallel to the base shows in the polariscope a uniaxial interference-figure (plate 4, fig. 1). The dichroism is distinct, and when a crystal is viewed through the prism planes with the aid of the dichroscope the two images are markedly different in colour: the crystals represented on plate 44 showed, for instance, the following pairs of colours (*o* for the ordinary image and *e* for the extraordinary image):

	o	*e*
Emerald (fig. 4)	yellowish-green	bluish-green.
Aquamarine (fig. 12) . . .	pale yellowish-green . . .	sky-blue.
Blue beryl (fig. 10)	almost colourless	sky-blue.
Golden beryl	gold-yellow	greenish-yellow.

The refractive power and the dispersion are both low, and the brilliancy and play of prismatic colours are correspondingly feeble; the effect of beryl as a precious stone depends rather on its fresh colour and its clearness. The refractive indices for yellow sodium-light

PLATE 44.

Beryl.

Fig.

1. **Beryl** ("Emerald"), in mica-schist.
   Habachthal, Salzburg.
2. **Beryl** ("Emerald"), small crystal, hexagonal prism with basal plane.
   From the emerald mines near the village of Muzo, Bogotá, Colombia, South America.
3. **Beryl** ("Emerald"), crystals in mica-schist.
   Emerald mines on the Takovaya stream, 85 kilometres east of Ekaterinburg, Ural Mountains.
4. **Beryl** ("Emerald"), clear, somewhat fissured crystal in calcite.
   Muzo, Bogotá, Colombia.
5. **Beryl,** colourless, transparent crystal.
   Neighbourhood of the village of Shaitanka, Ekaterinburg, Urals.
6. **Beryl** (Golden beryl), deep wine-yellow, transparent crystal; hexagonal prism.
   Mursinsk, Ekaterinburg, Urals.
7. **Beryl,** pale yellow, transparent crystal.
   Mursinsk, Ekaterinburg, Urals.
8. **Beryl** ("Aquamarine"), greenish-blue with smooth, bright prism faces and corroded termination.
   Nerchinsk, Transbaikalia, Siberia.
9. **Beryl** ("Aquamarine"), greenish-blue and transparent. Prism of the first order with pyramid of the second order and basal plane.
   Adun-Chalon Mountains, Nerchinsk, Transbaikalia, Siberia.
10. **Beryl,** blue crystal.
    Slieve Corra, Mourne Mountains, Co. Down, Ireland.
11. **Beryl,** blue, cylindrical.
    Adun-Chalon Mountains, Nerchinsk, Transbaikalia, Siberia.
12. **Beryl,** pale yellowish-green, perfectly clear and transparent. The edges between the prism and base have the appearance of being corroded.
    Borshchovochnoi Mountains, Nerchinsk, Transbaikalia, Siberia.
13. **Beryl** ("Aquamarine"), faceted stone.
14. **Beryl** ("Aquamarine"), hexagonal prism with bright faces, basal plane dull.
    Adun-Chalon Mountains, Nerchinsk, Transbaikalia, Siberia.


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were determined with a bluish-green beryl from Siberia to be 1·5719 (*o*) and 1·5674 (*e*). From these values it is seen that the double refraction is also low.

According to the colour and transparency of the mineral, the varieties mentioned above may be distinguished, and these will now each be described in turn; golden beryl we shall mention together with aquamarine, since these two varieties occur together. In addition to the colours mentioned, beryl may be colourless or pale rose-red, but stones of this description are only exceptionally cut as gems.

Emerald, the most valuable variety of beryl, is distinguished by its soft grass-green or emerald-green colour. This colour is most probably due to the presence of a small quantity, up to 0·3%, of chromic oxide, a metallic oxide which imparts this same shade of green colour to glass and to a blowpipe bead of borax. The crystals have the form of hexagonal prisms and are sometimes terminated by the basal plane (fig. 4) or with the base and small pyramid planes (fig. 2): those crystals which occur embedded in mica-schist very rarely have any definite terminations (fig. 3). Transparent crystals sometimes appear cloudy in the interior, and they are frequently cracked and marked by internal fissures; large stones quite free from these fissures being extremely rare. Stones which at first appear quiet clear may after a lapse of some time show fissures. The majority of crystals are so fissured and cloudy that they are only slightly transparent. All emeralds, even the clearest, contain fluid enclosures in microscopical cavities with jagged and frayed outlines; these are so constantly present that they are a help to the recognition of a genuine emerald.

In the Ural Mountains, emerald is found embedded in mica-schist near the Takovaya stream, eighty-five kilometres east of Ekaterinburg. It occurs here in association with pale greenish beryl, alexandrite and phenacite, and was first discovered by a peasant in the year 1830. Fig. 3 shows a good, typical specimen from this locality. Most of the crystals are penetrated by the mica-schist and are fissured, cloudy and irregularly coloured; but such stones are now cut as beads. The mines remained abandoned for many years, but have recently been opened up again by "The New Emerald Company", and Uralian emeralds and alexandrites again placed on the market. The earlier workings (till 1882) yielded during a period of two and a half years 360 kilograms of emerald and 41 kilograms of alexandrite.

An exactly similar occurrence of emerald is also worked on the "Smaragd-Palfen" in the Habachthal in the Salzburg Alps. The crystals (fig. 1) average 2 cm. in length and 5 mm. in thickness, and they are frequently clouded by enclosed scales of mica.

The finest emeralds come from near the village of Muzo in the state of Bojaco in Colombia, South America (figs. 2 and 4). Here the mineral occurs with calcite and black limestone in crevices in clay-slate. The mines were long ago worked by the Peruvians, in whose possession the Spaniards found many fine emeralds. The crystals rarely exceed one or two centimetres in length, but that represented in fig. 4 measures 3 cm.

In North America, a few large crystals of emerald have been found at Stony Point in Alexander Co., North Carolina; but in these the emerald-green colour is mainly confined to an outer layer. Emeralds are also known from New South Wales, but the mining for them is confronted with too many difficulties to be profitable.

The most ancient emerald mines are those situated in Upper Egypt, on the Jebel Zabara near the coast of the Red Sea, about 120 kilometres from Um Rus and 35 kilometres from the haven of Shenu Sheik. Here, as in the Urals, the emerald occurs embedded in a dark mica-schist, and the stones are said to be of the finest quality. The extensive mines are stated to have been worked as long ago as seventeen centuries before Christ, and it must have been these so-called Cleopatra's emerald mines that yielded the emeralds worn by the ancients.

Aquamarine and Golden beryl often present a richer development of crystal faces than does the variety emerald, and their forms have already been mentioned (figs. 180, and 181). The crystals are often perfectly clear and transparent and are of fresh and bright colours. Aquamarine may range from colourless, through pale yellowish-green and bluish-green, to a decided blue shade; this range of colour is more or less represented on plate 44 in figs. 5, 12, 14, 9, 8, 10 and 11. Or again, the colour may range from pale yellow (fig. 7) to a rich gold-yellow as in the fine crystal of golden beryl not shown to its full beauty in fig. 6. These varieties are found only in cavities in granitic rocks, and are usually associated with crystals of quartz and topaz.

The principal localities are in the neighbourhood of the villages of Mursinka (figs. 6 and 7) and Shaitanka (fig. 5), near Ekaterinburg in the Urals. Large corroded crystals are found at Alapaifsk, also in the Urals. The crystals shown in figs. 8, 9, 11 and 14 are from the Adon-Chalon Mountains in the Nerchinsk district of Transbaikalia, and that in fig. 7 from the Borshchovochnoi Mountains in the same district. Good crystals of a blue colour have been found in the Mourne Mountains in Ireland (fig. 10). Colourless, reddish, greenish, and bluish crystals are also found in granite at San Piero in the Island of Elba.

In Brazil, very large crystals of aquamarine of gem-quality have been found in the district of Minas Novas in Minas Geraes, and have recently been placed on the market. These crystals are usually of a pale yellowish-green colour and are bounded by prisms and pyramids of the first and second orders, a twelve-sided pyramid and the base, the symbols of these forms being ∞P, $\infty P2$, P, $2P2$, $3P_{2}^{3}$, $0P$. Although somewhat water-worn and marked with etching-figures, these were no doubt at one time sharply developed crystals. In North America, several localities are known for aquamarine: for example, Stony Point in Alexander Co., North Carolina; Litchfield and other places in Connecticut; Albany in Maine, where golden beryl is found.

Common beryl. Under this heading may be classed all specimens, which, being cloudy or opaque and of an unattractive colour, are of no value to the jeweller. It usually occurs as rough hexagonal prisms terminated irregularly or simply by the base, and is often found embedded in quartz, as at Rabenstein in Bavaria (plate 45, fig. 1) and Metzling in Bohemia (fig. 2). The crystals are often of considerable size, and enormous crystals weighing over a ton (one weighing 2900 lbs.) have been found at Grafton in New Hampshire.

Applications of Beryl. — Transparent stones, as well as cloudy ones if only they are of a good colour, are used for cutting as gems; whilst material of poorer quality is employed for the preparation of the little-used beryllium compounds. Even by the ancients the emerald was held in high esteem as a gem-stone. We have it on the authority of Herodotus that the ring of Polycrates carried an emerald seal; and an engraved emerald belonging to this period has been discovered. It is said that Alexander caused his likeness to be engraved in emerald and that the work was done by Pyrgoteles. It is related of Nero that, owing to a weakness of the eyes, he watched the performances in the circus through an emerald. Aquamarine was also well known to the ancients under the name beryllos. According to Pliny, the most prized was the greenish beryl with a colour like that of the sea, and next to this the "chrysoberyl" (i. e. golden beryl). The greenish and bluish beryls were employed even since Hellenistic times, and especially in the Augustan age, for the finer examples of engraving, but they were also much worn as unengraved jewels. Fig. 3 of plate 40 *a* shows a scarab cut in beryl.

PLATE 45.

Beryllium Minerals.

Fig.

1. **Beryl,** prismatic crystal of common beryl, with cleavage cracks parallel to the base; in quartz.
   From a quartz quarry on the Hühnerkobel near Rabenstein, Zwiesel, Bavaria.
2. **Beryl,** hexagonal prism broken at both ends parallel to the base.
   Metzling, Ronsberg, Bohemia.
3. **Helvite,** yellow tetrahedra in matrix.
   Schwarzenberg, Saxony.
4. **Chrysoberyl,** trilling in granite.
   Greenfield, Saratoga Co., New York, U. S. A.
5. **Chrysoberyl,** heart-shaped twin-crystal in granite.
   Maine, U. S. A.
6. **Chrysoberyl** ("Cymophane"), polished, with bluish band of reflected light.
   (After Max Bauer, "Precious Stones", plate XII, fig. 11.)
7. **Chrysoberyl** ("Alexandrite"), trilling with smaller irregular crystals in mica-schist.
   From the emerald mines on the Takovaya stream, 85 kilometres east of Ekaterinburg, Ural Mountains.
8. **Chrysoberyl** ("Alexandrite"), trilling.
   Same locality.
9. **Phenacite,** hexagonal prism with rounded terminal faces, the latter dusted over with chlorite.
   From the emerald mines on the Takovaya stream, Ekaterinburg, Ural Mountains.
10. **Phenacite,** short prismatic crystal.
    Mount Antero, Chaffee Co., Colorado, U. S. A.
11. **Phenacite,** long prismatic crystal in quartz.
    Kammerfos, Kragerö, Norway.

12*a* and *b*. **Euclase,** bluish-green, darker at the end.
From the gold-washings on the Sanarka river, Orenburg, southern Urals.

13*a* and *b*. **Euclase,** unusually large crystal with cleavage surface in one direction.
Boa Vista, Ouro Preto, Minas Geraes, Brazil.


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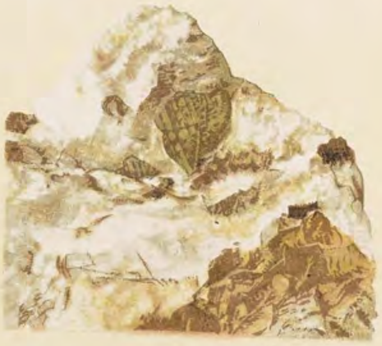
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13 a


13 b


11


12 a


12 b

Beryllium Minerals.

Phenacite. This is a silicate of beryllium with the very simple formula Be_2SiO_4. An analysis of a specimen from the Urals gave beryllia (BeO) 44·7 %, silica (SiO_2) 55·14 %, and traces of alumina and magnesia. Crystals are hexagonal and are bounded by one or two six-sided prisms, the ends being sometimes rounded (plate 45, fig. 9) or provided with rhombohedral faces (text-fig. 182). In this figure the faces *m* and *a* belong respectively to the hexagonal prisms of the first and second orders, and it will be noticed that the rhombohedral faces *x* are not placed directly over the faces or edges of the prisms, as in ruby and calcite, but that the edges of intersection run obliquely. This rhombohedron is, in fact, a rhombohedron of the third order, and its faces occupy the positions of half of the faces of a scalenohedron or of one-quarter of the faces of a twelve-sided double pyramid. Phenacite therefore belongs to the rhombohedral-tetartohedral division of the hexagonal system (p. 36).

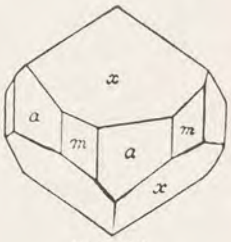


Fig. 182.
Crystal of Phenacite.

The hardness (H. = $7^1/_2$) lies between that of quartz and topaz, and the specific gravity is 2·96 to 3·0. Crystals may be colourless, yellowish-white, yellowish-brown or of a pale rose-red tint, and they may be of all grades of transparency. The refractive index for the ordinary ray has been determined for Uralian phenacite as 1·6527.

Phenacite is found in the emerald mines near the Takovaya stream in the Ural Mountains, the large crystals from this locality frequently having their faces dusted over with chlorite (fig. 9). Small lenticular crystals occur with topaz and amazon-stone in granite veins at Miask in the Ilmen Mountains also in the Urals. Crystals of a short-prismatic habit are found on Mount Antero in Chaffee Co., Colorado (fig. 10), while others of a long-prismatic habit are found embedded in quartz near Kragerö in Norway. Smaller crystals are met with at Framont in the Vosges Mountains, and very rarely at Reckingen in Wallis, Switzerland, and a few other localities.

When faceted, phenacite gives a gem of considerable brilliancy, but, except in Russia, it is only exceptionally worn as a precious stone.

Euclase. Being one of the rarest of minerals, euclase is only exceptionally used as a precious stone, and the majority of the crystals that have been found are reckoned with the treasured possessions of the public collections of minerals. It contains the same chemical constituents as beryl with the addition of water, though these constituents are not combined in the same proportions: the formula is $H_2O.2BeO.Al_2O_3.2SiO_2$ or $HBeAlSiO_5$.

Crystals belong to the monoclinic system and are of prismatic habit with obliquely placed terminal faces. In text-fig. 183 the narrow prism faces are taken to be the unit prism ∞P, the wider faces then having the symbol $\infty \grave{P}2$; above the former is the primary pyramid P, and above the latter the pyramid $2\grave{P}2$; at the side are four clinodomes, $P\grave{\infty}$, $2P\grave{\infty}$, $3P\grave{\infty}$, $6P\grave{\infty}$; and behind (with parallel faces in front at the bottom) are three more pyramids and a small orthodome. Parallel to the plane of symmetry (not present as a crystal face in the figure) is a very perfect cleavage; this is represented in plate 45, fig. 13. The hardness (H. = $7^1/_2$) is about the same as that of beryl, but the specific gravity (3·10) is considerably higher. The crystals are transparent, and may be colourless, yellowish-green or bluish-green; that represented in fig. 12 shows a deeper blue colour near the terminal faces than in the

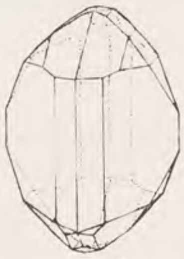


Fig. 183.
Crystal of Euclase.

lower portion of the crystal. The refractive indices fall between the values 1·65 and 1·67. Blue crystals are strongly pleochroic, the colours being dark blue and bluish-green.

The two principal localities for this mineral are represented by the crystals on plate 45. The crystal shown in fig. 12 (also plate 19, fig. 15) is from the Bakakin gold-washings in the district of the Sanarka river in government Orenburg, southern Urals. This crystal is of interest as being the first crystal of euclase found in the Urals; it was described by the Russian mineralogist General N. I. Koksharov, whose ideal representation of it is reproduced in text-fig. 183, and it was presented by Queen Olga of Württemberg to the Natural History Museum at Stuttgart.

The large crystal shown in fig. 13 (and plate 19, fig. 16) is from Boa Vista near Ouro Preto in Brazil, the same locality at which the dark yellow topazes are found. This crystal weighs 30 grams, and is bounded by the faces of two prisms ∞P and $\infty P\grave{2}$, two clino-domes $2P\grave{\infty}$ and $P\grave{\infty}$, two pyramids P and $3P\grave{3}$, and by a large cleavage face parallel to the plane of symmetry. Euclase was first discovered in Brazil and is less rare there than in the Urals. In recent years beautifully clear and sharply developed crystals have come from Brazil, but owing to their rarity they command high prices; for instance, a small, good crystal costs about £20.

A third locality is in the Grossglockner district in the Austrian Alps, where quite small, colourless crystals have been found in mica-schist.

When cut as a gem-stone, euclase displays a bright lustre and fresh colour combined with a high degree of transparency. Owing, however, to the perfect cleavage, the stone must not be dropped or knocked about, otherwise it will become fissured if not broken. Indeed, the name euclase means in Greek easily broken.

Chrysoberyl. In its chemical composition, this mineral is analogous to spinel, but in crystalline form there is no relation between these two species. Here beryllia takes the place of magnesia in spinel, the formula being $BeO.Al_2O_3$. The percentage composition corresponding with this formula is: beryllia (BeO) 19·8 per cent. and alumina (Al_2O_3) 80·2 per cent. Often, however, some iron (3—5 per cent. of ferric oxide) is present, and in the emerald-green variety a little chromic oxide.

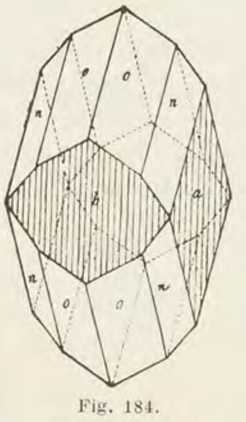


Fig. 184.

Simple crystal of Chrysoberyl.

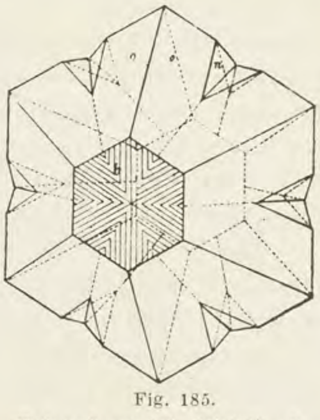


Fig. 185.

Twinned crystal (triplet) of Chrysoberyl (var. Alexandrite).

The crystals belong to the rhombic system, but, being usually twinned, they sometimes present the appearance of hexagonal crystals. The form of a simple crystal is shown in text-fig. 184, where *b* is a face of the macro-pinacoid, *a* of the brachy-pinacoid, and *o* and *n* are rhombic pyramids with the symbols P and $2P2$. Simple crystals are, however, quite exceptional, and we usually find two individuals twinned together giving a heart-shaped compound crystal (plate 45, fig. 5), or three individuals producing a pseudo-hexagonal form (fig. 8). A twin, or rather trilling, of the latter kind is represented diagrammatically in text-fig. 185, where we have an interpenetration of three crystals each of the same form as in text-fig. 184. The faces *b* of the three crystals coincide and correspond to the basal plane of a hexagonal crystal, while the rhombic pyramid *o* forms the apparent hexagonal pyramid: the twinning is, however, rendered evident by the re-entrant angles formed by the faces of the rhombic pyramid *n*, and by the feather-like striations on the face *b*. In the actual crystals the faces of the pyramid *n* are not always present, and then there are no re-entrant angles, as shown in plate 45, fig. 7 and 8, and plate 19, fig. 14, these crystals having quite the appearance of hexagonal pyramids truncated by the base.

Also in its optical characters, chrysoberyl presents some striking and unusual features. The colour may be citron-yellow, brownish-yellow, asparagus-green, olive-green, or emerald-green (plate 45, figs. 4—8).

Transparent crystals of an emerald-green colour are remarkable in that they show this colour only in daylight, and are violet-red, like amethyst, in lamplight; this is best seen when the crystal is viewed through in a direction perpendicular to the striated face *b*, or in a faceted stone when the large table facet is cut parallel to the same face *b*. This peculiar variety of chrysoberyl was discovered in Russia on the very day on which the coming of age of the Czarevitch Alexander Nicolajevitch, afterwards Czar Alexander II, was celebrated, and in his honour it was named *alexandrite* by the Finnish mineralogist Nils von Nordenskiöld. Red and green being in addition the national military colours, this stone is much admired as a gem-stone in Russia, and it fetches a high price. It has been described as an emerald by day and an amethyst by night. The difference in colour is to be explained by the very strong dichroism of the mineral. To the unaided eye the green colour is especially seen in a diffused light falling on the surface of the stone, and the red colour in a glaring and penetrating light: with the dichroscope the two images are respectively deep greenish-blue and rose-red to violet. Most crystals of alexandrite are clouded by fissures and enclosed scales of black mica, and perfectly clear stones are extremely rare.

Stones of an asparagus-green or yellowish colour frequently exhibit another appearance of a special kind, namely a bluish milky band of reflected light, and as the stone is moved about this band travels over the surface (plate 45, fig. 6). This variety of chrysoberyl is known us *cymophane* or "oriental cat's-eye". The chatoyant sheen is only displayed by cloudy and translucent stones, not by those which are transparent or opaque. It is probably due to the presence of innumerable microscopically minute cavities arranged in certain directions in the interior of the crystal.

Perfectly clear and transparent chrysoberyl presents much the same range of colours as the more common mineral olivine — which it also closely resembles in crystalline form — and it is therefore often known as "oriental chrysolite". The refractive power of the mineral is very strong, the mean index of refraction being 1·748. The lustre of the cut stone is therefore high, especially as, owing to the high degree of hardness, it takes a good polish. In hardness (H. = $8^{1}/_{2}$), indeed, chrysoberyl takes a third place amongst minerals, being exceeded only by diamond and corundum. The specific gravity (3·6 — 3·8) is also high, and amongst precious stones is exceeded only by zircon, corundum, and some varieties of garnet. Few minerals are so resistant to chemical reagents as chrysoberyl: it is not attacked by acids nor fusible before the blowpipe, and is decomposed only by fused alkalis.

Chrysoberyl occurs embedded in granite and crystalline schists; with the weathering of these rocks it is set free, and it is consequently usually found in river-sands and gravels.

It is found, together with garnet and spinel, in gneiss at Marschendorf in Moravia; with tourmaline, garnet, and apatite in granite at Greenfield in Saratoga Co., New York (Plate 45, fig. 4), at Haddam in Connecticut, and at Norway and Stoneham in

Maine (fig. 5). It is also found in the gem-gravels of Minas Geraes in Brazil and of Ceylon, and in the gold-washings of the Sanarka district in the southern Urals. The stones from Brazil are mainly transparent and of an olive-green colour, whilst those from Ceylon belong to the cloudy cymophane variety. Alexandrite is found, together with emerald and phenacite, embedded in mica-schist near the Takovaya stream in the Ekaterinburg district, and it has also more recently been found in Ceylon. The stones from Ceylon exhibit at the same time the emerald-green colour of alexandrite and the chatoyant reflection of cymophane; they are, however, more olive-green in colour and are more feebly dichroic (grass-green and yellowish-pink) than the Russian.

For use in jewellery the transparent stones are usually cut in the brilliant form; and with alexandrite the stone is always mounted *à jour*, so that the difference in colour by daylight and lamplight will be the most striking. Except in Russia, alexandrite is only little used as a gem-stone, but the other varieties of chrysoberyl find more extensive application. Crystals of alexandrite are much sought after by mineral collectors and they command a high price, specimens like that shown in fig. 7 being worth several pounds.

Helvite. Although never used as a precious stone, this mineral may be considered here as an appendix to the minerals containing beryllium. An analysis of helvite from Schwarzenberg, Saxony gave: beryllia 12·03 %, manganous oxide 41·76 %, ferrous oxide 5·56 %, silica 33·26 %, and sulphur 5·05 %, corresponding with the formula $(Mn, Be, Fe)_7Si_3O_{12}S$. The sulphur is probably combined with part of the metals as sulphide, since, when acted upon by hydrochloric acid, the mineral gives off hydrogen sulphide. Helvite, in being a combination of silicate and sulphide, thus shows a relation to lazurite.

The crystals (plate 45, fig. 3) have the form of the regular tetrahedron; they are sulphur-yellow or honey-yellow with little transparency. They are always quite small, rarely exceeding 4 mm. along their edges. The specific gravity is 3·1—3·3, and the hardness rather over 6. The best crystals are found embedded in gneiss at Schwarzenberg in Saxony, the locality of the specimen figured in plate 45.

Topaz.

The name topaz is applied by the jeweller to transparent gem-stones of a yellow colour, but only few of these really belong to the mineral topaz: the majority of them are varieties of quartz, whilst others are corundum. The true topaz contains the constituents of both these minerals, namely the silica of quartz and the alumina of corumdum, combined in equal molecular proportions, but in addition to these it also contains fluorine, the mineral being a fluo-silicate of aluminium. The fluorine may be considered to replace part of the oxygen, and the formula may be written as $4\,Al_2SiO_5 + Al_2SiF_{10}$, or more simply as $(AlF)_2SiO_4$. Furthermore, a portion of the fluorine may sometimes be replaced by hydroxyl (OH), so that the mineral is not constant in composition. An analysis of topaz from Schneckenstein in Saxony gave: silica 33·53 %, alumina 56·54 %, and fluorine 18·62 %.

Crystals of topaz belong to the rhombic system, and they are invariably prismatic in habit. Faces of at least two prisms are always present, and, according to the relative length of these faces the crystals may be of a short or long prismatic habit. The prism faces are usually striated vertically, and the angles between them are $124\frac{1}{2}°$ for one prism and $86\frac{3}{4}°$ for the other. The crystals are provided with different faces at their upper

PLATE 46.

Topaz.

Fig.

1. **Topaz,** pale yellow, with large basal plane, pyramids, brachydome and prisms.
   Schneckenstein, near Auerbach, Saxony.
2. **Topaz,** pale yellow, with basal plane, 2 brachydomes, pyramids and prisms.
   Schneckenstein, near Auerbach, Saxony.
3. **Topaz,** pale yellow crystal with quartz on topaz-rock; on the right is steatite.
   Schneckenstein, near Auerbach, Saxony.
4. **Topaz,** pale greenish-blue, with large brachydome, the upper edge of which is corroded.
   Neighbourhood of the River Urulga, Nerchinsk district, Transbaikalia, Siberia.
5. **Topaz,** colourless and transparent, on smoky-quartz.
   Mount Makrushi, near Alabashka, Mursinsk, Ural Mountains.
6. **Topaz,** pale greenish-blue, with a large brachydome and dull basal plane.
   Mount Makrushi, near Alabashka, Mursinsk, Ural Mountains.
7. **Topaz,** blue, with felspar.
   Mursinsk, Ural Mountains. (*After M. Bauer.*)
8. **Topaz,** rose-violet crystals: (a) terminated by pyramid planes,
   (b) cleaved parallel to the base.
   Gold-washings in the neighbourhood of the River Sanarka, Govt. Orenburg, Russia.
9. **Rose-topaz,** long fissured crystal terminated by drusy pyramid planes.
   Minas Geraes, Brazil.
10. **Topaz,** dark yellow, fissured, terminated by pyramid.
    Minas Geraes, Brazil.
11. **Topaz,** white clouded crystals, with brown quartz and beryl.
    Adun-Chalon, Nerchinsk district, Transbaikalia, Siberia.
12. **Topaz,** pale brownish, doubly-terminated crystal on rock.
    Nathrop, Colorado.
13. **Topaz,** faceted stone.
14. **Topaz,** faceted stone.


1

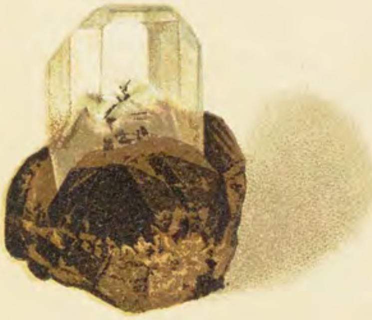

3


4


2


6


7


5


13


8 b


8 a


14


9


10


11


12

ends, according to the locality at which they are found, and, being usually attached to the matrix, they only rarely show terminal faces at the other end. The simplest combination is that of the two prisms with a pyramid (plate 46, figs. 9 and 10); in other crystals a large basal plane is present, together with pyramids and dome faces (figs. 1, 2 and 6); or again, the base may be absent, and the crystals terminated by a steep dome (fig. 11), or a steep dome and steep pyramid faces (fig. 12).

These several modifications are better illustrated by the accompanying text-figures, three of which are drawn with terminal faces at both ends. In all of them we see the two prisms $M = \infty P$ and $l = \infty \breve{P} 2$; in text-figs. 186 and 189 these are about equal in size, while in the other two figures l is much larger than M. In combination with these prisms we have in text-fig. 186 the rhombic pyramid $o = P$, as in plate 46, figs. 9 and 10. In text-fig. 187 the pyramid (here a more obtuse pyramid $^1/_2 P$) is much smaller,

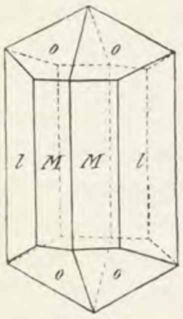


Fig. 186.

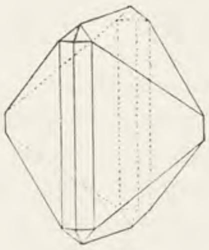


Fig. 187.

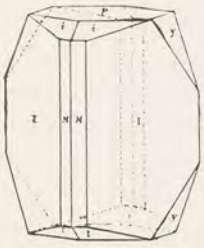


Fig. 188.

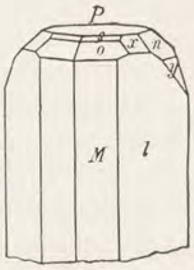


Fig. 189.

Crystals of Topaz.

From Brazil. From Nerchinsk, Siberia. From Mursinsk, Urals. From Schneckenstein, Saxony.

and in addition we have a large brachy-dome $2 \breve{P} \infty$, as in the attached crystals in fig. 11 of the plate. In text-fig. 188 the base $P = 0 P$ is present, and the pyramid ($^1/_3 P$) is still flatter (fig. 6, plate 46). Finally, in text-fig. 189, there are above the primary prism M two pyramids $o = P$ and $s = {}^2/_3 P$, above the prism l there is the pyramid $x = \frac{4}{3} \breve{P} 2$, to the right two brachy-domes $y = 4 \breve{P} \infty$ and $n = 2 \breve{P} \infty$, and at the top the basal plane $P = 0 P$; these being the forms shown by the crystals in figs. 1 and 2 of the plate.

The colouring of topaz is very variable (see plate 46); crystals may be perfectly colourless, pale yellow, dark yellow, brown, pink, violet-red, bluish-green, or blue. When transparent, the mineral has a brilliant glassy lustre, although the refractive power and dispersion are not specially strong. The mean refractive index is 1·612 for red light, 1·616 for yellow, and 1·621 for blue, so that topaz is more strongly refracting than quartz and beryl. The colours are often not permanent when exposed to light and heat: some crystals fade on exposure to daylight, and the yellow Brazilian topaz (fig. 10) when subjected to a moderate heat (over 300° C.) becomes a delicate rose-red, not quite so deep as of the crystal in fig. 9, the colour of which is probably original.

The dichroism of topaz, though distinct, is never very strong. A colourless water-worn pebble when held before the dichroscope shows pale green and pale rose-red images, but these colours are so very faint that it is only by their contrast that they are distinguishable. The pale yellow Saxon topaz gives colourless and pale greyish-yellow images, while the darker yellow Brazilian topaz gives colourless and pale yellow in a thin ($^1/_2$ cm.) crystal, and pale yellow and dark wine-yellow in a thicker (2 cm.) crystal. A Brazilian topaz, made pink by heating, shows pale violet-red and a pale yellowish-red when viewed through the prism faces (as with the preceding crystals); but when viewed through the basal plane with a greater thickness of material it shows rose-red and yellow colours in the dichroscope. The naturally-occurring pink crystals from Brazil are more strongly dichroic than the "burnt" pink topaz, the two images being here yellow and violet. The rose-red crystals from the Sanarka River give reddish-violet and rose-red. Since topaz is rhombic the absorption of light is different along the three axes, as may be readily seen when a crystal is examined in different directions with the dichroscope. A yellowish-red crystal, which had not been heated, from Brazil gave the following pairs of colours:

in the direction of the macro-axis *b*: dark yellow and rose-violet,
in the direction of the brachy-axis *a*: rose-violet and red,
in the direction of the vertical-axis *c*: red and dark yellow.

Topaz possesses a perfect cleavage in one direction, this being parallel to the basal plane; and for this reason crystals when broken away from the underlying matrix almost always show a smooth and bright cleavage face, as may be seen in figs. 1, 2, 8 *a* and *b*, 9 and 10. In fig. 12 the crystal shows a cleavage crack across the middle. Cleavage flakes of topaz when examined in convergent polarized light show the interference-figure of an optically biaxial crystal (plate 4, figs. 3 and 4).

The hardness of topaz is between that of quartz and corundum, and figures as No. 8 in the scale. The specific gravity of 3·56 is almost exactly the same as that of diamond. The mineral is very resistant to acids and to weathering agents, so that it scarcely ever shows signs of decomposition. In some crystals, cavities partly filled with liquid carbon dioxide are to be observed: and when such crystals are heated they often burst.

Although most frequently found as well-developed crystals, topaz also occurs as columnar masses with a divergent grouping, as in the variety known as pycnite, and as compact masses to which the name pyrophysalite is applied.

Crystals of topaz occur either in granitic rocks, often in association with tinstone, or in the cavities of recent volcanic rocks such as rhyolite (fig. 12). In both cases the mineral has been deposited by hot solutions or vapours which have accompanied the eruption of the igneous magma. With the weathering of these rocks the more stable topaz is set free, and it is then found as rolled crystals and pebbles in river-gravels.

The more important localities are the following. Pale wine-yellow crystals of the characteristic habit shown in text-fig. 189 and plate 46, figs. 1—3, are common at the Schneckenstein near Auerbach in Saxony. Here they occur, together with crystals of quartz, attached to the surface of a breccia consisting of fragments of a tourmaline-rock cemented together by quartz and topaz, the whole being known as a topaz-fels or topaz-rock; enveloping the crystals is often some white or yellowish steatite, as shown on the right in fig. 3. Small, colourless crystals of topaz are found in the deposits of tin-ore at Ehrenfriedersdorf and Altenberg in Saxony, Zinnwald and Schlaggenwald in Bohemia, and in Cornwall; and similar crystals are met with in cavities of the granophyre of the Mourne Mountains in Ireland.

In Russia, topaz occurs in cavities in granite at the same places that beryl is found, and sometimes magnificent, large and clear crystals are met with. On Mount Makrushi at Alabashka, near Mursinsk in the Ekaterinburg district of the Urals, beautiful, pale blue crystals (figs. 6 and 7) and more rarely colourless crystals (fig. 5) are found: these are terminated by a large basal plane, and large brachy-dome and pyramid faces. They are accompanied by fine crystals of felspar (fig. 7), reddish-white lithia-mica, albite, and smoky-quartz (fig. 5). On the eastern side of Lake Ilmen, in the neighbourhood of the smelting works of Miask in the Ilmen Mountains (southern Urals), small, colourless and perfectly developed crystals are found, together with green felspar (amazon-stone), phenacite and black mica. In the Bakakin gold-washings on the Sanarka River, Government Orenburg, rose-red and violet-blue crystals are found (fig. 8 *a* and *b*), which resemble the Brazilian both in colour and form, being terminated by the pyramid. In the same district, rose-topaz has also been found in quartz-veins, together with green tourmaline and a green mica known as fuchsite.

Fine crystals of topaz are also met with in eastern Siberia, but, whilst in the Urals the crystals usually occur singly in cavities, they are here united in druses, as shown in fig. 11, representing a specimen from the Adon-Chalon Mountains in the Nerchinsk district of Transbaikalia. Here the white crystals are terminated by the large brachy-dome $2 P \infty$ without the basal plane, and they are accompanied with crystals of smoky-quartz and beryl. Topaz crystals of a similar form, but yellowish or bluish in colour, are also found in the neighbourhood of the Urulga River in Nerchinsk; these often show signs of corrosion (fig. 4), and they are distinguished by their exceptional beauty of colour and transparency and by their large size; crystals measuring 28 centimetres in length and 16 cm. in thickness have been found here. The localities are situated in the Borshchovochnoi and Kuchuserken ranges, but there is much confusion in the statements of the exact places where the crystals are found. As Koksharov has pointed out, this is due to the great similarity of the crystals from the several localities, and to the remoteness of this region. The peasants collect the variously coloured stones, such as topaz, beryl, etc., from several spots in the mountain ranges of the Nerchinsk district and bring them to the town of Nerchinsk for sale. They are there bought up by dealers, who attach more importance to the transparency, perfection of crystalline form or value for cutting as gems than to any exact statement of locality, and are sold again at fairly high prices in Irkutsk, Ekaterinburg and even at the fairs of Nizhniy-Novgorod, from whence they pass into eastern Russia and the rest of Europe. The statements in mineral collections of the exact locality for specimens of topaz, beryl, and other minerals from this far-off region must therefore always be considered as doubtful.

In Brazil, crystals of pale yellow, dark yellow, and pink topaz (figs. 9 and 10) are found in the neighbourhood of Ouro Preto in the state of Minas Geraes; they occur in nests, together with quartz, rutile, and haematite, in a rock which has been completely altered to clay; and sometimes the topaz crystals are found embedded in the quartz. The colourless and blue topazes of Brazil are found only in the gem-gravels, together with diamond, beryl, chrysoberyl, rock-crystal, andalusite, and other minerals, in the Minas Novas district. The colourless pebbles are known locally as "pingos d'agoa" (drops of water). Very similar to the yellow Brazilian topaz, both in form and colour, are crystals, often of considerable size, from Mugla in Asia Minor.

In Mexiko, beautiful, water-clear topaz crystals are met with in the tin mines of San Luis Potosi and Durango; and in the United States, pale yellow and brownish-yellow crystals are found in the cavities of a porphyritic rock (rhyolite) at Nathrop in Colorado (fig. 12). The crystal shown in this figure is remarkable in being bounded by faces (steep pyramids and brachy-dome) at the two ends. Colourless, pale blue or greenish crystals are also found at Stoneham in Maine, and here large, opaque crystals weighing as much as 10 to 20 kilograms have been met with. Fine, water-clear crystals of considerable size are known from Otani-yama in Japan, and colourless and pale blue material suitable for cutting is found in the New England district in New South Wales. Other localities might be mentioned, but from those which have been stated we see that fine crystals of topaz is of fairly common occurrence.

The topaz which is made use of for gem purposes comes almost exclusively from Russia, Brazil, and Australia. The parcels usually consist of broken pieces and are often mixed with beryl.

Colourless topaz is known as precious topaz and also as "pingos d'agoa" or drops of water; it is cut in the brilliant form and mounted *à jour*. A few years ago a large number of perfectly water-clear stones were placed upon the market, but now they are again rather rarer. Such stones, although very bright and clear, have not the lustre and brilliancy of the diamond, in comparison with which they appear dull. They cannot be distinguished from diamond by the specific gravity, but are readily distinguished by their double refraction and refractive indices, the latter being readily determined with the aid of a refractometer. A two-carat stone costs about fifteen shillings. Yellow topaz is now not much used for cutting, and the majority of yellow stones which are sold as topaz are really quartz ("golden topaz" and "Spanish topaz"); it is usually converted by heating into the more valuable rose-topaz. This is often very similar to pink tourmaline, but the two can be distinguished by their dichroism and better still by their specific gravity: in pure methylene iodide topaz sinks and tourmaline floats. In recent years this pink "burnt" topaz has again come into favour for jewellry. The violet-red crystals from the Sanarka River are much too rare to be of any importance as gems. Bluish-green and blue topaz is almost always sold in the trade as beryl or aquamarine, and indeed by mere inspection it is not easy to distinguish the two stones. They are, however, easily distinguished by their specific gravity, beryl floating in methylene iodide or in bromoform, whilst topaz sinks. A mineral collector will, as a rule, have to pay more for a crystal of beryl than for a crystal of topaz, but for gem purposes the two minerals are of about equal value.

Garnet.

The name garnet is applied to a group of minerals which, though identical in crystalline form and of the same chemical type, vary considerably in chemical composition; in other words, they are members of an isomorphous group. They are all silicates, and several of the varieties contain calcium together with either alumina, ferric oxide, or more rarely chromic oxide; other varieties contain alumina together with either ferrous oxide, magnesia, or more rarely manganous oxide. There are thus two main groups — the lime-garnets and the alumina-garnets (lime-alumina-garnet being included in both):

Calcium-aluminium-garnet	$Ca_3Al_2Si_3O_{12}$.	Iron-aluminium-garnet . . .	$Fe_3Al_2Si_3O_{12}$.
Calcium-iron-garnet . . .	$Ca_3Fe_2Si_3O_{12}$.	Magnesium-aluminium-garnet	$Mg_3Al_2Si_3O_{12}$.
Calcium-chromium-garnet	$Ca_3Cr_2Si_3O_{12}$.	Manganese-aluminium-garnet	$Mn_3Al_2Si_3O_{12}$.

The actual percentage composition of garnets belonging to the more important varieties, which will be described in more detail further on, is given in the following table of analyses: —

	SiO_2	Al_2O_3	Fe_2O_3	Cr_2O_3	FeO	CaO	MgO	MnO
1. Almandine: Zillerthal, Tyrol	39·12	21·08	6·00	—	27·28	5·79	—	0·80
2. Hessonite: Ala, Piedmont	38·13	18 35	7·17	—	—	35·40	0·02	0·13
3. Pyrope: Krems, Bohemia	40·45	19·67	4·05	2·60	6·90	5·78	20·79	—
4. Demantoid: Syssersk, Urals	35·56	0·57	30·80	—	0·64	33·05	0·16	—
5. Uvarovite: Bissersk, Urals	36·93	5·68	1·96	21·84	—	31·05	1·54	—

PLATE 47.

Garnet.

Fig.

1. **Hessonite** ("Cinnamon-stone"), Rhombic-dodecahedron.
   Ceylon.
2. **Hessonite** ("Cinnamon-stone"), faceted.
3. **Garnet,** showing shelly structure on fractured surface.
   Ala valley, Piedmont, Italy.
4. **Hessonite,** small crystals with diopside.
   Mussa-Alp, Ala valley, Piedmont, Italy.
5. **Grossularite,** rhombic-dodecahedron.
   Wilui, Yakutsk, Siberia.
6. **Grossularite,** icositetrahedron.
   Wilui, Yakutsk, Siberia.
7. **Grossularite** (Rose-garnet), rhombic-dodecahedron.
   Xalostoc, Morelos, Mexico.
8. **Andradite,** brown rhombic-dodecahedron with white wollastonite in blue calcite.
   Cziklowa, Hungary.
9. **Melanite,** rhombic-dodecahedron with icositetrahedron.
   Frascati, Albanian Hills, Rome, Italy.
10. **Uvarovite** (Chrome-garnet), small crystals on brown chrome-iron-stone.
    Saranovskaya, 12 kilometres from Bissersk, northern Urals.
11. **Almandine,** rhombic-dodecahedron.
    Granatenkopf, Gurgl, Oetzthal Alps.
12. **Almandine,** icositetrahedra on matrix.
    Greenland.
13. **Almandine,** rhombic-dodecahedron with icositetrahedron; embedded in mica-schist.
    Fort Wrangell, Alaska.

14*a* and *b*. **Almandine,** cut.

15. **Andradite,** yellowish-brown crystals with calcite on magnetite.
    Dognacska, Hungary.
16. **Pyrope,** in serpentine.
    Zoeblitz, Saxony.
17. **Demantoid,** faceted.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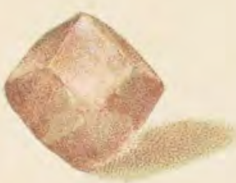
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14 a


14 b


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16


11

Weber & Schwarz, (Inhaber Messing & Schwabe) Kunstanstalt, Stuttgart.

It will be seen that Nos. 2, 4, and 5 are essential lime-garnets, 2 being a calcium-aluminium-garnet, 4 a calcium-iron-garnet, and 5 a calcium-chromium-garnet, whilst 1 is an iron-aluminium-garnet, and 3 a magnesium-aluminium-garnet. Further, it will be noticed that none of them correspond exactly in composition with the pure compounds, but are mixtures of several of these.

Before passing to a description of the more important varieties, we will now enumerate those characters which are common to all the varieties of garnet.

All garnets crystallize in the cubic system, and the simplest and at the same time the commonest form of crystal is the rhombic-dodecahedron, which form is on this account sometimes called the garnetohedron. In plate 47 the crystals shown in figs. 1, 5, 7, 8, 11, and 15 present this form. Less frequent as a simple form is the icositetrahedron with the symbol 2 O 2, as shown in figs. 6 and 12. The combination of these two simple forms is to be seen in fig. 13 (text-fig. 190) and less distinctly in fig. 9. In addition to these, a hexakis-octahedron $3\,O\,{}^3/_2$ is sometimes present as narrow faces truncating the edges between the rhombic-dodecahedron and the icositetrahedron (text-fig. 191). A completely developed crystal presenting this combination of three forms is bounded by 84 (= 12 + 24 + 48) faces. Forms other than those mentioned are of rare occurrence on garnet, and twinned crystals are not known.

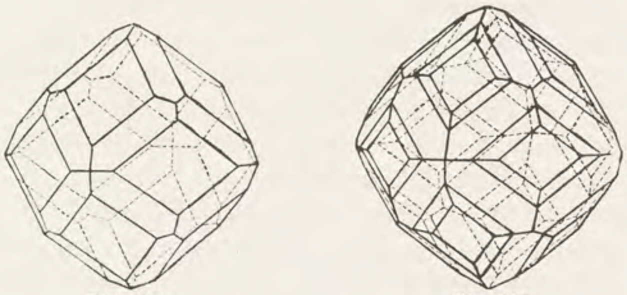

Fig. 190. Fig. 191.

Crystals of Garnet.

The hardness of garnet is about the same as that of quartz. There is no distinct cleavage, and the crystals are often traversed by irregular fissures. The specific gravity varies between wide limits, 3·4—4·3, corresponding with the variations in chemical composition; the lower limit being 3·4, all varieties of garnet sink in methylene iodide.

As may be seen by a glance at plate 47, the range of colour presented by garnet is very considerable, blue being the only colour not represented; white or colourless garnet is quite rare. Sometimes the crystals are built up of alternately lighter and darker layers, as may be seen when such a crystal is broken open (fig. 3) or in a thin section; this is especially the case in the variety melanite.

Being a cubic mineral, garnet is not dichroic; but in opposition to this rule it is sometimes doubly-refracting, though the anomalous double refraction is never so strong as to allow of a confusion between garnet and other minerals. The refraction is strong in all varieties, the refractive index varying from 1·74 to 1·82. The dispersion is also strong, though, owing to the intense coloration of the mineral, this is not conspicuous.

Garnets occur embedded in rocks of many different kinds, for instance, granite, phonolite, serpentine, crystalline schists, and limestones; and they also occur attached to the walls of crevices in crystalline silicate rocks. As a rule, each kind of garnet is confined to a particular class of rock. We now proceed to a description of the different varieties and the mode of occurrence of each.

Almandine is a dark-red garnet which in chemical composition is an iron-aluminium-garnet. The colour often shows a tinge of bluish-violet, though it may also be carmine-red or yellowish-red. By the dealer in precious stones the name almandine is more particularly applied to garnets of a bluish-red colour, but by the mineralogist the name is applied to all iron-aluminium-garnets whatever be their colour. Almandine is the heaviest of all garnets, the specific gravity being 4·3, a value which amongst precious stones is exceeded only by some specimens of zircon. The rich colour of the stone is sometimes combined with perfect transparency, but usually almandine is fissured and only slightly transparent. It is the commonest of the garnet varieties, and is indeed a widely distributed mineral, occurring more particularly in the crystalline metamorphic rocks (gneiss, mica-schist, chlorite-schist, and granulite). A cloudy and fissured crystal isolated from the rock is shown in plate 47, fig. 11, and rather clearer crystals are represented in figs. 12 and 13. The first of these is a rhombic-dodecahedron, fig. 12 an icositetrahedron, and fig. 13 a combination of these two forms (text-fig. 190).

The localities at which almandine is found are so numerous that only a few of the most important can be mentioned in this place. In Europe, large crystals are abundant in the chlorite-schist of the Granatenkopf in the Oetzthal Alps (plate 47, fig. 11), as also in the Zillerthal in the Tyrol, and in the St. Gotthard district. Smaller crystals are found in the Riesengebirge, Black Forest, and Odenwald; at Fahlun in Sweden; at Mursinsk, Miask, Zlatoust, and other places in the Ural Mountains; and in fact in all mountainous districts where crystalline rocks abound. Specially fine crystals occur embedded in mica-schist at Fort Wrangell in Alaska (fig. 13) and in Greenland (fig. 12). Material of gem-quality is mined in Rajputana, Jaipur, and other parts of India, and is also obtained from the gem-gravels of Ceylon. In recent years a garnet which appears to be almandine has been obtained from German East Africa: it comes into the market as beautifully-clear, platy fragments showing either the bluish-red colour of alamandine or the blood-red of pyrope, and it is strongly doubly-refracting.

Almandine and other closely allied garnets have been used as precious stones since very early times. The old names ἄνϑραξ and carbunculus have reference to the red colour, similar to that of a glowing coal; and the Syriam garnet, which probably has its name from the ancient trade centre in Pegu (although garnet is not found at that place), was probably a similar stone. The bluish-red stones, or almandine proper, are sometimes known as oriental garnet, and in colour these are occasionally distinctly violet; but as this colour does not show to advantage in lamplight such stones are of less value. It was much used in Grecian and Roman times for engraved gems. Almandine when of a brownish-red colour is known as vermeille garnet. The garnet from German East Africa has been incorrectly known in Bohemia (where it was at first cut in large quantities) as "Fashoda garnet". Apart from the purity, clearness, and size of the stones, the value of almandine depends largely on its colour, being greater when this approaches more nearly to a pure ruby-red, and less when yellowish-red and violet.

Hessonite, or cinnamon-stone, has a honey-yellow, yellowish-red, or hyacinth-red colour (plate 47, figs. 1 and 2), similar to that of cinnamon-oil. In chemical composition it is a calcium-aluminium-garnet; and it has the lowest specific gravity (3·4—3·6) and refractive index (1·74 for red light) of all the garnets. It is found as crystals, together with crystals of diopside and chlorite, attached to the wall of crevices in serpentine in the Ala valley in Piedmont (fig. 4), the crystals from this locality having the form shown in text-fig. 191. The material used in jewellery comes mainly from Ceylon, sometimes as simple rhombic-dodecahedra (fig. 1), but more usually as irregular, water-worn fragments, which are found together with hyacinth (zircon) and other minerals in the gem-gravels. It is indeed often confused with hyacinth, from which it may be distinguished by its lower specific gravity and its single refraction; in value the two stones are about equal. Hessonite was much admired at the time of Alexander the Great, and it is still in high favour.

Here we may also mention another variety of calcium-aluminium-garnet, which, though of no importance as a precious stone, is frequently found as well-developed crystals. This is known as *grossularite* or "gooseberry-stone", on account of its pale green colour in some specimens (fig. 5 and 6). The crystals shown in these two figures are respectively a rhombic-dodecahedron and an icositetrahedron. Such crystals are found, together with idocrase (plate 49, figs. 1—3), near the junction of the Achtaragda and Wilui Rivers in eastern Siberia. Grossularite is typically a mineral of contact-metamorphic origin, occurring embedded in limestones where these have been altered by contact with an igneous rock. Under these conditions it is found as white and brownish-red crystals at Auerbach in Hesse, and with magnetite at Dognacska in Hungary. A beautiful rose-red garnet occurs embedded in limestone at Xalostoc in Mexico (fig. 7). Other localities for grossularite are Gleinitz near Jordansmühl in Silesia, Monzoni in southern Tyrol, Rumford in Maine, etc. Large crystals, sometimes with limestone attached to them, have been found in sand beneath the cathedral at Breslau, but where these came from originally is not known.

Pyrope is perhaps the best known of the gem-varieties of garnet. In colour it is blood-red to a brilliant fire-red, the name pyrope meaning in Greek fiery. The name has thus the some meaning as carbuncle, and formerly the two varieties were doubtlessly confused with one another; there is, however, not only a difference in colour between them, but also a difference in their chemical composition and mode of occurrence. Pyrope is a magnesium-aluminium-garnet, but also contains some iron and chromium (2—6 $^0/_0$ chromic oxide). It occurs embedded in olivine-rocks or in the serpentines which have been derived from the alteration of such rocks (plate 47, fig. 16); and on the complete breaking down of the serpentine the pyrope is set free, being then found loose in the soil or in sands. Crystals are extremely rare, the mineral usually having the form of grains, which rarely exceed a centimetre in diameter and are usually only a few millimetres. The specific gravity of 3·7—3·78 is considerably less than that of almandine.

Since early times the best known localities for pyrope are in the north of Bohemia, and for this reason it is often known as Bohemian garnet. The garnet-bearing district, with an area of seventy square kilometres, lies on the southern slopes of the Mittlegebirge (Midland Mountains) and to the north of the Eger river, that is, to the west of Trebnitz and the south-west of Leitmeritz and Meronitz, and with a small portion in Saxony (the specimen shown in plate 47, fig. 16, being from Zöblitz in Saxony). About one-tenth of this district is rich in garnet The garnets are accompanied by zircon, ceylonite, corundum, tourmaline, olivine, opal, and other minerals. Originally the grains of pyrope were embedded in an olivine-rock which become altered by weathering to serpentine; later this material was broken up by volcanic eruptions giving rise to a volcanic tuff; still later this tuff was removed by ice action, and now the garnets are mainly found in a layer of glacial drift having a thickness of up to seven metres. Some of this material has been again sorted by running water, and garnets are consequently also found in the beds of the existing streams, so that they have been transported on no less than three separate occasions from their place of origin. The garnet is won by sinking pits in these secondary deposits. Most of the stones obtained are so small that 500 or more do not weigh more than a lot (= $16^2/_3$ grams, or rather less than $^1/_2$ oz. avoirdupois), while stones the size of a pea are quite rare. Since the stones are all of the same quality as regards colour and clearness, their value increases rapidly with the weight of individual stones, the value of the smaller material being little more than the cost of production.

The garnet industry of Bohemia, which has its centre at Turnau on the Isar, is in many respects similar to the agate industry at Idar and Oberstein in Germany.

At both the greater part of the population is engaged in the gem-cutting industry and its allied branches, and in both the work was started upon material found in the vicinity, but is now extended to imported stones of all kinds. Owing to the lower rate of wages in Bohemia, there is a keen competition between these two centres of the gem-cutting industry.

In beauty, as well as in the size of the stones, the Bohemian pyrope is surpassed by the garnet found in association with the diamond in South Africa. This also is a chromiferous magnesium-aluminium-garnet, and it is known in the trade as "Cape ruby". It shows a pure and glowing carmine-red colour combined with a brilliant lustre and strong fire, and it is the most valuable of the garnets. Like the Bohemian pyrope, it is also found only as angular grains; and it is associated with a paler red pyrope and the other minerals mentioned under diamond (p. 210) in the "blue ground" of the dry diggings and in the sands of the river diggings, though only in small amounts.

Demantoid and **Melanite.** These two varieties of garnet though differing widely in colour — the former being green and the latter black — are essentially the same in chemical composition, being calcium-iron-garnets, though melanite contains in addition some titanium dioxide. Both of them, together with some other varieties, are included under the mineralogical name andradite.

Demantoid is transparent with a pale yellowish-green to deep emerald-green colour, and its specific gravity is 3·83. It is found as grains and kidney-shaped nodules in crevices in a serpentine-like rock or in auriferous sands in the Ural Mountains. Colourless to pale green pebbles are found in the gold-washings near Nijni-Tagilsk, and beautifully coloured grains in the serpentine near the Bobrovka stream in the Syssersk district. Recently large quantities of this material have been placed on the market, and it has largely increased the use of transparent green stones in jewellery. When well cut, the stones display a brilliant lustre and a strong fire, the fine appearance being but poorly represented in fig. 17, plate 47. Those of a darker green colour may perhaps be mistaken for emerald, but they are readily distinguished by the specific gravity; in bromoform or methylene iodide demantoid sinks, whilst emerald floats: further, emerald is doubly refracting and dichroic, whilst demantoid is not.

Melanite is black and opaque and always forms well-developed crystals with the rhombic-dodecahedron and the icositetrahedron in combination (plate 47, fig. 9, and text-fig. 190). Unlike other garnets, melanite occurs as a constituent of certain volcanic rocks (phonolite, leucitophyre), the small black crystals being visible to the unaided eye; or as seen in thin sections of the rock under the microscope they usually show six-sided outlines and an alternate banding of lighter and darker layers. It is found in the volcanic rocks of the Kaiserstuhl near Freiburg in Baden, at Rieden near the Lake of Laach, and at Frascati in the Albanian Hills near Rome (fig. 9).

Calcium-iron-garnet is also found as beautiful green and brown crystals at Schwarzenberg and Breitenbrunn in Saxony; and nodules similiar to the Uralian demantoid occur in serpentine at Dobschau in Hungary. Green calcium-iron-garnet is, in fact, of common occurrence as a secondary mineral in association with serpentines, as, for example, a variety known as topazolite from the Ala valley in Piedmont, and the small crystals from the neighbourhood of Dillenburg in Nassau.

Uvarovite or calcium-chromium-garnet, is very similar in appearance to the emerald-green demantoid, but it always occurs as crystals, being found as small, sharply-developed rhombic-dodecahedra on the surface of chromic iron-ore. In plate 47, fig. 10, the underlying chromite has been oxidized on the surface to a yellowish-brown alteration product. Uvarovite has a specific granity of 3·42, and it contains about 22% of chromic

PLATE 48.

Tourmaline.

Fig.

1. **Tourmaline,** black. Prism with rhombohedron; with albite and quartz on white granite.
   San Piero in Campo, Island of Elba, Italy.
2. **Tourmaline,** rose-red. Prism with dull, yellowish basal plane.
   San Piero in Campo, Island of Elba, Italy.
3. **Tourmaline,** brown. Prisms of the first and second orders with rhombohedron.
   Dobrawa, near Unterdrauburg, Carinthia.
4. **Tourmaline,** bluish-green with dull termination.
   Minas Geraes, Brazil.
5. **Tourmaline,** black crystal on granite; terminated by two rhombohedra ($+R$ and $-{}^1/_2R$, the latter truncating the three edges of the former) and the basal plane.
   Hoerlberg, near Lam, Bavarian Forest.
6. **Tourmaline** ("Rubellite"), carmine-red. Prism of second order and two rhobohedra ($+R$ and $-2R$).
   Sarapulka, 12 kilometres from Mursinsk, Urals.
7. **Tourmaline,** inside red, outside green.
   Minas Geraes, Brazil.
8. **Tourmaline** ("Rubellite"), in lithia-mica.
   Pala, San Diego Co., California.
9. **Tourmaline** ("Indicolite"), blue, faceted stone.
10. **Tourmaline,** pale green. Prism of the second order with $-2R$ and $+R$.
    Campo longo, St. Gotthard, Switzerland.
11. **Tourmaline,** black. Prism of the second order with three faces of the prism of the first order and a rhombohedron.
    Nedre-Havredahl, near Kragerö, parish of Bamle, Norway.
12. **Tourmaline,** brown. Prisms of the first and second orders with $-2R$ and R.
    Gouverneur, St. Lawrence Co., New York.
13. **Tourmaline,** crystals on granite, dark at the lower ends and pale coloured at the upper ends.
    San Piero in Campo, Island of Elba, Italy.
14. **Tourmaline,** brown, faceted stone.
15. **Tourmaline,** rose-red, blue below. Prisms of the first and second orders with rhombohedron.
    San Piero in Campo, Island of Elba, Italy.
16. **Tourmaline,** green, faceted stone.
17. **Tourmaline,** dark green, broken at both ends.
    Minas Geraes, Brazil.

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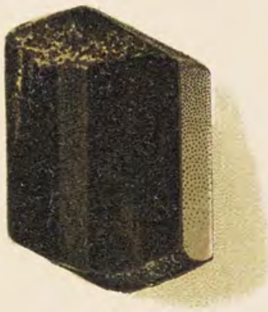

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oxide. Crystallized specimens are found near the smelting works of Bissersk in the northern Urals (fig. 10), and occasionally clear crystals have been cut, but these are too small and rare for the mineral to be of any importance as a precious stone.

Tourmaline.

Tourmaline is of special interest on account of its crystalline form and its physical characters, and it is at the same time of importance as a precious stone and as a rock-forming mineral. The name is a corruption of the Cingalese word turamali, the mineral having been brought under this name from Ceylon by the Dutch in 1703: previous to this it was known in Germany as schorl, a name now usually restricted to the black, fibrous varieties.

The crystals are prismatic in habit and often show a six-sided prism in combination with a three-sided prism (plate 48, fig. 11, and text-fig. 192); and according to the relative sizes of these two prisms the crystals are nine-sided or triangular in cross-section. Since the crystals are usually attached by one end to the matrix (figs. 1 and 13), terminal faces are developed only at the free end, but the presence of the triangular prism is alone sufficient to prove that tourmaline is rhombohedral-hemimorphic (p. 35). When the crystals are doubly terminated, which is comparatively rare, there is a different development of faces at the two ends, as clearly shown in text-fig. 192. In this figure l is the triangular prism of the first order, and s the hexagonal prism of the second order; at the upper end, the three faces P form a triangular pyramid truncating the edges of a more acute triangular pyramid o; while at the lower end we have the three parallel faces P (which together with the faces P at the top form a rhombohedron) the edges of which are truncated by narrow faces of an obtuse triangular pyramid n. Taking P to be the primary pyramid with the Naumannian symbol $+R$, o is then $-2R$, $n = -{}^1/_2 R$, $s = \infty P 2$, and $l = \dfrac{\infty R}{2}$. The angle between the faces of the primary form is $133^0\ 10'$; and when this has been determined with the aid of the contact goniometer, the other faces can be determined by noticing which edges are truncated.

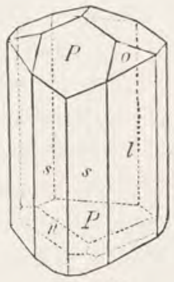

Fig. 192.
Crystal of Tourmaline.

Of the crystals represented in plate 48, fig. 1 shows a combination of the hexagonal prism (s) and the primary pyramid (P). In figs. 3 and 11 to the same forms are added narrow faces of the triangular prism (l). In fig. 5, with the top of the crystal directed towards the observer, we have the primary form $+R$ truncated by narrow faces of the next obtuse pyramid $-{}^1/_2 R$, and in the centre the basal plane $0R$. In fig. 6 we see the forms $s\ P\ o$, and in fig. 12 $s\ l\ P\ o$, while in fig. 2 the crystal is terminated by the basal plane alone. Occasionally the crystals display an extremely rich development of faces, many more than represented in the figures here given.

Even when a crystal of tourmaline is broken at its two ends, as in fig. 17, the hemimorphic character is betrayed by its peculiar electrical behaviour. When a crystal of tourmaline is subjected to changes of temperature, either during cooling or heating, it develops an electrical charge on its surface, and it then has the property of attracting to itself small and light objects. This pyro-electrical character of tourmaline was first noticed by the Dutch, at the time they brought the mineral from Ceylon: crystals which had fallen into the hot ashes of a turf fire were seen to have particles of ash adhering to them. For this reason the mineral was called *aschtrekker*, meaning in Dutch ash-drawer. It must further be remarked that the two ends of the crystal become charged with electricity of opposite kinds, one end being positively and the other negatively charged. This may be most conveniently demonstrated by a method devised by Professor Kundt: a crystal is heated in an oven to a temperature not exceeding 120° C., it is quickly passed through the flame of a spirit-lamp to remove any electrical charge that may to present, and is then placed on a dry surface and allowed to cool; during the cooling a dry mixture of flowers of sulphur and red-lead is dusted over the crystal through a fine sieve, when the sulphur will be attracted to the positively charged end and the red-lead to the negatively charged end of the crystal, and the two ends will be so coloured yellow and red. The best kind of material to use for this experiment is a dark green Brazilian crystal such as shown in fig. 17. According as the temperature of the crystal is rising or falling so will there be a difference in the electrical charges; the end which becomes electrically negative during cooling will become positive during a rise in temperature; this end of the crystal is called the analogous pole, and the other end is then the antilogous pole. We have here an excellent example of a connexion between the form of a crystal and its physical characters; and in all hemimorphic crystals (for example, hemimorphite, p. 131), where we have an axis with a different development of faces at its two ends, that axis is a polar electrical axis.

The optical characters of tourmaline also present certain remarkable features. In the first place, the range of colours is very extensive, almost every shade of colour being represented, and often the fine colour is combined with perfect transparency and clearness. Some crystals are colourless or so faintly tinged with pink, green, or blue that the colour is only noticeable in thicker layers: and with increasing depth of colour there may be a gradual passage from delicate rose-red to deep ruby-red, from a soft green to a dusky green, from a pale blue to intense indigo-blue or bluish-green of various shades, or from a light yellowish-brown to black. In many instances different parts of one and the same crystal are differently coloured. For example, the larger portion of a prismatic crystal may be pale coloured and its free end dark coloured, as in the so-called negro-heads (plate 1, fig. 7); or the lower end may be dark and the upper end pale coloured (plate 48, fig. 13); or again, one end of a crystal may be rose-red and the other end bright green, and so forth. Often also the zoning of the different colours is parallel to the faces of the prism; in fig. 7 the inner red portion is surrounded by a colourless layer and this again by an outer green layer. Tourmaline displays an endless variety in the zoning and distribution of its many colours.

The differences in the absorptive power of tourmaline for light is a very striking feature of the mineral. Some crystals when viewed through in a direction perpendicular to the prism planes are green or brown and transparent, but when viewed through the basal plane they are quite opaque even when only a thin plate is employed. Tourmaline being a doubly refracting substance, a ray of light on entering a crystal is resolved into two rays, the ordinary and the extraordinary (p. 58); and of these the ordinary, which vibrates perpendicularly to the principal axis, is almost wholly absorbed, only the extraordinary ray being allowed to pass through the crystal. The transmitted light is therefore plane-polarized, and on this peculiar property of tourmaline depends its use, when cut as a plate parallel to the prism, as a polarizer or analyser in the polariscope; such tourmaline plates, however, have the disadvantage of being deeply coloured, and further the light is not completely polarized by them. Although all crystals of tourmaline do not exhibit such a marked difference in the absorption of the ordinary and extraordinary rays, yet this property of dichroism is always an important character of the mineral, and one readily recognized with the aid of the dichroscope. In the following table are stated the pairs of colours seen when a series of tourmaline crystals (all, except the last, being from Brazil) was examined with the dichroscope.

Colour of crystal.	Thickness of crystal.	Colour of ordinary ray.	Colour of extraordinary ray.
Colourless	1 cm.	colourless	colourless
Pale green, almost colourless	1 cm.	pale yellowish-green	pale water-blue
Green	2–3mm.	greenish-yellow to pistachio-green	water-blue to pale-green
Green	6 mm.	brown to black	green
Bluish-green	3 mm.	bluish-green	water-blue to colourless
Dark bluish-green	3 mm.	dark bluish-green, almost black	bluish-green
Blue	5 mm.	bluish-green	pale blue
Pale rose-red	5 mm.	rose-red	colourless
Pale rose-red	1 cm.	violet-rose	rose-red with tinge of yellow
Deep violet-red	7 mm.	reddish-violet	delicate rose-red
Deep carmine-red (from the Urals)	8 mm.	reddish-violet	yellow passing to rose-red

The strong dichroism of tourmaline must be taken into account by the lapidary, and a stone should be so cut from a crystal that the large table facet will be parallel to the prism: if it is perpendicular to the length of the prism the colour may be too deep, and in any case the light will be more strongly absorbed.

The refraction of tourmaline is not very high, but the double refraction is strong; the exact values of these vary somewhat with the colour of the stone and its chemical composition. Colourless tourmaline from the Island of Elba has a refractive index for the ordinary of 1·6397 and for the extraordinary ray 1·6208 as determined in sodium-light. The value of tourmaline as a gem-stone thus depends more on its bright colours than on any brilliancy of lustre.

The mineral possesses no cleavage. Its hardness is a little greater than that of quartz, being about $7^{1}/_{2}$, and the specific gravity varies from 3·0 to 3·2.

The chemical composition of tourmaline is one of extreme complexity, and although the mineral has repeatedly been analysed by mineralogical chemists it has not yet been possible to arrive at a general formula entirely free from objections. Difficulties are presented in the analytical operations owing to the presence, not only of so many constituents (fourteen appear in the following table), but of such elements as lithium, boron, titanium, and fluorine, which are not easily determined quantitatively. The following analyses may be quoted as examples: —

I, green tourmaline from Brazil, analysed by Jannasch.

II, brown tourmaline from Dobrawa in Carinthia (plate 48, fig. 3), analysed by Rammelsberg.

III, black tourmaline from Alabashka in the Urals, analysed by Jannasch.
IV, pale green tourmaline from Brazil, analysed by Riggs.
V, colourless tourmaline from De Kalb in New York, analysed by Penfield and Foote (1889).

	I Green	II Brown	III Black	IV Pale green	V Colourless
Silica (SiO_2)	37·05	38·09	35·41	37·39	36·72
Titanic oxide (TiO_2)	—	—	—	—	0·05
Boron trioxide (B_2O_3) . . .	9·09	11·15	10·14	10·29	10·81
Alumina (Al_2O_3)	40·03	32·90	33·75	39·65	29·68
Ferric oxide (Fe_2O_3)	—	—	—	0·15	—
Ferrous oxide (FeO)	2·36	0·06	13·42	2·29	0·22
Manganous oxide (MnO) . . .	2·35	—	—	1·47	—
Lime (CaO)	0·47	1·25	0·17	0·49	3·49
Magnesia (MgO)	0·32	11·79	1·57	—	14·92
Soda (Na_2O)	3·18	2·37	2·08	2·42	1·26
Potash (K_2O)	—	0·47	0·34	0·25	0·05
Lithia (Li_2O)	0·60	—	—	1·71	—
Water (H_2O)	3·23	2·05	3·41	3·63	2·98
Fluorine (F)	1·15	0·64	0·28	0·32	0·93
Total	99·83	100·77	100·57	100·06	101·11

In all of these analyses silicon, aluminium, and boron are largely present, and, in addition, II and V contain much magnesium, III much iron, and IV an appreciable amount of lithium. The tourmalines may therefore be classified chemically as magnesium-tourmaline, iron-tourmaline and lithium-tourmaline. Such a classification is, however, of little practical use, and here we shall, with the jeweller, group the tourmalines according to their colour and transparency.

Tourmaline is very resistant to acids, and only after fusion is it attacked by hydrofluoric acid. It is fusible before the blowpipe, the darker coloured varieties containing more iron being, as a rule, more easily fusible. In nature the mineral is usually found in a perfectly fresh condition, and only rarely is it altered to mica.

Tourmaline occurs embedded in granitic rocks and crystalline schists, either as isolated grains and thicker crystals or as radial aggregates of acicular crystals — the so-called tourmaline "suns". Sometimes its presence as a rock constituent is only to be recognized under the microscope; in text-fig. 193 radial aggregates of tourmaline needles embedded in quartz are shown in a thin section of granite. Embedded crystals on a larger scale are shown in plate 48, fig. 8, where the matrix is a lithia-mica. The occurrence of black tourmaline embedded in the quartz of granite is very common, and frequently the prisms have been broken across and cemented together again by quartz. Attached crystals are found, together with quartz, felspar, and other crystallized minerals, on the walls of cavities in granite (plate 48, figs. 1, 5, and 13; plate 1, fig. 7). Isolated crystals and water-worn fragments of tourmaline are also often found in river-gravels.

Black Tourmaline or *Schorl* is the most abundant variety and is rich in iron oxide. In thick pieces it is black and opaque, but in thin sections under the microscope it is transparent with a dark brown or blue colour and strong dichroism. It sometimes forms very large crystals, which have usually been broken and cemented together again by quartz: smaller crystals are represented in plate 48, figs. 1, 5, and 11. More frequently it is met with as radial aggregates in granite. A few localities yielding the better crystals are: Hörlberg near Lam in the Bavarian Forest (fig. 5), Sonnenberg near Andreasberg in the Harz Mountains, Auerbach and Oberkainsbach in the Odenwald, the Island of Elba (fig. 1), Kragerö in Norway (fig. 11), Eibenstock in the Saxon Erzgebirge (here as large tourmaline "suns"), Alabashka near Mursinsk in the Urals, Pierrepont in St. Lawrence Co., New York (as very brilliant crystals bounded on all sides by faces), Monroe and Haddam in Connecticut, Greenland, Madagascar, etc. Black tourmaline finds no application as a precious stone.

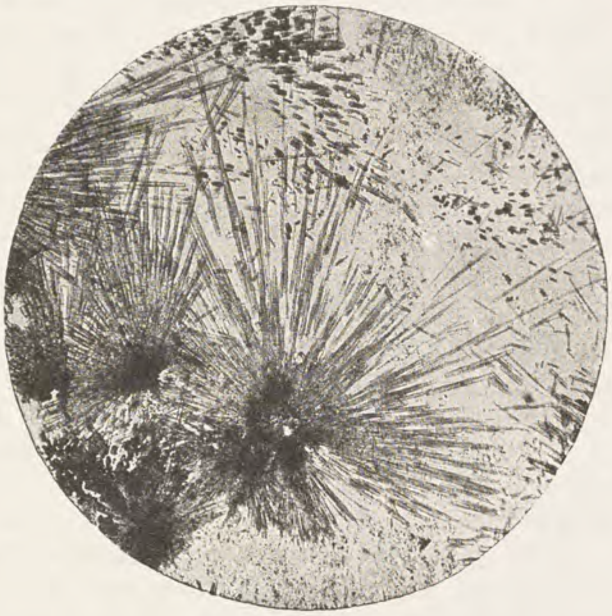

Fig. 193.
Tourmaline-granite from Luxullion, Cornwall. (Magnification 45).

Brown Tourmaline may be of a pale (fig. 12) or darker (fig. 3) shade, to almost black in colour. It contains much magnesia (analysis II) with only little iron, and is usually cloudy and fissured and with little transparency, although sometimes it is perfectly clear and transparent (fig. 14). It is found as embedded crystals in a white mica-schist at Dobrawa near Unterdrauburg in Carinthia (fig. 3), and in limestone at Gouverneur in St. Lawrence Co., New York (fig. 12). Material suitable for cutting is found in the gem-gravels in the district of Ratnapura in Ceylon, where tourmaline of other colours than brown is very rare. As a precious stone brown tourmaline is not very extensively used, and when cut into plates parallel to the prism it is sometimes employed in polarizing apparatus.

Red Tourmaline or *Rubellite* is widely distributed, but material of gem-quality is found at only a few localities. Good crystals of a pale rose-red colour are found in cavities of the granite at San Piero in Campo on the Island of Elba (fig. 2); these are often of a pale bluish or greenish colour at their lower end (fig. 15). Smaller crystals are found embedded in lithia-mica at Rožna in Moravia and Penig in Saxony. The best crystals are found in granite or in the weathered debris of this rock at Sarapulka and Shaitanka, respectively 12 and 48 kilometres from Mursinsk in the Ekaterinburg district of the Urals (fig. 6). These often closely approach the true ruby in their deep carmine-red or ruby-red colour; and they are consequently known as "Siberian ruby", they may, however, be readily distinguished by their lower specific gravity and strong dichroism.

Magnificant crystals of red tourmaline, often banded with green, are found at several places in the United States; thus, on Mount Mica near Paris in Maine, at Haddam in Connecticut, and more recently, at Mesa Grande in San Diego Co., California. In the neighbourhood of the last-named locality several mines are worked for tourmaline, and large amounts of material of gem-quality have within recent years been placed on the market. The red tourmaline embedded in lithia-mica shown in fig. 8 is from Pala, also in San Diego Co., California. Red tourmaline also occurs in Brazil (fig. 7) and Madagascar, and two very fine specimens from Burma are exhibited in the Mineral Gallery of the British Museum.

Green Tourmaline of gem-quality comes principally from Minas Geraes in Brazil (figs. 4, 16, and 17), either as loose, sharply-developed crystals sometimes bounded by many faces, or as water-worn crystals. Some specimens approach the emerald in their green colour and are known as "Brazilian emerald": they may be distinguished from the true emerald by their higher specific gravity and stronger dichroism. Green tourmaline also occurs together with red tourmaline in the United States. A locality which has been long known for pale green tourmaline is Campo longo in the St. Gotthard district (fig. 10), where the crystals are embedded in a white crystalline dolomite.

Blue Tourmaline or *Indicolite* of a pure blue colour is of rare occurrence, though stones of a bluish-green and greenish-blue colour are more abundant. It is found together with the other coloured varieties in Brazil, and has been called "Brazilian sapphire". Crystals of a more greenish shade of blue are met with at Paris in Maine and Goshen in Massachusetts.

Application of Tourmaline. — Although formerly not much used in jewellery, tourmaline is at the present day greatly in favour, and large quantities of red, green, and bluish-green stones are now cut at Idar and Oberstein. The different coloured varieties as well as colourless tourmaline are classed under the term precious tourmaline, the fanciful and misleading names such as "Siberian ruby" and "Brazilian emerald" being fortunately little used by jewellers: no doubt the reason of this is that only recently has the value of tourmaline as a precious stone been fully recognized. Perfectly clear stones of a rich colour command high prices, but fissured and cloudy stones, which are extensively used as beads, are plentiful and correspondingly low in value.

Rose-red tourmaline may perhaps be confused with pink topaz, but it may be distinguished by its lower specific gravity and its different dichroism. The same characters also serve to distinguish tourmaline of different colours from emerald, ruby, sapphire, and spinel.

For polarizing apparatus tourmaline is now no longer made use of. Plates cut parallel to the prism from deeply coloured, brown or green crystals were formerly employed to a limited extent as polarizers and analysers (p. 59); and the so-called tourmaline tongs consist of two such plates mounted in a wire frame. When a suitable crystal section is placed between the two plates and viewed close to the eye this simple piece of apparatus shows the optical interference-figure of the section (plate 4).

Idocrase.

This mineral is frequently known as vesuvian or vesuvianite, since it occurs as specially fine crystals in the ejected limestone blocks of Monte Somma, the ancient portion of Vesuvius. Crystals are usually well developed and quite simple in form, and they afford the best examples of tetragonal crystallization. The accompanying text-figures and the majority of the crystals represented in plate 49 are bounded by the two square prisms M and d, the tetragonal pyramid c, and the basal plane P; and they differ amongst themselves mainly in the relative size of the basal plane. In figs. 4 and 17

PLATE 49.

Idocrase.

Fig.

1. **Idocrase** (or Vesuvianite), isolated crystal developed on all sides; prism and pyramid of the first order with small prism of the second order.
   Wilui River, Yakutsk, Siberia.
2. **Idocrase,** like the preceding, with the basal plane in addition.
   Wilui River, Yakutsk, Siberia.
3. **Idocrase,** crystals in crystalline limestone.
   Wilui River, Yakutsk, Siberia.
4. **Idocrase,** crystal with same forms as in fig. 1.
   Canzocoli, Predazzo, southern Tyrol.
5. **Idocrase,** same as preceding with shorter prism.
   Canzocoli, Predazzo, southern Tyrol.
6. **Idocrase,** with large basal plane.
   Egg, Christiansand, Norway.
7. **Idocrase,** similar to the preceding.
   Sandford, Maine, U. S. A.
8. **Idocrase,** large crystal elongated in the direction of one of the horizontal axes.
   Egg, Christiansand, Norway.
9. **Idocrase,** prism of the first order ([illegible] front), prism of the second order (at the side), pyramid of the first order, and basal plane (at the top); with nepheline.
   Monte Somma, Vesuvius, Italy.
10. **Idocrase,** short-prismatic, with base.
    Testa ciarva, Ala valley, Piedmont, Italy. (From a band of idocrase in the serpentine.)
11. **Idocrase,** long-prismatic.
    Testa ciarva, Ala valley, Piedmont, Italy. (From a band of garnet in [illegible] serpentine.)
12. **Idocrase,** large crystal.
    Testa ciarva, Ala valley, Piedmont, Italy.
13. **Idocrase,** prisms of the first and second orders with base; in limestone.
    Templeton, Ontario, Canada.
14. **Idocrase,** black and dull, same forms as No. 9.
    Monte Somma, Vesuvius, Italy.
15. **Idocrase,** pyramid in blue limestone.
    Lewis and Clarke Co., Montana, U. S. A
16. **Idocrase,** brown crystals in chlorite-schist.
    Achmatovsk, Zlatoust, Ural Mountains.
17. **Idocrase,** large, cavernous crystal.
    Magnet Cove, Arkansas, U. S. A.
18. **Idocrase,** green crystals in crystalline limestone.
    Achmatovsk, Zlatoust, Ural Mountains.


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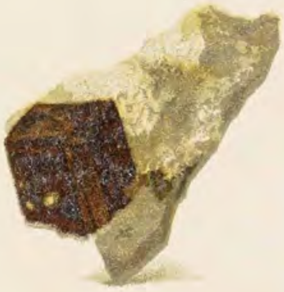
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the basal plane is absent; and in fig. 13 there are no pyramid planes. The crystals in figs. 5 and 11 differ only in the relative length of the prism faces. In fig. 8 the crystal is distorted by elongation in the direction of one of the horizontal axes. Some crystals of idocrase, especially those of small size, are very rich in faces, with several pyramids and eight-sided pyramids and prisms. Twinned crystals are unknown, but parallel grouping of crystals and zonal growths are not uncommon.

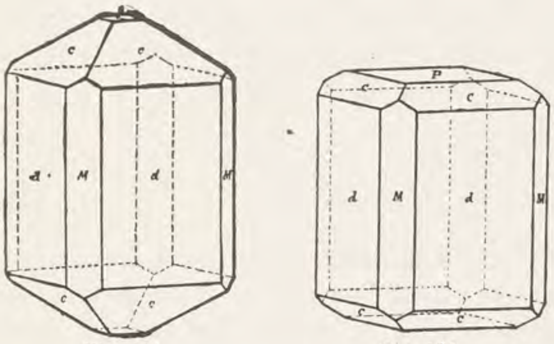

Fig. 194. Fig. 195.

Crystals of Idocrase.

In addition to crystals, columnar aggregates, either straight a divergent, sometimes occur, as in the variety called egeran from Haslau near Eger in Bohemia.

The more usual colours are, as shown in plate 49, brownish-green and yellowish-brown; crystals of a pronounced yellow, reddish-brown (fig. 13), green (fig. 12), or black (fig. 14) are rarer. A bright blue colour is met with in the variety known as cyprine, which occurs as a granular aggregate, together with pink zoisite (thulite), in the parish of Souland, Telemark, Norway. Crystals of idocrase usually have only a slight degree of transparency; their lustre is vitreous. The refraction is fairly strong, but the birefringence very weak, the refractive indices for the ordinary ($\omega = 1{\cdot}7235$) and extraordinary ($\varepsilon = 1{\cdot}7226$) rays being only slightly different. The refractive indices vary slightly, however, in different crystals, probably owing to variations in the chemical composition. The same is true of the specific gravity, which varies from 3·35—3·45. The hardness is $6^1/_2$. The dichroism is not strong, and owing to the slight transparency of the crystals it is only rarely to be observed. Crystals from the Ala valley in Piedmont show in the dichroscope a greenish-yellow (*o*) and a grass-green (*e*) image.

Although so simple in crystalline form, in chemical composition idocrase is very complex. Analyses show the presence of water (1—2$^0/_0$), magnesia (3$^0/_0$), lime (36$^0/_0$), ferrous oxide (3$^0/_0$), alumina (16$^0/_0$), silica (37$^0/_0$), and often also fluorine (1$^0/_0$), boron, sodium, ferric oxide, and other consituents. No satisfactory chemical formula has yet been deduced. Idocrase is only slightly attacked by acids, and it is fusible before the blowpipe.

Idocrase is typically a mineral of contact-metamorphic origin, occurring, together with garnet and wollastonite, in limestones which have been altered to marble by contact with eruptive rock-masses. Crystals of idocrase embedded in crystalline limestone are represented in several figures in plate 49: in fig. 15 the matrix is a blue limestone The mineral also occurs in crevices in chlorite-schist (fig. 16) and in other rocks.

Some of the more important localities are: Monte Somma, Vesuvius (figs. 9, 14), the crystals being here embedded in blocks of crystalline limestone ejected by the ancient volcano. Mussa-Alp in the Ala valley, Piedmont (figs. 10, 11, 12), in serpentine. Canzocoli near Predazzo, Tyrol (figs. 4 and 5), in limestone at its contact with syenite. Also in contact limestones at Monzoni in southern Tyrol, Cziklowa and Dognacska in Hungary, and Auerbach in Hesse. Of Russian occurrences, the following may be mentioned: the district of the Wilui River in eastern Siberia (figs. 1 and 2), where idocrase and grossularite (plate 47, figs. 5 and 6) occur as fine crystals bounded on all sides by faces in a tuff-like rock (fig. 3); the Achmatovsk mines in the Zlatoust district of the Urals, as brown crystals on chlorite-schist (fig. 16) and as green crystals in limestone (fig. 18). Other localities are: Egg near Christiansand in Norway (figs. 6 and 8), and very similar crystals are found at Sandford in Maine (fig. 7); Templeton in Ontario (fig. 13); Lewis and Clarke Co., Montana (fig. 15); and as large, corroded crystals at Magnet Cove in Arkansas (fig. 17).

Idocrase finds only a limited application as a precious stone, crystals from Vesuvius being occasionally cut at Naples, and those from the Ala valley at Turin.

Epidote.

This mineral is known sometimes as pistacite, on account of its characteristic colour resembling that of the pistachio-nut; this peculiar shade of green is shown in plate 50, fig. 1, and on the broken surface of the crystal in fig. 5, and it is also to be seen in the other crystals (with the exception of that in fig. 8) when they are held up against the light.

The crystals belong to the monoclinic system and are remarkable in being elongated in a direction perpendicular to the single plane of symmetry, that is, they are prismatic in habit in the direction of the ortho-axis *b*. This prismatic habit is especially pronounced in the long crystal shown in fig. 7, which is set up in the usual position adopted for monoclinic crystals with the plane of symmetry vertical; in fig. 3 the orientation is the same, only here the prism is much shorter. In the other figures on plate 50 the crystals are set up with the axis *b* vertical. As explained on p. 37 the choice of the clino-axis and vertical axis is arbitrary: in the (twinned) crystal in text-fig. 196 the ortho-axis *b* is parallel to the edge between *M* and *e*, the clino-axis *a* parallel to the edge between *M* and *o*, and the vertical axis *c* parallel to the edge between *T* and *z*. The face *M* then belongs to the basal pinacoid $0P$, *T* to the ortho-pinacoid $\infty P \bar{\infty}$, *e* is a face of the negative ortho-dome $-P\bar{\infty}$, and *l* and *r* of positive ortho-domes $2P\bar{\infty}$ and $P\bar{\infty}$ respectively; *z* the unit vertical prism ∞P, *o* the clino-dome $P\grave{\infty}$, and *n* the primary positive pyramid *P*.

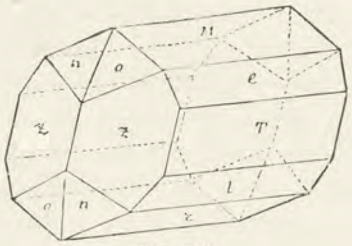

Fig. 196.
Twinned crystal of Epidote.

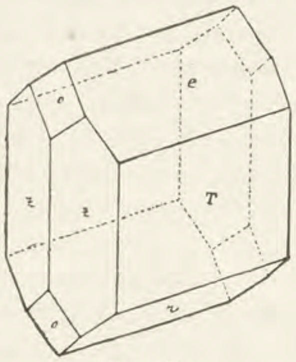

Fig. 197.

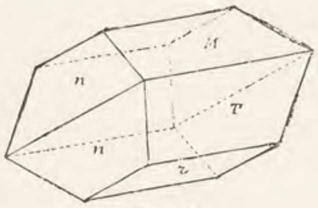

Fig. 198.

Crystals of Epidote.

Whilst in fig. 196 the crystal is prismatic in habit in the direction of the axis *b*, in fig. 197 it is tabular parallel to the ortho-pinacoid *T*, and in fig. 198, there is a tendency to a prismatic development along the edge of the pyramid *n*.

The crystals here represented are bounded by only few faces, but some crystals are very rich in faces, and for epidote more than 220 different forms have been recorded. These have, of course, not been all found on a single crystal, but on several crystals

PLATE 50.

Epidote.

Fig.
1. **Epidote,** pistachio-green crystal.
   Arendal, Norway.
2. **Epidote,** group of crystals.
   Arendal, Norway.
3. **Epidote,** doubly-terminated crystal.
   Prince of Wales Island, Alaska.
4. **Epidote,** thick, prismatic crystal.
   Knappenwand, Untersulzbachthal, Salzburg.
5. **Epidote,** twin-crystal with asbestos.
   Knappenwand, Untersulzbachthal, Salzburg.
6. **Epidote,** thin crystal.
   Knappenwand, Untersulzbachthal, Salzburg.
7. **Epidote,** long crystal.
   Knappenwand, Untersulzbachthal, Salzburg.

8a and b. **Epidote,** twin-crystal.
Ala valley, Piedmont, Italy.


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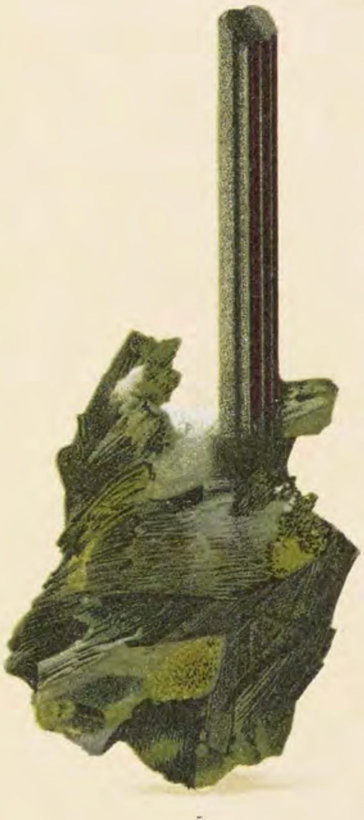
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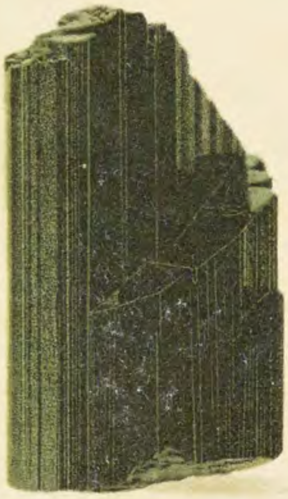
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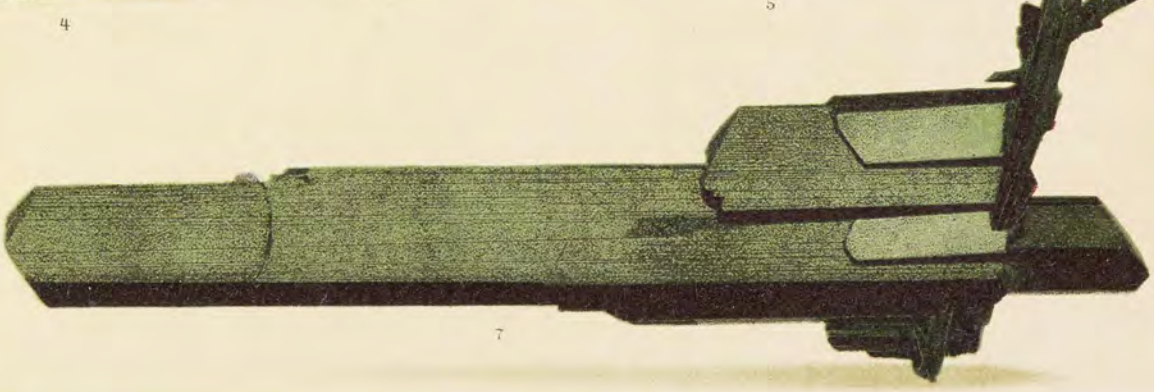
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from various localities, especially on the magnificant examples from the Knappenwand in the Untersulzbachthal, Salzburg.

Twinned crystals, with the ortho-pinacoid as the twin-plane, are of very frequent occurrence. These usually show re-entrant angles between the small faces at the ends of the crystals, as in text-fig. 196, and plate 50, figs. 5 and 8; but apparently simple crystals with an interlamination of fine twin-lamellae are frequent.

The crystals are sometimes broken and the portions displaced and again cemented together, as in the quartz crystal shown in plate 2a, fig. 7. Crystals with a zonal shelly structure are met with at Arendal, and from these successive envelopes of material can sometimes be readily removed.

In some of the transparent crystals with a pistachio-green colour, the strong pleochroism can be recognized with the unaided eye; viewed in one direction (perpendicular to the face *T*) they appear brown, and in another direction across the prism they are green. With the dichroscope the pleochroism may be seen in all directions, providing the crystals are sufficiently transparent. It is owing to the strong pleochroism that in certain crystals there may be seen with the unaided eye portions of a biaxial interference-figure, especially the hyperbolic brushes (as in plate 4, fig. 4, only more diffused) with coloured margins and rings. Such crystals are said to be idiocyclophanic, since they show rings of themselves, the double refraction and strong absorption of the crystal itself acting like a polarization apparatus. The refraction is fairly strong, the mean index being 1·7621 for green light.

The crystals possess a perfect cleavage parallel to the base (*M* in fig. 196), and a less distinct cleavage parallel to the ortho-pinacoid (*T*). The hardness is 6—7, and the specific gravity varies with the chemical composition from 3·3 to 3·5. The chemical constituents of epidote are silica, alumina, ferric oxide, lime, water, etc., but these are not present always in the same amount. The relative amounts of alumina and ferric oxide are especially subject to wide variation, and Professor G. Tschermak assumes that in epidote there is an isomorphous mixing of the molecules $H_2 Ca_4 Al_6 Si_6 O_{26}$ (a lime-alumina silicate, as in zoisite) and $H_2 Ca_4 Fe_6 Si_6 O_{26}$ (a lime-iron silicate). An analysis, by Ludwig, of epidote from the Knappenwand is given under I, and one, by Rammelsberg, of material from Arendal under II: —

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	H_2O	Total
I.	37·83	23·43	13·31	0·48	23·47	—	2·06	100·58
II.	38·76	20·36	16·35	—	23·71	0·44	2·00	101·62

Epidote is very resistant to acids, and only after fusion is it decomposed by hydrochloric acid. It is therefore but little affected by weathering processes: indeed many other minerals give rise to epidote by their alteration, as is shown by the occurrence of pseudomorphs of epidote after felspar, garnet, hornblende, and scapolite. This secondary epidote is usually granular, fibrous, or columnar, though sometimes it forms good crystals, and it may always be recognized by the characteristic pistachio-green colour. The larger crystals are found attached to the walls of crevices in crystalline rocks.

The finest crystals, far surpassing all others in size, brilliancy, and richness in faces, are from the Knappenwand in the uppermost portion of the Untersulzbachthal in Salzburg (plate 50, figs. 4—7): they occur in crevices in an epidote-schist, and are accompanied by colourless apatite, finely fibrous asbestos (shown in fig. 5), calcite, and a few other crystallized minerals. This occurrence was discovered in the year 1866, and the yield has been extraordinarily rich, so that these fine crystals are to be seen in every collection of minerals. Fine crystals of a brownish-yellow colour are found in the Ala valley in Piedmont, the large twinned crystal in fig. 8 a and b being from here. Other Alpine localities are: Zillerthal in the Tyrol, here as rose-red as well as green crystals; Zermatt in Wallis; Bourg d'Oisans in Isère, as bunches of columnar crystals terminated by drusy faces of the clino-pinacoid. Crystals very similar to the last are also found at Striegau in Silesia.

Large, cloudy, pistachio-green crystals are found in veins at Arendal in Norway (figs. 1 and 2). In these the form is much the same as in text-fig. 198, the upper face being the pyramid *n*, the large face to the front *M*, and the others *T* and *r*. Recently, large crystals of an unusual habit have been found in association with copper ore in metamorphosed limestone on Prince of Wales Island, Alaska. The larger crystals have the form of nearly square tables flattened parallel to the ortho-pinacoid, but in the smaller crystals this tabular habit is less pronounced and these sometimes assume the ordinary prismatic habit of epidote parallel to the axis of symmetry (fig. 3). These crystals are terminated by the clino-pinacoid, and when twinned these faces are marked by feather-like striations. With the epidote from this locality there are found, besides other minerals (magnetite, garnet), crossing twins of quartz similar to those from Japan. Fine crystals of epidote, often aggregated in druses, are found in the Achmatovsk mine near Zlatoust in the Urals, a mine noted for the fine mineral specimens which it has yielded.

An epidote in which the iron is largely replaced by manganese is found in the manganese mines of San Marcello in Piedmont, and, from the locality, it is called *piedmontite*. The crystals have the usual form of epidote, but they are cherry-red to reddish-black in colour, with little transparency, and a cherry-red streak. It mostly occurs as massive or fibrous aggregates in calcite.

The calcium aluminium silicate $H_2 Ca_4 Al_6 Si_6 O_{26}$, present together with the corresponding iron compound in epidote, also crystallizes alone in rhombic forms as the mineral *zoisite*. This usually forms columnar aggregates, without terminal faces, of a dull grey or yellowish colour; and it presents no specially characteristic features which enable this mineral to be readily recognized at sight. The specific gravity is 3·3, and the double refraction is weak. In one variety, known as thulite, it shows a bright rose-red colour; this occurs as granular masses, together with sky-blue idocrase (cyprine), in quartz in the parish of Souland, Telemark, Norway. Together with green hornblende (smaragdite) and brown garnet (plate 66, fig. 7), zoisite is a constituent of the prettily coloured rock eclogite occurring in the Fichtelgebirge in Bavaria and at the Sau Alp in Carinthia.

Application of Epidote. — This mineral is only rarely cut as a gem-stone. The transparent crystals from the Knappenwand supply suitable material for cutting, but these are much sought after by collectors, and the mineralogist prefers a fine crystal bounded by natural crystal-faces to a gem artificially cut. The colour is, moreover, not altogether pleasing and being very intense the stone has to be cut very flat, the most suitable form of cutting being the trap-cut.

PLATE 51.

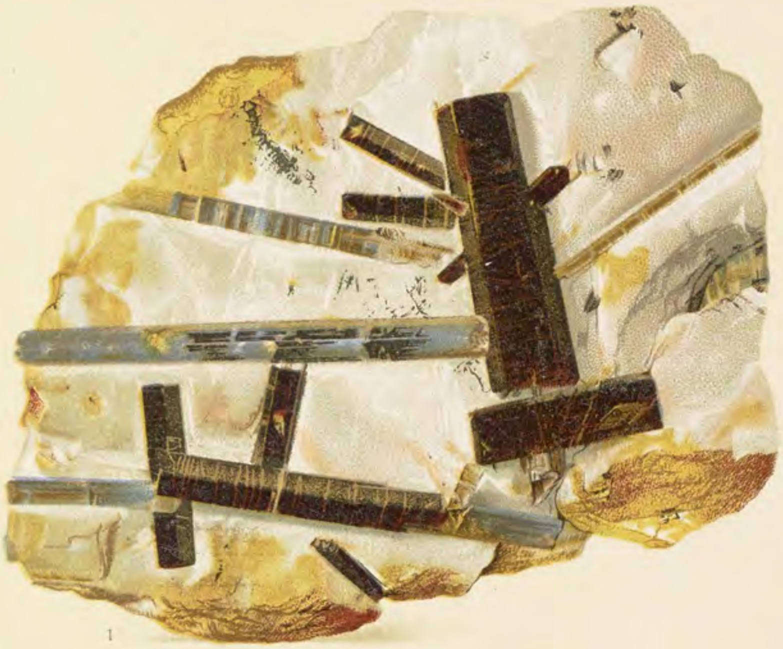
Cyanite, Staurolite, Andalusite, Axinite.

Fig.

1. **Cyanite** (or Kyanite), blue crystals with brown staurolite in white mica-(paragonite-) schist.
   Monte Campione, Faido, St. Gotthard, Switzerland.
2. **Cyanite,** in quartz.
   St. Gotthard, Switzerland.
3. **Cyanite,** bluish-green in quartz.
   Litchfield, Connecticut, U. S. A.
4. **Staurolite,** simple (i. e. untwinned) crystal; rhombic prism with base.
   Brittany, France.
5. **Staurolite,** twin-crystal with the two individuals intercrossing at right angles.
   Brittany, France.
6. **Staurolite,** twin-crystal with the two individuals intercrossing obliquely.
   Fannin Co., Georgia, U. S. A.
7. **Andalusite,** rhombic prism with rough faces; in mica-schist.
   Lisens Alp, Tyrol.

8 and 9. **Andalusite** (variety "Chiastolite"), in mica-schist.
   Lancaster, Massachusetts, U. S. A.

10. **Axinite,** group of crystals.
   Bourg d'Oisans, Isère, France.
11. **Axinite,** crystal coated with chlorite.
   Piz Valatscha, Scopi, Graubünden, Switzerland.
12. **Axinite,** crystal coated with chlorite.
   Monte Prosa, St. Gotthard, Switzerland.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Cyanite and Andalusite.

These two minerals, cyanite (plate 51, figs. 1—3) and andalusite (figs. 7—9), are identical in chemical composition, but different in crystalline form and all their physical characters. They are dimorphous forms of aluminium silicate, Al_2SiO_5, and contain, with the exception of fluorine, the same constituents as topaz.

Cyanite, or kyanite, as the name implies, is a mineral which is characteristically of a blue colour; this is usually a cornflower-blue (plate 51, figs. 1 and 2) or sky-blue, but sometimes bluish-green (fig. 3), whilst white, grey or almost black colours may also occur. The crystals are triclinic, and usually have the form of elongated columns or blades without terminal faces. In text-fig. 199 the large face *M* belongs to the macro-pinacoid, *T* to the brachy-pinacoid, the terminal face *P* to the basal pinacoid or base, and *o* and *l* are narrow prism planes. Twinned crystals, with the large face *M* as the twin-plane, are very frequent; the long crystal lying horizontally across the middle of fig. 1, plate 51, is a twin of this kind, and distinctly shows the re-entrant angle. Crystals of cyanite are sometimes intergrown with crystals of staurolite in a regular manner; this is shown in the long crystal in the lower part of fig. 1, the right-hand end being blue cyanite and the left-hand end brown staurolite. This remarkable regular intergrowth of two totally distinct minerals is further explained in text-fig. 199: the rhombic staurolite (the smaller crystal on the front) is attached to the triclinic cyanite with the faces *b* and *M* parallel and the edges of the prisms also parallel.

Fig. 199.
Regular growth of Staurolite on Cyanite.
(After Tschermak.)

In its physical characters, cyanite is remarkable in presenting considerable differences in hardness on different faces of its crystals and in different directions on the same face: on the face *M* in a direction parallel to the prism edge the hardness is 4—5, whilst on the same face in a direction at right angles the hardness is 6—7; and on the face *T* the hardness is about 7. These difference met with on one and the same crystal are as widely separated as the hardnesses of fluor-spar and quartz. The name disthene, employed by French writers, alludes to this difference in hardness. The crystals possess a very perfect cleavage parallel to the broad face *M*, and this is always shown by fractured pieces of the mineral (fig. 2). There is also a plane of separation parallel to the base *P*, which gives rise to cracks and striations on *M* nearly, but not quite, perpendicular to the prism edge. The specific gravity is 3·6. The pleochroism is very distinct in dark blue crystals, the two images seen in the dichroscope being dark blue and pale blue.

The mineral is not attached by acids. By weathering it passes into potash-mica, but as a rule it is little altered.

Cyanite occurs in crystalline schists, and the finest specimens are found with crystals of staurolite in a white mica-schist (soda-mica or paragonite) in the St. Gotthard district (fig. 1, plate 51), or embedded in the patches of quartz (fig. 2) in the same rock. A very similar occurrence is known at Litchfield in Connecticut. The occurrence in the gold-bearing sands of the Sanarka River in the southern Urals is of interest, since crystals resembling euclase in colour are found together with others of a deep blue. Cyanite also occurs as a constituent of the rock known as granulite.

Clear, deep blue cyanite is sometimes used as a gem-stone, but material suitable for this purpose is very rare. It is then known as sappharé, a name originally given in error instead of sapphire, but although the error has long been recognized the name is still used. Owing to its low degree of hardness in certain directions, cyanite is little suited for use as a gem-stone, and since the colour is usually patchy and the stone only rarely clear, it is not much employed.

Andalusite. This mineral is identical with cyanite in chemical composition, but differs in its crystalline form. The crystals are rhombic, and are usually bounded only by a rhombic prism and the base, and since the angle between the prism faces is 90° 48′, the crystals are very nearly square in cross-section (plate 51, fig. 7). Generally the crystals are quite opaque and of a grey or reddish colour, and they are altered on their surface to potash-mica Clear and transparent andalusite is known practically only as pebbles from the gem-gravels of Brazil. The pleochroism of this material is so strong that the pebbles show an olive-green or a blood-red colour according to the direction the light is transmitted: in the dichroscope the two images are olive-green or oil-green and deep blood-red, similiar to those shown by the alexandrite of Ceylon. Although these two minerals are so similar in their pleochroism, they may be readily distinguished by their specific gravity and hardness: andalusite with a specific gravity of 3·1—3·2 floats in pure methylene iodide, while alexandrite (3·6) sinks; again, andalusite is much softer (H. = 7) than alexandrite. The refraction is not strong, the mean index being 1·638 for red light; and the lustre is therefore not much more than that of ordinary glass.

Crystals of andalusite when they occur embedded in clay-slate usually enclose much carbonaceous matter, which is collected along certain planes in such a manner that a cross-section of the crystal shows a black cross in marked contrast with the paler material of the rest of the crystal (plate 51, fig. 8 and 9). Owing to the resemblance of this cross to the Greek letter chi (χ), this variety of andalusite is known as chiastolite, or cross-stone. The black carbonaceous material is accumulated mainly in the centre of the crystal and along the edges of the prism, and in a cross-section there are darker rectangular patches, with their sides parallel to the prism faces, from which extend black lines to the centre. In fig. 8 these black patches at the corners are smaller and we have a black cross on a white ground, whilst in fig. 9 the black patches are much larger and little of the purer material remains, so that here we have a white cross on a black ground. In the latter figure the outer margins of the black areas are indefinite, there being here a gradual passage of the black material from the crystal into the surrounding rock. The carbonaceous material has no doubt been taken up and enclosed in the crystal during its growth, but exactly how this happened is not quite clear. Professor C. Hintze has suggested that a skeletal growth (similar to the skeletal growths in plate 2, fig. 3, of iron-pyrites and fig 10 of bismuth) rich in carbonaceous material was first formed by rapid crystallization, and that subsequently the interspaces became filled up by a slower growth of the pure andalusite substance.

Chiastolite is found only in clay-states which have been subjected to the metamorphic action of granite or some other igneous rock. The crystals are usually quite small and acicular, and they are found in vast numbers at Gefrees in the Fichtelgebirge, in Bavaria, in the slates around the Skiddaw granite in Cumberland, and at many other places. Thicker crystals (figs. 8 and 9) are found at Lancaster in Massachusetts. Large crystals of andalusite are found embedded in a vein of quartz in mica-schist at the Lisens Alp, Tyrol. Recently, considerable numbers of fine, large crystals of chiastolite have been found in clay-state at Mount Howden, ten miles north of Bimbowrie, in South Australia. The transparent pebbles already mentioned are found in the gem-gravels of the Rio dos Americanas in the Minas Novas district of Minas Geraes.

The transparent Brazilian andalusite is cut as a gem-stone, and chiastolite is cut in slices and polished; both are worked at Oberstein and the latter in large quantities. The striking black cross of chiastolite makes this stone especially suitable for amulets.

Staurolite.

Whilst chiastolite shows a cross in the interior, staurolite often has a cross-like form in the external shape of its crystals (plate 51, figs. 5 and 6), and the name staurolite again means cross-stone. This form is due to the twinning with interpenetration of two rhombic crystals. A simple crystal (fig. 4) is bounded by the faces of a rhombic prism, with a prism angle of $129^{1}/_{2}$, and the basal plane. The large simple crystal in fig. 1 shows, in addition to the forms in fig. 4, a face of the brachy-pinacoid (to the left) and a small face of the macro-dome $P\bar{\infty}$ over the obtuse prism edge (at the top to the left). When two individuals intercross at right angles, as in fig. 5 and text-fig. 200, they have in common a plane which would truncate the edge between the base and the brachy-pinacoid, this plane — a brachy-dome with the symbol $\frac{3}{2}P\breve{\infty}$ — being then the twin-plane. Obliquely intercrossing twins (fig. 6) have the pyramid $\frac{3}{2}P\breve{\frac{3}{2}}$ as the twin-plane.

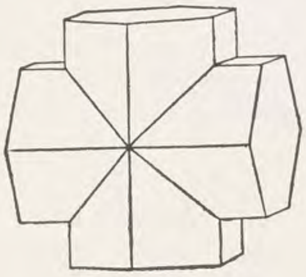

Fig. 200.
Twinned crystal of Staurolite.

The hardness of staurolite is about the same as that of quartz, and the specific gravity varies between 3·4 and 3·8. The colour is always brown. Staurolite sometimes occurs in regular intergrowth with cyanite (p. 255).

The chemical composition is very complex and variable, and a satisfactory formula has not yet been deduced. The mineral contains silica 30%, alumina 50%, ferrous oxide 12%, together with some magnesia, ferric oxide, and water. It is scarcely attacked by acids.

Staurolite principally occurs embedded in gneiss and mica-schist: and when these rocks are disintegrated by weathering the crystals are found loose in the surface soil, as in Brittany (figs. 4 and 5) and in Fannin County, Georgia (fig. 6). Brown crystals with a certain degree of transparency are found embedded with cyanite in white mica-schist in the St. Gotthard district (p. 255; plate 51, fig. 1).

Axinite.

This mineral receives its name on account of the characteristic axe-like form (ἀξίνη) of its sharp-edged crystals. All the faces and edges are inclined at oblique angles, and the crystals are therefore triclinic. The designation of the different faces is therefore quite arbitrary: in the text-fig. 201, we may take *p* to be the left vertical prism and *u* the right vertical prism, *a* the macro-pinacoid, *s* a macro-dome, and *r* and *x* as pyramid faces. We could, however, equally well take *p* as the macro-pinacoid, *u* the brachy-pinacoid, *a* the right vertical prism, *r* the base, *s* a brachy-dome, and *x* a pyramid. Indeed different crystallographers have adopted different orientations for the crystals in their endeavour to simplify the symbols for the faces.

The characteristic colour, as represented in plate 51, fig. 10, is clove-brown to brownish-violet, but it may also be pearl-grey or plum-blue. The lustre is brilliant and vitreous in character. Sometimes the crystals are dusted over with chlorite, and they are then dull and bluish-green with little transparency (figs. 11 and 12). The pleochroism is specially strong, the different shades of colour shown in fig. 10 being partly due to this. According to the direction a crystal is examined with the dichroscope the images are coloured cinnamon-brown and olive-green or violet-blue.

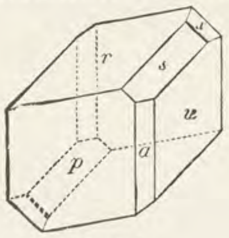

Fig. 201.
Crystal of Axinite.

The hardness is 6—7, and the specific gravity 3·3. The mineral is fusible before the blowpipe and imparts a pale greenish colour to the flame, proving the presence of boron. In this species also the chemical composition is very complex. An analysis of axinite from Bourg d'Oisans gave the following numbers, corresponding with the formula $H(Ca,Fe,Mn)_3Al_2BSi_4O_{16}$: —

SiO_2	B_2O_3	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	H_2O	Total
41·5	4·6	17·9	3·9	4·0	3·8	21·7	0·7	2·2	100·3

Axinite occurs in crevices especially in diabase and hornblende-schist. The earliest known locality is Bourg d'Oisans in Isère (fig. 10). In the Swiss Alps, the crystals are often coated with chlorite, as, for example, those from Piz Valatscha on Mt. Scopi (fig 11) and from Monte Prosa, St. Gotthard (fig. 12). Other well-known localities are Treseburg in the Harz, Thum in Saxony, Botallack Cliff near St. Just in Cornwall, Kongsberg in Norway, etc.

Clear crystals of axinite are sometimes cut as gem-stones, but only rarely are they met with in the trade. They may be distinguished from other brown stones by their peculiar shade of colour and their pleochroism.

Lapis-lazuli.

Lapis-lazuli, or azure-stone, is an almost opaque mineral distinguished by its intense blue colour, this colour being best shown by the very rarely-occurring crystals. A remarkable crystal is represented in plate 62, figs. 11 *a* and *b*: this is a rhombic-dodecahedron with the octahedron and very small faces of the icositetrahedron 2 O 2. More frequently, the mineral occurs as irregular grains intermixed with other minerals, which may be present in smaller or greater amounts and predominate over the blue mineral. A typical specimen is represented in plate 62, fig. 12; here the blue material is lapis-lazuli and the white and brown is calcite, and in addition we see yellow, metallic specks of iron-pyrites; the latter is partly altered to limonite, this being the cause of the brown colour of some of the calcite The best stones are of a deep blue colour with little intermixed impurities, and the somewhat inferior specimen figured in the plate is chosen rather to illustrate the typical character of the mineral. In some specimens the colour is pale blue, or passing into a reddish-violet, while in others it is greenish, but it is only those of a deep blue that are valued. When powdered, the pure mineral still shows the deep blue colour. And when the intermixed impurities are removed by washing, the dark blue powder which remains is the valuable pigment *ultramarine*. This purified material, like the crystal in fig. 11, represents a mineral species known as *lazurite*, the name lapis-lazuli being more correctly applied to the mixture of lazurite with other minerals (fig. 12).

In its chemical reactions this mineral is very remarkable, and in composition it is by no means simple. The fact that it effervesces in hydrochloric acid might be ascribed to the presence of admixed calcite, but the gas which is evolved consists of the evil-smelling sulphuretted hydrogen in addition to carbon dioxide. This cannot be from the iron-pyrites, which is not attacked by hydrochloric acid, and it must consequently result from the decomposition of the lazurite. At the same time the colour of the mineral is destroyed by the acid, and a jelly of silica separates; we must therefore conclude that lazurite is a silicate containing sulphur. The detailed investigations of W. C. Brögger and H. Bäckström have shown that the colouring material of lazurite is identical in composition with the artificial ultramarine, this being a silicate and sulphide of sodium and aluminium with the formula $Na_4(NaS_3.Al)Al_2(SiO_4)_3$. In the natural mineral, however, this is mixed with the isomorphous minerals haüyne and sodalite, and an analysis of material from Central Asia is explained by the intermixture of lazulite, sodalite, and haüyne in the molecular proportions of 15·7 : 7·4 : 76·9. The closely allied minerals haüyne (plate 62, fig. 10) and sodalite (fig. 8) are of importance as rock-forming minerals, and will be described in this connexion farther on, but lazurite being of importance in the precious stone lapis-lazuli is considered in this place.

The fact that lapis-lazuli always contains admixed calcite is readily explained by its mode of occurrence, it being a mineral of metamorphic origin in limestones altered by contact with igneous rock-masses. Water-vapour and sulphur compounds exuded by the igneous magma has penetrated the heated limestone, which may have contained some sodium and aluminium, and lazurite has been formed after much the same manner that ultramarine is manufactured.

The specific gravity of the impure lapis-lazuli is of course very variable, that of the purest naturally-occurring material being about 2·5: for the crystal represented in fig. 11 the value 2·516 was determined, and another smaller crystal gave 2.51. The hardness is about $5^1/_2$.

Lapis-lazuli is on the whole quite a rare mineral, and the material suitable from use as a precious stone comes from remote regions in Asia. The most important mines are situated in Badakshan, near the source of the Kokcha, a tributary of the Oxus in the north-east corner of Afghanistan. The stones obtained here are conveyed by way of Bukhara into Russia, or they find their way into the market through China and Persia. As with other precious stones (e. g. the Syriam garnet, p. 242), the places through which they have passed before coming into the market are sometimes stated to be the localities at which they are found. In this way lapis-lazuli is sometimes erroneously said to come from Bukhara, China, and Persia. Another Asiatic locality where the stone is mined is in the neighbourhood of Lake Baikal. The richest deposits are on the Bistraya river, where nodules of lapis-lazuli weighing as much as 50 kilograms have been found. The material from here is blue, but also violet and green, and it contains less iron-pyrites than that from Badakshan. Lapis-lazuli is also known from the Chilian Andes, and as a rarity from Vesuvius and the Albanian Hills near Rome.

Application. — Lapis-lazuli is usually cut with a flat surface and worn as a ring- or pin-stone, or it is cut as small beads and worn on chains. It is also used, like agate, for some larger objects, such as knife-handles, seals, paper-weights, etc. On a still larger scale it is sometimes used for inlaying and mosaics, as on the walls and ceilings of the palaces of princes, and the columns of churches.

Even in remote times lapis-lazuli was worn as an ornamental stone, it having been found in the ruins of ancient Troy (p. 203). Only rarely was it used as a material for engraving, the lack of homogeneity rendering it unsuitable for this purpose. At different periods the stone has been known by different names: to the Greeks it was known as kyanos, a name now applied to the blue mineral cyanite (p. 255). Later, it was called sapphire, as may be gathered from a passage in Pliny: "in the blue sapphire sparkle specks of gold, like the blue sky bedecked with stars" — the "specks of gold" being, of course, the grains of iron-pyrites scattered through the stone The name lapis-lazuli was first used in the middle ages.

Agate which has been artificially coloured blue is sometimes sold as lapis-lazuli, and especially at watering-places to the unwary. The deception can, however, be recognized at a glance, agate being translucent and more compact in structure, and further considerably harder.

Formerly, the pigment ultramarine was obtained from lapis-lazuli, and was then very expensive, but now it is prepared synthetically.

Turquoise.

Like lapis-lazuli, turquoise or calaite, is an opaque precious stone valued for its fine colour. The colour is a pure sky-blue (plate 82, figs. 10—12), or it may be bluish-green or green. The mineral is compact and exhibits no crystalline form, but sometimes, when forming an encrustation, it presents a botryoidal surface. Usually, however, it forms veins, filling the cracks and crevices in rocks, and in this respect resembling opal in mode of occurrence. It exhibits a soft, waxy lustre, and in thicker pieces is opaque. Thin flakes when examined under the microscope are transparent, and under a high power the material is seen to consist of an aggregate of minute grains and scales.

The colour of turquoise loses none of its beauty by lamplight. On exposure to a strong light, such as direct sunlight, for a long time the colour of some specimens fades, and in all cases it is destroyed by fire. When heated before the blowpipe, the mineral becomes black and, without fusing, falls to powder; this affords a method of distinguishing between true turquoise and the very similar imitations, which are fusible before the blowpipe. A splinter of turquoise held in the non-luminous flame of the Bunsen-burner imparts a green colour to the flame, since the mineral contains phosphoric acid and copper. In its chemical composition, turquoise is of interest in being the only precious stone containing phosphoric acid; it is essentially a hydrated phosphate of aluminium, containing small amounts of copper (2—7 % copper oxide) and iron probably in combination as phosphates. An analysis of turquoise from Persia gave: phosphoric acid 29·4 %, alumina 42·2 %, ferrous oxide 4·5 %, copper oxide 5·1 %, and water 18·6 %. The chemical formula is $[Al(OH)_2]_3PO_4$, the group $Al(OH)_2$ being partly replaced by $Fe(OH)_2$ and $Cu(OH)$ or by hydrogen. The hardness of the mineral is 6, and its specific gravity 2·6—2·8.

The most important locality is in Persia, between Nishapur and Meshed, where the turquoise occurs in a weathered porphyritic rock and has been mined since very early times. Besides being found in situ, it is also found as pebbles in the debris of the river courses. Turquoise mines are also worked in the Meghâra valley in the Sinai Peninsula (plate 82, fig. 10). Here the mineral occurs in the Nubian sandstone, and on Mount Serbâl in porphyry. These mines were worked by the ancient Egyptians 4000 B. C., and at the present time by the Egyptian Development Syndicate. Turquoise of excellent quality is also found at several localities in the western states of the United States: thus, in the Columbus district of Nevada (plate 82, fig. 11); Cochise Co., and Mineral Park in Mohave Co., Arizona; and several places in New Mexico (fig. 12), especially in the neighbourhood of Santa Fé. Green turquoise, of no value as a precious stone, occurs as veins in quartz-schist at Jordansmühl in Silesia.

From early times turquoise has been worn by both civilized and savage races as an ornamental stone, being admired an account of its bright sky-blue colour. The stone is cut and polished with a convex surface, like the opal. Large stones are often set with a border of small brilliants, or are worn as pin-stones: smaller stones are mounted close together to give more effect to the colour. As a material for engraved gems it was used especially in the Augustan period, but curiously green turquoise was mainly employed for this purpose, and glass imitations were also made. At the present day much of the material sold as turquoise is nothing more than a glass imitation; this may be recognized by a careful inspection of the lustre, which is vitreous in glass and waxy in turquoise; further, if a fragment is broken off this will be more transparent and glassy in the imitation stone. Much better imitations of turquoise have been made by submitting to a great pressure a chemical precipitate having the same composition and colour as the natural stone: this is difficult to detect, but before the blowpipe it is fusible, whilst genuine turquoise falls to a black powder.

The so-called *bone-turquoise* or *odontolite* is also sometimes passed off as real turquoise. This consists of the fossil bones and especially teeth and tusks of extinct animals (Mastodon) which have been coloured blue by phosphate of iron. It is found mainly at Simone in France. In lamplight this material appears of a dull grey colour; and it may further be distinguished from true turquoise by the fact that it effervesces with acid (owing to the calcium carbonate present in bone), and when heated it gives a smell of burning organic matter.

The value of turquoise depends on the purity of the sky-blue colour and on the size of the stones; material of a greenish-blue or green colour is now held of little value. A good quality stone weighing one carat costs about fifty shillings, but stones of larger size are worth much more than this per carat.

Variscite. In external appearance this mineral (plate 82, fig. 13) is very similar to green turquoise. It also is compact in texture, and in composition a hydrated phosphate of aluminium, the formula being $\mathrm{Al\,PO_4 . 2\,H_2O}$, corresponding to phosphoric acid 44·9%, alumina 32·3%, and water 22·8%. The fine emerald-green or verdigris-green colour is due to the presence of small amounts of iron oxide and chromic oxide. This mineral occurs, like turquoise, as veins in the crevices of rocks. It is found in quartz-schist or quartz at Messbach near Plauen in Saxony, in Montgomery County in Arkansas, and in Utah (plate 82, fig. 13).

Minerals of the Quartz Group.

Of all minerals, quartz is the most abundant and widely distributed. It is an essential constituent of rocks of many kinds, and it thus forms a large part of the earth's crust. With the weathering of these rocks, the resistant and insoluble quartz remains in the soil, and there are few soils and surface accumulations in which quartz is not largely present. It forms part of the rocks of the highest mountain peaks, and as loose grains it forms the sand of the sea-shore.

Crystals of quartz, clear as water and ice, are found in the Alps in the region of perpetual snow, and it was quite natural that the ancients believed them to be ice which had been so intensely frozen that it could not be again melted. The Greek word κρύσταλλος (krystallos), meaning clear ice, therefore came to be applied to these crystals of quartz, and even to the present day they are known as rock-crystal.

Quartz, with its marked differences in colour, transparency, and structure, is represented by an very large number of varieties, to which special names were applied long before it was known that they belonged to the same mineral-species: and owing to the importance of many of these varieties as precious stones these names are still in use. Rock-crystal is a colourless, transparent variety, amethyst is violet quartz, smoky-quartz is brown and transparent, and other names are applied to the yellow varieties; while cloudy material with little transparency is called common quartz.

The material of which quartz is composed is silica or silicon dioxide, SiO_2 But besides forming prismatic and pyramidal crystals of quartz, silica also forms thin tabular crystals of a much rarer mineral known as tridymite. The same material also forms finely fibrous masses with a botryoidal, reniform, or stalactitic exterior; being then known as chalcedony. Finally, when combined with a variable amount of water it forms amorphous masses of opal. Quartz, chalcedony, and opal are all of importance in that they supply a large number of precious and semi-precious stones; while tridymite is of interest as representing a different crystalline modification of silica.

QUARTZ AND ITS VARIETIES.

Between the form of quartz crystals and their colour and transparency there is in some degree a certain connexion. The simplest forms are met with in the cloudy common quartz, crystals with a larger number of faces are usually of the rock-crystal and smoky-quartz varieties, while complexity of internal structure is more often associated with amethyst.

The simplest form is the double hexagonal pyramid (plate 52, figs. 1, 5, and 6), with an angle of $133^{0}\ 44'$ between two adjacent faces which meet in a sloping edge. The horizontal edges of this double pyramid are almost always truncated by the faces of a hexagonal prism, which may be smaller (figs. 7, 8, and 4) or larger (figs. 3 and 9) in size. These prismatic faces are almost invariably marked by striations perpendicularly to the edges of the prism (plate 54, fig. 1); when the crystal is set up vertically, as in the figures, these striations will be horizontal, and they are very often helpful in correctly orientating a distorted crystal. The faces of the pyramid are frequently of different sizes (plate 54, fig. 1); at each end of the crystal three of the faces being larger and brighter than the three alternate faces. The apparent hexagonal pyramid of quartz is therefore a combination of two rhombohedra, the positive rhombohedron $+R$ and the negative rhombohedron $-R$; the symbol of the hexagonal prism then being ∞R. The angle between the faces of each of these rhombohedra is $94^{0}\ 15'$.

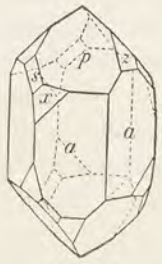

Fig. 202.
Left-handed crystal of Quartz.

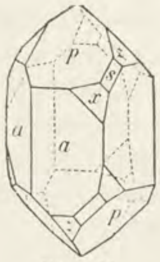

Fig. 203.
Right-handed crystal of Quartz.

In addition to these commonly-occurring faces these are sometimes present smaller rhomb-shaped faces lying above the vertical edges of the prism (plate 54, figs. 5 and 6). These so-called rhomb faces have the position of a pyramid of the second order, but

PLATE 52.

Quartz I.

Fig.

1. **Quartz,** bipyramidal crystals on haematite.
   Cleator Moor, Cumberland.
2. **Quartz,** crystal with red and brown patches of colour.
   Zinnwald, Erzgebirge, Bohemia.

3 and 4. **Quartz,** doubly-terminated crystals found embedded in gypsum.
Mari, Salt Range, Punjab, India.

5. **Quartz,** hexagonal bipyramid.
   Java.
6. **Quartz,** black, hexagonal bipyramid.
   Monte Amiata, Tuscany, Italy.
7. **Quartz,** so-called "stink-quartz", hexagonal bipyramid with prism.
   Pforzheim, Baden.

8 and 9. **"Eisenkiesel",** red ferruginous quartz, or "Compostela hyacinth".
Santiago de Compostela, Galicia, Spain.

10. **"Eisenkiesel",** yellow ferruginous quartz.
    Sundwig, Iserlohn, Westphalia.
11. **Quartz,** with zonal structure.
    Streitfeld, Usingen, Taunus, Germany.

12a and b. **Quartz,** so-called "capped quartz", the upper part fitting on the lower.
Cornwall.

13. **Quartz,** pseudomorphous after blue, fibrous crocidolite; so-called "Hawk's-eye". Owing to the oxidation of the iron along certain bands, the material is passing into the yellow "Tiger-eye". A cut and polished surface.
    Griquatown, Orange River, South Africa.
14. **"Tiger-eye",** quartz pseudomorphous after crocidolite. A cut and polished surface.
    Griquatown, Orange River, South Africa.

15 and 16. **Cat's-eye,** cut *en cabochon.*
(After Max Bauer, "Precious Stones", Plate XVIII, figs. 4*a* and *b*.)

17. **"Blood-stone",** or "Heliotrope", engraved.
18. **"Chrysoprase",** (18) rough and (19) polished.
    Baumgarten, Frankenstein, Prussian Silesia.


1


2


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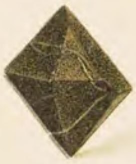
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12 b


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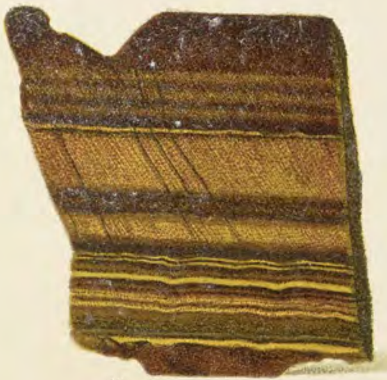
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in a perfect crystal they are developed at the two ends of alternate prism edges (*s* in text-figs. 202 and 203): if developed as a simple form they would give a double triangular pyramid. The edges between these rhomb faces and *one* of the adjacent prism faces are sometimes truncated by faces of another form (plate 54, figs. 2 and 3; *x* in text-figs. 202 and 203); these are known as trapezohedral faces, and they are placed obliquely above and below alternate edges of the prism. Their position is that of the faces of a twelve-sided double pyramid, but instead of twenty-four faces only six are developed. In quartz, therefore, only one quarter of the full number of faces possible in the general form of the hexagonal system are developed; the crystals are consequently described as tetartohedral, and they belong to the trapezohedral-tetartohedral class of the hexagonal system. The Naumannian symbols for these faces are somewhat complex; for the rhomb faces $s = \frac{2P2}{4}$, and for the trapezohedral faces $x = \frac{6P\frac{6}{5}}{4}$. The symbols for the other faces in text-figs. 202 and 203 are $a = \infty R$, $p = +R$, and $z = -R$. Numerous other faces have been recorded on quartz crystals but they are rare, and the basal plane is extremely rare as a small corroded face. Narrow faces of steeper rhombohedra are seen in plate 54, fig. 3.

Except in very rare cases, the trapezohedral faces are placed beneath the positive rhombohedron (*p*), and lie either to the right or to the left of a prism face. Right-handed (text-fig. 203; plate 54, fig. 2), and left-handed (text-fig. 202, plate 54, fig. 3) crystals of quartz are therefore to be distinguished. These are related to one another like the right and left hands; one is the mirror-reflection of the other, and they cannot be brought into superposable positions. Such crystals are said to be enantiomorphous, and there is a close connexion between their external form and their optical properties: right-handed crystals rotate the plane of polarization of plane-polarized light to the right, and left-handed crystal rotate it to the left.

Irregularities and distortion of the form is very frequent in crystals of quartz, due, as already explained (p. 42, and plate 2a), to the unequal extension of the faces. Twisted crystals, due to the aggregation of particles in not quite parallel positions, have also been mentioned in the same place. Some crystals of quartz exhibit a pronounced shelly or zonal structure, being built up of a number of concentric shells of material, and indicating that the conditions under which the crystals grew must have varied from time to time. In plate 52, fig. 11, this structure is marked out by the alternation of lighter and darker bands. In the

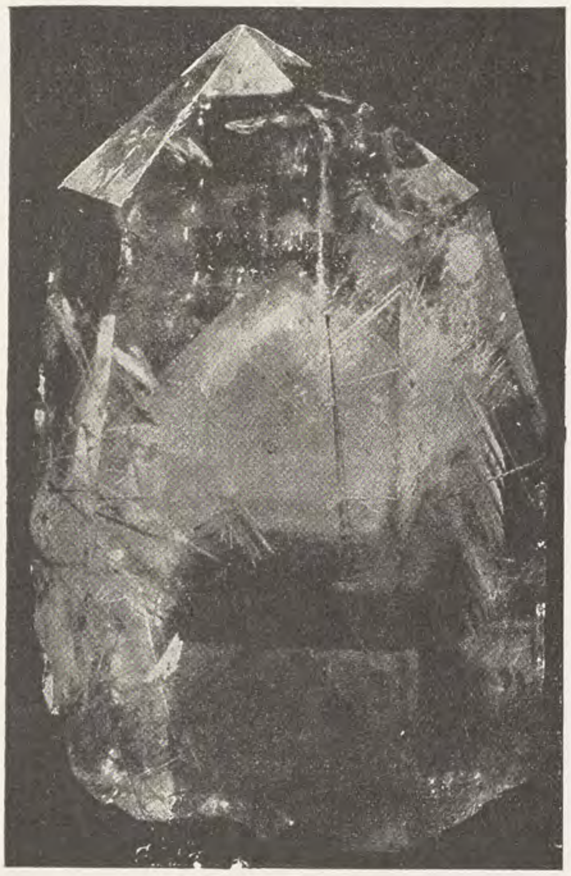
Fig. 204.
Rock-crystal showing layers of growth ("Ghost-quartz"): from Goyaz, Brazil.

transparent rock-crystal shown in text-fig. 204, the stages of growth of the crystal are marked out by thin, snow-white layers parallel to the external faces, and we see one crystal within another; such a specimen is known as ghost-quartz. Here the thin, snow-white layers are due to the enclosure in the quartz of vast numbers of minute air spaces. In other cases the stages of growth are rendered evident by bands of chlorite or other foreign material, which was thinly deposited on the surface of the crystal before its growth was completed: the crystal can then often be readily broken up into the several shells of material, as in the so-called capped quartz (plate 52, figs. 12 a and b). An internal lamellar structure of another kind is detected when crystals are carefully examined in polarized light: this consists in the repeated interlamination of thin layers of right-handed quartz and of left-handed quartz, a pecularity in structure especially characteristic of amethyst.

Twinning is of frequent occurrence in quartz, but the twinned crystals have, at first sight, quite the appearance of simple crystals, the twinning being rendered evident only in the distribution or surface characters of the faces; only rarely do they show re-entrant angles, enabling them to be recognized at a glance as twins. The several types of twinning of quartz are illustrated in plate 53.

In the crystal represented in fig. 1 the only evidence of twinning is seen in the irregular distribution of bright and dull areas on the rhombohedron faces (best seen on the rhombohedron face to the front in the figure): the brighter areas belong to the positive rhombohedron ($+R$), and the dull areas to the negative rhombohedron ($-R$). To explain this coincidence of the faces of the two rhombohedra, consider two crystals placed side by side in parallel position, as in text-figs. 202 and 203, and with a face of the positive rhombohedron (p) directed to the front: if now we rotate one of the crystals through 180° about the vertical axis, a smaller face z of the negative rhombohedron will come to the front and be parallel to p of the other crystal. The two crystals will then be in twinned position with respect to one another, and if they were grown together with interpenetration the faces p and z would be coincident. This type of twinning is rendered still more evident if the crystals carry trapezohedral faces, since in the twinned crystals these faces will be present above *all* of the prism edges: in fig. 2 we have such a twin intergrowth of two right-handed crystals, and in fig. 3 of two left-handed crystals, while in fig. 4 the intergrowth is of a left-handed crystal with a right-handed. Twins of the kind shown in figs. 2 and 3 are common, but distinctly developed twins like fig. 4 are extremely rare and are to be seen in very few collections (the one figured being in the collection of Mr. Gustav Seligmann, of Coblenz). The last of these, being met with in amethyst from Brazil, is known as the Brazil twin; and although it is rarely shown by the distribution of the trapezohedral faces, it is in fact extremely common, as proved by the optical examination of crystals.

In the twins so far considered the two individuals are intergrown with their axes parallel. In figs. 5 and 6 the twinning is much more conspicuous, the principal axes of the two individuals been almost at right angles (actually 84° 33′). Here the twin-plane is a face of a pyramid of the second order $P\,2$. Twinned crystals of this type have long been known from Bourg d'Oisans in Isère (fig. 5), and more recently large numbers have come from Japan (fig. 6, and plate 54, fig. 12). Smaller examples are known from Munzig in Saxony, occurring here with mispickel, and with epidote from Alaska.

The *physical characters* of quartz also present several points of interest, and of special importance is that circular polarization (p. 61). A plate cut from a clear crystal perpendicularly to the edges of the prism, when examined in the polariscope between crossed nicols is not dark, as with other optically uniaxial crystals, but is uniformly

PLATE 53.

Quartz II. Twin-crystals.

(With the exception of No. 4, all the specimens were photographed with a black background.)

Fig.

1. **Rock-crystal,** interpenetrating twin of two crystals with dull (— *R*) and bright (+ *R*) rhombohedron faces.
   St. Gotthard, Switzerland.
2. **Smoky-quartz,** twin of two right-handed crystals.
   St. Gotthard, Switzerland.
3. **Rock-crystal,** twin of two left-handed crystals.
   Maderanerthal, Switzerland.
4. **Amethyst,** twin of a right-handed crystal and a left-handed crystal.
   Brazil.
5. **Rock-crystal,** crossing twin; twin-plane the pyramid *P* 2.
   La Gardette, Bourg d'Oisans, Isère, France.
6. **Quartz,** crossing twin; twin-plane *P* 2.
   Kimpōzan, province Kai, Japan.

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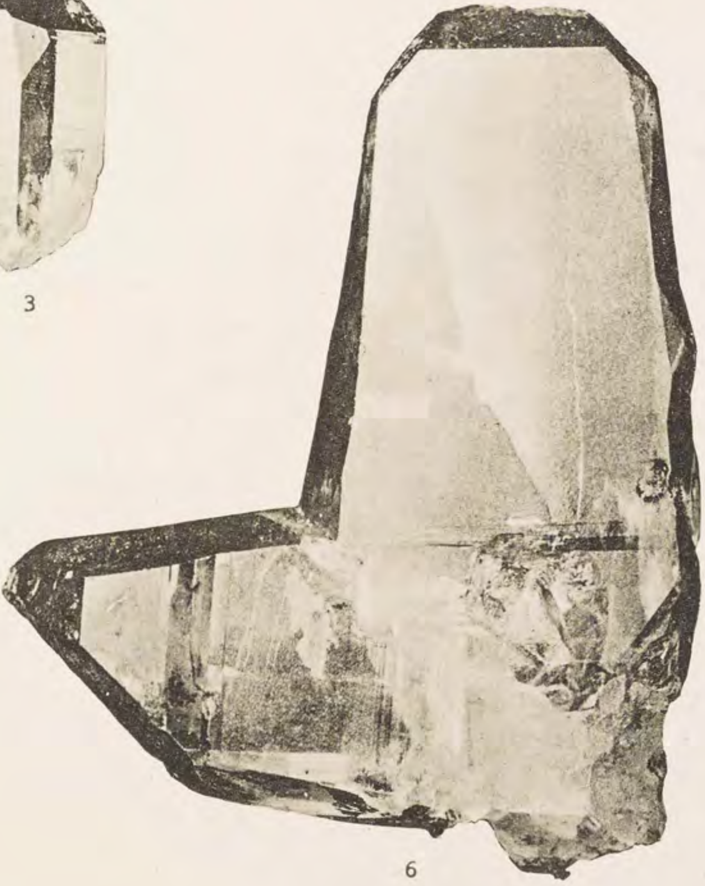

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coloured. Further, as the upper nicol (the analyser) is rotated, the colours change, and from the order in which these appear we can determine whether the rotation of the plane of polarization is to the right or to the left. If, for example, the plate shows a red colour, the analyser must be rotated to the right (clock-wise) with a plate of right-handed quartz, or to the left (counter-clock-wise) with a plate of left-handed quartz, for the colours to appear in the order of succession shown in the spectrum of white light—namely, red, yellow, green, blue. If the analyser be rotated to the right with a plate of left-handed quartz, this order of the colours will be reversed. A plate cut from a twinned crystal consisting of an intergrowth of right-handed and left-handed quartz will, in different portions, show the two orders in the succession of colours. In such a plate, where there is an overlapping of right-handed and left-handed quartz, the rotary polarization will be neutralized, and between crossed nicols there will be darkness: this is well shown in text-fig. 205 along the black lines in the middle of each of the clear sectors. The clear portion on one side of each of these lines is right-handed quartz and that on the other side left-handed quartz. The finely banded portions in the same figure consist of a more intimate interlamination of right-handed and left-handed material.

In convergent polarized light plates of quartz show a uniaxial interference-figure of a peculiar kind: the black cross does not extend towards the centre beyond the innermost ring, the centre of the figure being clear, or, in white light, coloured (plate 4, fig. 2). A still further modified interference-figure is shown by a plate cut from a twinned crystal consisting of right-handed and left-handed material: where there is over-lapping of the two portions a complex system of coloured spirals (Airy's spirals) is seen.

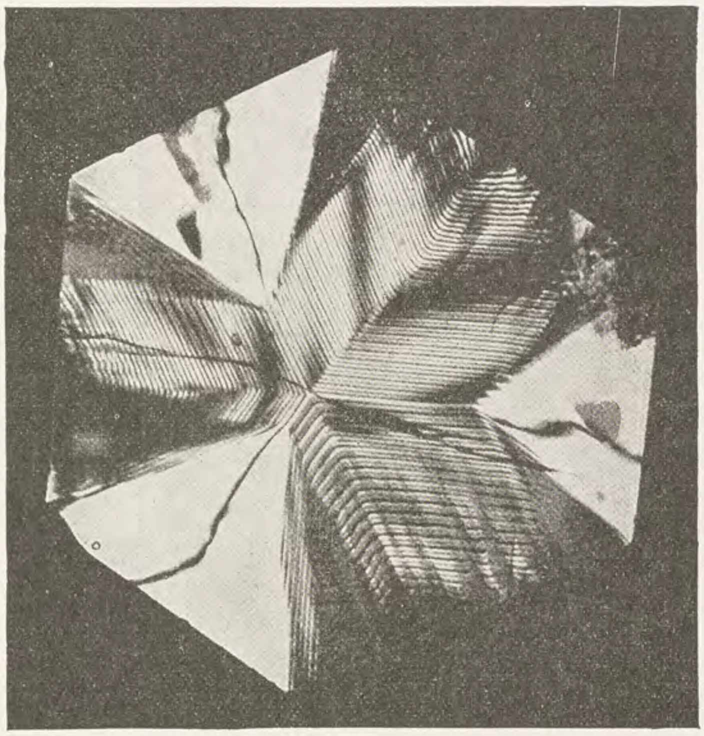

Fig. 205.
Plate of Amethyst cut perpendicularly to the principal axis; in parallel polarized light.

The *refraction* and dispersion of quartz are both low, and consequently a cut stone displays neither a brilliant lustre nor a strong fire; the double refraction is also low. The refractive indices in sodium-light are 1·54415 for the ordinary ray and 1·55329 for the extraordinary ray.

The *colouring* of quartz is sometimes due to the presence of mechanically admixed pigments: for example, the red colour of the crystals in plate 52, figs. 8 and 9, is due to iron (ferric) oxide, the yellow colour of the crystals in fig. 10 to hydrated oxide of iron, and the black of figs. 6 and 7 to carbonaceous matter. In the transparent, coloured varieties of quartz, however, the colouring matter is not present in this form, but is actually dissolved in the quartz substance, like a salt is dissolved in water. This is present only in minute traces, and different investigators are not agreed as to whether it is organic or inorganic, both hydrocarbons and titanium compounds having been suggested as the cause of the colour.

The hardness of quartz is 7 on the scale, and its specific gravity is 2·65. The mineral breaks with a conchoidal or splintery fracture; and sometimes a very imperfect cleavage parallel to the faces of one rhombohedron is observable.

The *melting point* of quartz is about 1700° C., and the fused material consolidates as a clear glass; this melts at a slightly higher temperature and can be worked like ordinary glass. In recent years extensive use has been made of fused quartz for chemical apparatus, such as crucibles, etc. The softening temperature of this silica glass is about 800° C. higher than that of ordinary glass, and it further has the very great advantage that it is not affected by sudden changes of temperature: a crucible of silica glass may be raised to a red-heat and immersed into cold water without being broken or cracked. The specific gravity of this fused quartz is only 2·2, and its refractive index 1·45.

Quartz is very resistant to chemical reagents, and is completely dissolved only by hydrofluoric acid. That quartz is sometimes acted upon by natural solutions is shown by the occurrence of corroded crystals with etched figures on the faces (p. 21, plate 55, fig. 3). From the orientation of the etched figures it is sometimes possible to distinguish between right-handed and left-handed crystals of quartz.

Enclosures of other minerals are very frequently seen in crystals of quartz. In plate 54, fig. 9, we see needles of green actinolite, somewhat resembling blades of grass, enclosed in a colourless crystal: and in fig. 8 a network of brown needles of rutile, like the rutile in plate 19, fig. 10. Bundles of long rutile needles are enclosed in the crystal shown in plate 55, fig. 4. Rock-crystal with these enclosures of rutile is known as hair-stone, magnificant specimens of which have recently been obtained from Goyaz in Brazil. The black enclosures in plate 54, fig. 7, consists of asphalt. In the thin rock-section shown in plate 59, fig. 3, we see enclosures of glass in the quartz of a porphyry; this rock was formerly in a molten condition, and the growing quartz crystals caught up drops of the molten material before it had consolidated to a glass. The quartz of granite is frequently rich in enclosures of liquid carbon dioxide and of saturated solutions of sodium chloride. The enclosure of native gold in quartz has already been mentioned (p. 75). Quartz sometimes form regular intergrowths with felspar (as in graphic granite), and more rarely with calcite.

Although formed so abundantly in nature, the *artificial production* is quartz is not readily achieved. Small crystals have been prepared by the action of superheated water vapour on glass and gelatinous silica, and also deposited from solutions containing fluorine. The conditions under which enormous crystals of clear quartz have been formed in nature are not known.

Quartz is the most stable of minerals and it frequently takes the place of other minerals when these are altered, pseudomorphs of quartz being of common occurrence. Occasionally, however, other minerals may replace quartz, as in the rare pseudomorphs of steatite after quartz (plate 69, fig. 11).

We now pass to a more detailed description of the several *varities* of quartz.

Rock-crystal is the transparent, water-clear variety of crystallized quartz. The crystals are brilliant and often carry the rarer faces *s* and *x* of text-figs. 202 and 203. In size they vary very considerably: the largest crystals are over a metre in length and circumference and weigh several hundredweights, whilst others are so small that they can only be seen under the microscope. Distorted crystals are common in rock-crystal, while twisted crystals are more usual in smoky-quartz. Rock-crystal is represented in plate 1, fig. 9; plate 2, fig. 8; plate 2a, figs. 1, 4, and 7; plate 54, figs. 1, 4, 5—9, and 11; and as twinned crystals in plate 53, figs. 1, 3, 5, and 6.

Rock-crystal is widely distributed in crevices and larger cavities, the so-called crystal caves, in the granitic rocks of the Alps, and is often accompanied by adularia, sphene, rutile, chlorite, and other crystallized minerals. The crevices and cavities are usually closed, and it requires a practised eye and considerable experience to detect their presence. A small quartz-vein visible on the side of a precipice may lead to a crystal cave. A person who makes his livelihood by searching for and collecting rock-crystal is known in Switzerland as a "Strahler". The occupation is a dangerous one, and the yield but small, it being only rarely that large crystals are found in numbers. Perfectly water-clear crystals of quartz, sometimes twinned according to the Brazil-law, are found in cavities in the snow-white marble of Carrara in Tuscany (plate 54, fig. 11). Large, clear crystals are known from the State of Goyaz in Brazil (plate 55, figs. 3 and 4, and text-fig 204), and fragments of gigantic crystals come from Madagascar. Good crystals also come from India; and these are often terminated by only one rhombohedron. Water-clear crystals, bounded on all sides by faces and sometimes enclosing asphalt, are found in Herkimer Co., New York (plate 54, fig. 7); and smaller crystals in the Marmaros Comitat in Hungary, and in the Hessian County of Schaumburg. Minute water-clear crystals are often found embedded in gypsum and carnallite. Rock-crystal with hopper-shaped depressions on the rhombohedral faces are found at Poretta in Italy (plate 2, fig. 8).

Application. — Ever since the Mycenaean epoch rock-crystal has been employed as a precious stone, for engraved gems, and for the carving of various costly ornaments. It is probable that the ancients had observed the magnification of objects when viewed through clear crystal cut with rounded surfaces; and it is therefore not unlikely that the gem engravers made use of lenses of rock-crystal in their minute work. The Roman physicians are said to have used spheres of rock-crystal as burning glasses for burning out wounds. At the time of the Roman emperors and during the Renaissance beautiful vases and bowls were artistically carved in rock-crystal. The so-called crystal used for similar vessels at the present day is only cut glass, rock-crystal being scarcely ever now employed for this purpose.

At the present day rock-crystal, which is mainly of Brazilian origin, is cut as spectacle lenses, weights for delicate balances, seals, paper-weights, crystal balls, etc. It is also extensively cut in the brilliant form for jewellery; such stones have quite a good effect by themselves, but in comparison with the diamond they appear dull, showing neither brilliancy of lustre nor play of prismatic colours. Rock-crystal with enclosures of needles of rutile or of green actinolite is cut with a low rounded surface, in order to show these enclosures to the full advantage: such material may be employed for letter-weights, seals, or balls. Pure rock-crystal is also used for the manufacture in fused silica of crucibles and other apparatus (p. 266).

Smoky-quartz (or "smoky-topaz") is a brown, transparent quartz. The colour varies from pale brown to dark brown, and when almost black the material is known as *morion* (plate 54, fig. 10). The colouring matter is probably a hydrocarbon or some other organic substance, since it is readily affected by heat, the colour of the crystals being destroyed at a temperature as low as 360° C. It must therefore be concluded that crystals of smoky-quartz were formed at a temperature less than 360° C. Enclosures of other minerals are much less frequent in smoky-quartz than in rock-crystal. The dichroism is strong; as seen in the dichroscope, the extraordinary image is brownish-yellow and the ordinary image pale brownish-violet or pale brown to almost colourless. The same crystal-faces are present on smoky-quartz as on rock-crystal, and we find the same distortion of the crystals, though twisted crystals are more frequent in smoky-quartz (plate 2, fig. 12; plate 2a, figs. 2 and 3) than in rock-crystal. A fine group of crystals of smoky-quartz is represented in the frontispiece; the crystals are doubly-terminated, and both right-handed and left-handed crystals are to be seen; the smaller white crystals are albite.

Smoky-quartz occurs in the Alps under the same conditions as rock-crystal. A remarkable crystal cave was discovered in 1868 on the Tiefen glacier near the Furka Pass: 300 hundredweights of crystals were found, the largest being 69 centimetres in height and weighing 133 kilograms. The best and largest of these crystals are now in the museum at Berne. The St. Gotthard district is especially rich in large, clear crystals of smoky-quartz; the specimen represented in the frontispiece, and those in plate 54, figs. 2 and 3, being from this district. In other regions smoky-quartz is, on the whole, rarer than rock-crystal. Clear material of good quality is found in Goyaz, Brazil.

Smoky-quartz has at various times been much used as a gem-stone, though now it is not much in favour. It is fashioned into seals, balls, and other small ornaments.

Yellow and brownish-yellow, transparent Quartz. Besides smoky-quartz, there are other colour-varieties of quartz which are of importance in the trade, being known to jewellers as "topaz" with some qualifying prefix.

Yellow quartz is citron- or orange-yellow in colour. The material as it comes into the market has usually the form of long, broken prisms rarely with terminal faces, while the prism-faces are often marked with etching figures. The fractured surfaces are conchoidal and smooth without ripple markings. The dichroism is strong, the colours being pale yellow for the ordinary ray and dark yellow for the extraordinary. In polarized light the material behaves like rock-crystal, though it is only rarely that there is an intergrowth of right-handed and left-handed quartz. Material of this description comes from Brazil, and it is only rarely met with in the trade.

"*Golden topaz*" differs from the preceding only very slightly in colour, but this is always of a pale shade. It comes into the market mostly as broken fragments, and only exceptionally are terminal faces present (plate 56, fig. 9). The fractured surfaces exhibit the peculiar ripple-like markings (so-called thumb-markings) so characteristic of amethyst, and in this respect "golden topas" differs from yellow quartz. In polarized light the material behaves like amethyst (compare text-fig. 205, p. 265), and, indeed, according to the statements of the traders it is a burnt amethyst. In any case, the material is imported as "golden topaz", and it is said to have been burnt in Brazil. When heated, amethyst changes to yellow in colour, but the material is usually thereby fractured, unless the heat be applied very gradually and uniformly, this being effected by embedded the crystals in sand.

As broken fragments, "golden topaz" is exported from Brazil in large quantities, and at the auction sales at Idar in Germany it fetches from 20 to 60 marks (£1 to £3) per pound according to the clearness and size of the pieces.

Citrine is a name applied by mineralogists to transparent quartz of a citron-yellow or wine-yellow colour, and it includes the two foregoing varieties; but in the trade this name is little used. The island of Arran is given as a locality; and a cut stone is represented in plate 54, fig. 13.

PLATE 54.

Quartz III.

Fig.

1. **Rock-crystal,** the faces of one rhombohedron are small, those of the other are large.
   Hot Springs, Arkansas, U. S. A.
2. **Smoky-quartz,** a right-handed crystal with large trapezohedral face.
   St. Gotthard, Switzerland.
3. **Smoky-quartz,** left-handed crystal with large trapezohedral faces.
   St. Gotthard, Switzerland.
4. **Rock-crystal,** with very steep rhombohedral faces.
   Kimpōzan, province Kai, Japan.
5. **Rock-crystal,** with rhomb face.
   Locality unknown.
6. **Rock-crystal,** with large rhomb face.
   Goyaz, Brazil.
7. **Rock-crystal,** with enclosures of asphalt.
   Herkimer Co., New York, U. S. A.
8. **Rock-crystal,** with enclosures of rutile.
   Tavetsch, Switzerland.
9. **Rock-crystal,** with enclosures of rutile.
   Norway (?) (More probably from the Alps).
10. **Smoky-quartz** ("Morion"), doubly-terminated crystals.
    Mursinsk, Ekaterinburg, Ural Mountains.
11. **Rock-crystal** on marble.
    Carrara, Tuscany, Italy.
12. **Quartz,** crossing twin; twin-plane $P\,2$.
    Kimpōzan, province Kai, Japan.
13. **Citrine,** faceted.
14. **Tridymite,** coated with chlorite.
    Zovon di Vo, Euganean Hills, Padua, Italy.

Stuttgart (Fritz Lehmann).


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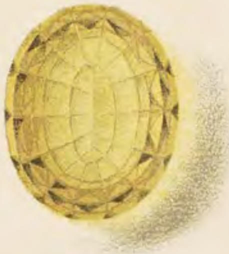
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"*Brown topaz*" also known as "Brazilian topaz" or "Uruguay topaz", is deep brownish-yellow, clear and fiery, and is the most beautiful of the gem-stones belonging to the quartz group. There appear to be two varieties included under this name. In one, the fragments are uniformly coloured to the tips of the crystals, and the pyramid-faces sometimes show an opalescent, milky appearance: when carefully heated, this material becomes colourless, regaining its colour on cooling. The other variety comes in more columnar pieces which are colourless at their tips, the end faces being dull and white. In both of the varieties dichroism is not noticeable. Although described as burnt amethyst, they have not the characteristic optical characters of amethyst; plates cut perpendicular to the principal axis behave like rock-crystal and yellow quartz and show an intergrowth of right-handed and left-handed quartz. It is probable that we have here stones which were originally brown, but in which the colour has been improved by burning. Such material comes from Brazil and Uruguay, and fetches 20—50 marks per pound.

"*Spanish topaz*" is a perfectly clear, light yellowish-brown stone, and the rich colour is combined with a strong fire, so that this variety gives a fine gem-stone. As distinct from the "brown topaz", it occurs as large crystals bounded by prisms and pyramids, and is strongly dichroic — pale yellow for the ordinary ray and yellowish-brown for the extraordinary. The fine colour seems to be the result of a careful application of heat, the original colour of the stones being brown. This variety is found at Hinojosa in the Spanish province of Cordoba, on the northern slopes of the Sierra Morena, and it is also said to come from New Zealand. Of all the brown and yellow varieties of quartz, it is the most expensive, clear stones of large size costing £25 per pound.

All these yellow and brown "topazes" are extensively employed as precious stones, and especially those of a deeper colour and brilliant lustre. They are readily distinguished from the true topaz by means of their specific gravity: when placed in methylene iodide or in bromoform topaz sinks, while all the varieties of quartz float.

Amethyst is a violet quartz, the colour being a pale or deep violet with a tinge of red or of blue. The nature of the colouring matter is not known; manganese and iron compounds have been suggested, but the question has not yet been decided. The change in colour which amethyst undergoes at high temperatures is also still open to discussion. It is usually stated that amethyst becomes yellow when heated, and that at a temperature of 250° C. it is completely decolorized. This, however, does not agree with a few experiments made by the author. Pale and dark violet amethyst was gradually heated in an oven, a temperature of 290° C. being reached in about three hours, when the colour was a dull greyish-violet; and on cooling again the stones regained their original pure violet colour. The same result was obtained when the material was raised to a low red-heat. Only after prolonged ignition in a platinum crucible over the full flame of a Teclu-burner did the stones become colourless, and yellow on cooling.

The dichroism of amethyst is always very feeble, scarcely any difference being noticeable in the two images seen in the dichroscope, although one is perhaps slightly more reddish and the other more bluish.

The colouring is often very irregular in its distribution in one and the same crystal: lighter and darker patches may be irregularly distributed, or darker coloured "pyramids of growth" (p. 41) may extend from certain faces. The latter distribution of colour is shown in plate 56, fig. 8, which represents a plate cut from a crystal perpendicular to the principal axis, three sectors being violet and the three alternate sectors almost colourless. The optical structure of such a plate as seen in parallel polarized light is represented in text-fig. 205. The three pale coloured sectors are seen to be clear with a dark line down their middle marking the junction of the two halves of respectively right-handed and left-handed quartz. On the other hand, the coloured sectors show in polarized light a close and repeated interlamination of right-handed and left-handed quartz, giving rise to the rippled appearance so characteristic of amethyst. This interlamination often gives rise to delicate striations on the rhombohedral faces, which run parallel to the edges of intersection of the alternate larger faces *P*, as shown in text-fig. 206; and it is also the cause of the characteristic ripple markings on the fractured surfaces of amethyst. In convergent polarized light, the paler coloured sectors give the interference-figure peculiar to quartz (plate 4, fig. 2); and the deeper coloured sectors, at points where the intermixture of right-handed and left-handed quartz is very intimate, give the interference-figure of an ordinary uniaxial crystal (plate 4, fig. 1), but at points where thicker layers are superimposed Airy's spirals are seen.

We thus see from an optical examination of sections of the crystals that amethyst consists of an intergrowth of right-handed and left-handed quartz; and the same is also shown, though only rarely, by the distribution of the trapezohedral faces on the crystals. The crystal represented in plate 53, fig. 4, and idealized in text-fig. 206, consists of a twin intergrowth of a right-handed crystal with a left-handed crystal, as already explained on p. 264. Most crystals of amethyst are, however, very simple in form, and frequently they show only an apparent hexagonal pyramid, several crystals being closely crowded together on a matrix of agate with only their tips projecting from the surface. Such crystals are often broken away from the matrix before being exported from Brazil, and are sold by auction at Idar as amethyst tips. The isolated crystal shown in plate 56, fig. 1, has no doubt been so broken from a druse, as suggested by the irregular fractured surfaces at the sides. That the apparent hexagonal pyramid is really a combination of two rhombohedra is clearly shown in plate 56, figs. 3 and 5, where the faces of one rhombohedron are large and those of the other rhombohedron are small; and again in fig. 2, where the faces of one set are smooth and the alternate faces are rough. In fig. 2 the apex of the crystal is truncated by a rough surface with approximately the position of the basal plane. In figs. 4, 6, and 7 prism-faces are also present; in the last of these the prism is unusually long and has a slight spiral twist; this crystal, further, shows a tendency to the form known as sceptre-quartz, the amethyst being grown on the end of a thinner rock-crystal with enclosures. Other peculiarities of growth met with in amethyst resemble those seen in rock-crystal and smoky-quartz: in plate 56, fig. 6, we have the same hopper-shaped depressions on the rhombohedral faces as on the rock-crystal in plate 2, fig. 8; and in plate 2, fig. 9, we see amethyst surrounded by a shell of rock-crystal. Twinned crystals with bright and dull areas on the rhombohedral faces (as in plate 53, fig. 1) also occur in amethyst, but these are more frequent in rock-crystal. The most usual form of amethyst crystals is the apparent hexagonal pyramid (plate 56, fig. 1), and these are never found of the enormous size sometimes met with in rock-crystal and smoky-quartz.

Fig. 206.
Twin-crystal (Brazil twin) of Amethyst.

Occurrence. — Amethyst is usually found in the vesicular or amygdaloidal cavities of volcanic rocks, the crystals resting on a layer of agate which coats the walls of the cavities. It so occurs in are amygdaloidal melaphyre at Oberstein on the

pl. 33 [illegible]
17/65

PLATE 56.

Quartz V. Amethyst.

Fig.

1. **Amethyst,** clear, with smooth, six-sided pyramid.
   Iredell Co., North Carolina, U. S. A.
2. **Amethyst,** the faces of one rhombohedron are bright and those of the other are rough. At the top of the crystal is a small basal plane, which is of extremely rare occurrence in quartz.
   Brazil.
3. **Amethyst,** the two rhombohedra are of different sizes.
   Minas Geraes, Brazil.
4. **Amethyst,** two large crystals irregularly grown together.
   "Siberia" (probably Mursinsk, Ekaterinburg, Urals).
5. **Amethyst,** one rhombohedron large, the other small.
   Brazil.
6. **Amethyst,** with hopper-shaped depressions on the faces.
   Zillerthal, Tyrol.
7. **Amethyst,** with a form resembling that of "Sceptre-quartz". The crystal has a slight helical twist about the vertical axis.
   Rothenkopf, Zillerthal, Tyrol.
8. **Amethyst,** cross-section of a large crystal. Three sectors are violet and the three alternate sectors colourless.
   Brazil.
9. **Citrine** (or "occidental topaz"), probably a "burnt" amethyst.
   Minas Geraes, Brazil.

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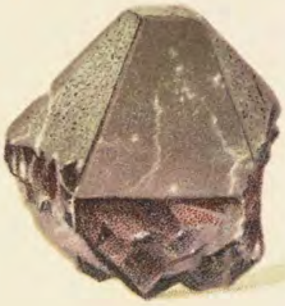

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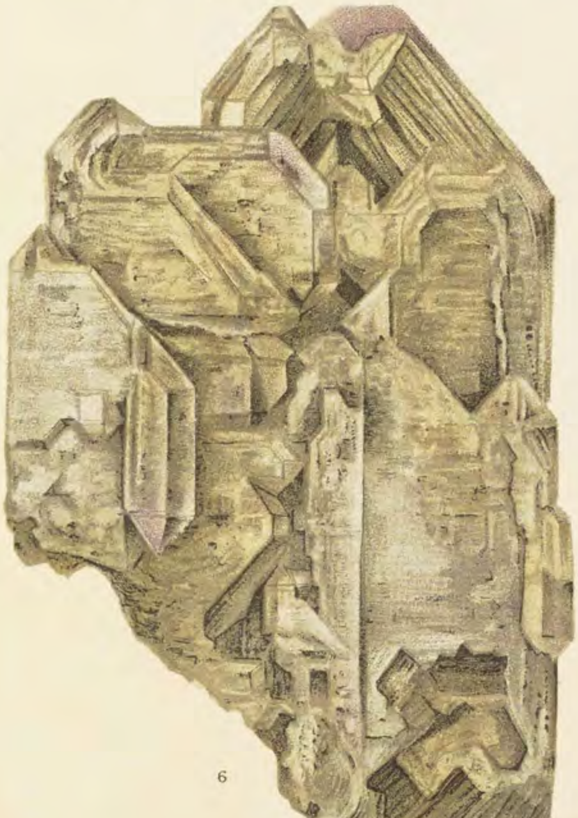

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Nahe in Germany, and more abundantly in Uruguay and Brazil (plate 56, figs. 2, 3, and 5). From the latter countries enormous amygdales with the interior lined with amethyst crystals are sometimes imported, but usually the material offered for sale consists of fragments and isolated crystals tips. In recent years beautiful crystals of amethyst bounded by faces on all sides and sceptre-formed crystals have been sent from Uruguay; these show a very irregular distribution of colour, being deep violet or colourless in parts, and they contain numerous enclosures of haematite, goethite, or rutile; and they are further of special interest in showing optically the simple structure of rock-crystal.

At some other localities amethyst occurs in veins traversing granite, then forming columnar aggregates or clusters of crystals bounded by prism- as well as pyramid-faces: for example, at Mursinsk in the Urals (plate 56, fig. 3), and Schemnitz in Hungary. Large crystals with hopper-shaped depressions on the faces (plate 56, fig. 6) and long prismatic crystals (fig. 7) are found in the Zillerthal, Tyrol. In North America, amethyst, sometimes suitable for cutting, is found at several localities, for example, in Iredell Co., North Carolina (plate 56, fig. 1), but these occurrences are of little importance as compared with those in South America.

With the weathering of the enclosing rocks the amethyst is set free, and is found with other pebbles in the beds of streams and rivers. Such water-worn masses, though dull and grey on their exterior, are often perfectly clear and beautifully coloured when cut, and they often yield the finest material, such as found in Brazil and Ceylon.

Application. — Amethyst has been used as a precious stone from very early times. As far back as the Mycenaean epoch it was engraved as gems and worn as amulets. It was considered as a preventive of intoxication, the Greek name amethystos meaning "not drunken".

The value of the stone depends on the depth of the violet colour and on the size of the clear pieces. Small fragments cost only five shillings per pound, while larger clear pebbles fetch fifty shillings per pound; selected pieces are worth £10 per pound, and the very best material fetches as much as £50 per pound. As with the other coloured semi-precious stones, the actual value at any time depends very much on the prevailing fashion. The stones are usually cut in the trap or step form, and are worn in brooches, pins, necklets, rings, etc. Amethyst has, however, the drawback that its colour does not show to advantage by lamplight, being then an unattractive greyish-violet. On the other hand, the "oriental amethyst" (that is, violet corundum) is a fine violet by lamplight, but this is a much rarer and more valuable stone.

Common quartz. When cloudy and with little transparency, quartz is distinguished from the preceding varieties as common quartz; and of this several varieties are also recognized, according to the colour of the material or any special colour effects. The crystal-form is always very simple, showing either the apparent hexagonal pyramid alone (plate 52, figs. 1, 5, und 6), or this in combination with a shorter or longer hexagonal prism (figs. 3, 4, and 9). Sometimes the crystals are completely developed on all sides, and they were then embedded in the matrix (figs. 5 and 6), or they carry faces at only one end, being attached to the matrix at the other end. Although simple in external form, the crystals are frequently complex in their internal structure. Frequently, the crystals are built up of layers with different degrees of transparency (fig. 11), and in some instances the alternate layers consist of right-handed and of left-handed quartz. Sometimes there is only a slight cohesion between the layers, and the crystals may be easily separated into shells, as in the so-called capped quartz (figs. 12 *a* and *b*) where one part fits exactly on another.

The colouring of common quartz is very varied, more especially in the compact and fibrous varieties. In plate 52 we see crystals ranging from almost colourless to nearly black, from pale yellow to a deep brownish-yellow, while others are pale rose-red, brownish-red, or red. In cases of this kind the colouring matter is due, as already mentioned (p. 265), to the presence of foreign material enclosed in the crystals: the black to organic matter, the red to ferric oxide, and the yellow and brown to hydrated ferric oxide. The green colour of massive quartz is due in some cases to nickel compounds.

Whilst the lustre of rock-crystal is characteristically vitreous, that of common quartz is sometimes greasy, and in the fibrous varities it may be silky.

The hardness of quartz exceeds that of most other common minerals; and for this reason wind-borne grains of sand exert a considerable wearing action on rocks, as is especially to be observed in deserts. It is well known that sharp-edged crystals and fragments of quartz are capable of scratching glass. When two pieces of quartz are vigorously rubbed together sparks are produced and a peculiar smell is often noticeable. This phenomenon is a result of the high degree of hardness; small fragments which become detached being raised to a glowing heat by the friction, and the smell is probably due to the burning of organic matter enclosed in the quartz.

Common quartz is the most abundant of all minerals, being met with at almost all places on the earth's surface. Attached crystals are of frequent occurrence in veins and in cavities of rocks, occurring either alone or in company with other minerals, for example, with felspar, plate 1, fig. 1, or with haematite, plate 52, fig. 1. Such veins and cavities lined with quartz crystals are met with in rocks of almost all kinds, with the exception of those of recent formation; for example, in granite (plate 1, fig. 1), gneiss and mica-schist, greywacke (plate 52, fig. 11) and sandstone, limestone and marl, and iron-stone (plate 52, fig. 1); and even the cavities in fossils of sedimentary rocks are sometimes lined with quartz crystals. Embedded crystals of any appreciable size are, on the other hand, of less frequent occurrence; these are found more especially in limestone (plate 1, fig. 8), in gypsum, and in quartz-porphyry (plate 52, fig. 5). The crystals embedded in quartz-porphyry are frequently rounded and corroded, as shown in the sections in plate 59, figs. 3 and 4.

As irregular grains, quartz is especially abundant as an essential constituent of rocks of many kinds of rocks; together with felspar and mica it forms granite and gneiss, with mica it is present in mica-schist, and as grains held together with a cementing material in sandstone and quartzite, while as loose grains it forms the sand of the sea-shore and sand-dunes. Quartz is in fact the most important of the rock-forming minerals. In many rocks the presence of quartz may be recognized by the unaided eye, whilst others must be examined as thin sections under the microscope. As seen under the microscope, quartz is always fresh and unaltered, colourless and transparent, and it frequently contains enclosures of liquid or of the ground-mass (plate 59, fig. 3). In thin sections of porphyritic rocks the quartz usually shows six-sided outlines often rounded and invaded by the ground-mass (plate 59, fig. 4). In granitic rocks the quartz grains are quite irregular in outline, the material usually filling the spaces between the other minerals. Owing to the low index of refraction, the surface of quartz in thin sections appears smooth; and the double refraction being also low, polarization colours of the first order are shown between crossed nicols (at least in very thin sections — in thicker slices colours of higher orders will be visible).

The localities for common quartz are without number; a few which yield the better crystals are mentioned in the explanation of plate 52.

Applications. — The common and abundant quartz-sand has many useful technical applications. It is largely used in the manufacture of glass, being fused with soda or glauber-salt, potash or lime. Easily fusible glasses contain soda and lime, and ordinary bottle-glass contains some iron; variously coloured glasses are made with the addition of metallic oxides (cobalt for blue, copper for red, etc.); and strongly refracting glass contains lead. A systematic and scientific study of different kinds of glass has in recent years been made by the firm of Schott in Jena; and the composition of the product has been varied to suit different conditions, for example, for use in thermometers, prisms, lenses for telescopes, microscopes, etc. Quartz is also used in the preparation of soluble glass (water-glass), hydrofluosilicic acid, etc. On account of its hardness, quartz is used as a sand-blast for producing dulled patterns on glass and stone. In the marble industry quartz-sand is used in sawing the blocks into thin slabs. With slaked lime it gives the extensively-used morter.

According to differences in colour and structure, the following varieties of common quartz are distinguished: —

Rose-quartz is a massive quartz of a delicate rose-red shade of colour, which is found at Zwiesel in Bavaria and a few other localities. The colour fades on prolonged exposure to light, and it is probably due to some organic compound. Crude imitations are sometimes made by immersing heated rock-crystal in water and allowing colouring matter to penetrate into the fissures so produced. Rose-quartz is sometimes cut into small spheres and other ornamental objects.

Eisenkiesel or *ferruginous quartz* is an opaque quartz brightly coloured red by ferric oxide or yellow by hydrated ferric oxide. Red crystals (plate 52, figs. 8 and 9) are found embedded in gypsum and aragonite at Santiago de Compostela in the north of Spain and are known as "Compostela hyacinth". Compact, red ferruginous quartz is found in association with diabase in the neighbourhood of Dillenburg in Nassau; and red material intermixed with white quartz from the Hessian village of Löhlbach is known as "Löhlbach agate". The red and white stones engraved as gems in Mycenaean times, and often referred to as jasper, are more probably eisenkiesel with intermixed white quartz. Yellow, and also red, eisenkiesel occurs as a secondary product in the middle Devonian limestone in the neighbourhood of Iserlohn in Westphalia (plate 52, fig. 10).

Avanturine is a variety of quartz showing a glittering, spangled effect, caused by the enclosure of numerous minute scales of mica or haematite. The same effect is displayed to a greater extent by the artificial avanturine-glass made on the island of Murano near Venice; in this the light is reflected from the surfaces of microscopic crystals of metallic copper, which by a secret process have been made to separate out in the glass.

Fetid quartz, or stink-quartz, is a name applied to quartz rich in organic material, which when struck or rubbed emits a smell of burning. Crystals of this variety are found in the Muschelkalk at Pforzheim in Baden (plate 52, fig. 7).

Radiated quartz, or star-quartz, a white quartz with a radially columnar structure, is found at Hohenelbe in Bohemia, Adorf in Waldeck, Warstein in Westphalia, and other localities.

Cat's-eye (plate 52, figs. 15 and 16) is a translucent quartz enclosing numerous, very fine fibres of asbestos or actinolite which are arranged parallel to one another. This finely fibrous structure gives rise to a peculiar reflection from the surface of the stone; and when the stone is cut and polished with a convex surface, the base of which is parallel to the fibres, the reflection takes the form of a band of light which moves across the surface as the stone is turned about. The ground-colour may be greenish-grey, bluish, yellow, or brown; the most valuable stones being those of a yellow colour with a sharply defined band of bluish-white. This chatoyant effect shown by quartz cat's-eye is due to the same cause as in the very similar but more valuable stone known as cymophane or oriental cat's-eye. The latter is a variety of chrysoberyl (p. 235) and may be readily distinguished from quartz by its greater density and hardness. The best specimens of quartz cat's-eye come from Ceylon, but cloudy pieces are also found at Hof in Bavaria and at Treseburg in the Harz.

Tiger-eye (plate 52, fig. 14), is a finely fibrous quartz coloured bright yellow by the intermixture of a large amount of hydrated iron oxide (limonite). The fibres though parallel in their arrangement are frequently wavy or sharply bent. On a polished surface the stone shows a highly lustrous, golden yellow reflection, which changes in intensity as the stone is moved about in the hand. First introduced some thirty years ago, it has been so extensively cut as pin-stones, umbrella-handles, small boxes, and many other small objects, that the market is now almost flooded with the material.

Tiger-eye is not a mineral of primary formation, but owes its origin to the alteration of the blue asbestiform mineral crocidolite (plate 66, fig. 8), a silicate of sodium and iron, which is also known as blue asbestos. With the weathering of this mineral the sodium is carried away in solution, the iron is oxidized and hydrated to limonite, and this together with the silica preserves the fibrous form of the original mineral. Tiger-eye is thus really a pseudomorph of quartz and limonite after crocidolite. An intermediate stage in the alteration is represented in the so-called *hawk's-eye* (plate 52, fig. 13), in which the stone has been hardened by the separation of the silica, but without the oxidation and hydration of the ferrous oxide. The yellow and blue colours are sometimes associated together in the same stone, giving an opportunity of carving representations of fishes, pheasants, etc. When ignited, tiger-eye becomes red, and such burnt stones are occasionally cut. Hydrochloric acid extracts the colouring iron compound, and the stones so decolorized will absorb other colouring matters from solutions. Material coloured in this way with red, blue, or green aniline dyes has unfortunately been extensively offered for sale, but the bad taste of the purchaser is soon brought home to him by the fading on exposure to light of these most inappropriate colours.

The mineral occurs in narrow veins which traverse a ferruginous quartz-rock in the Asbestos Mountains near the Orange River in South Africa. It is got out as slabs, and the fibres are disposed approximately perpendicular to the surfaces which formed the walls of the vein.

Prase is a columnar quartz coloured green by enclosed fibres of actinolite: it is found at Breitenbrunn in Saxony. Although much employed by the ancient Romans for engraved gems, it now scarcely ever used.

Hornstone is a compact, grey or yellowish quartz with a splintery fracture, the splinters being translucent like horn. It is always of secondary formation, occurring as fissured nodules in weathered rocks, or as a pseudomorph after various minerals.

Chrysoprase (plate 52, figs. 18 and 19) is a hornstone coloured green by a nickel compound. The splintery fracture is distinctly shown in fig. 18 by the paler coloured reflection from cracks near the surface. The colour is not very stable, being destroyed at quite a low temperature. It is therefore probable that the colour is due to a hydrated nickel silicate, which loses water and consequently its colour when heated. Like hornstone, chrysoprase is a secondary mineral; it is found, together with chalcedony, in crevices in serpentine at Kosemütz and Baumgarten near Frankenstein in Silesia. The stone is cut and polished with a convex surface and mounted on pins, or plates are used in mosaics. Recently, much chalcedony artificially coloured by chromium has been placed on the market, and it is difficult to distinguish this material from true chrysoprase.

Jasper is a name which has been in use from very early times, and it was probably formerly also applied to grey chalcedony and nephrite. It is now applied to red, opaque, dull stones which strictly speaking are rocks rather than simple minerals, since they consist of a mixture of different minerals. The intermixture is, however, so intimate that the several constituents cannot be recognized even under the microscope; but chemical analysis shows that the material is not pure quartz. The amount of quartz present varies widely and may be as low as 80 per cent., the remainder of the material consisting of ferric oxide, clay, compounds of ferrous oxide, and organic matter. The typical *red jasper* is the *ball-jasper* from the pisolitic iron-ore district of Auggen in southern Baden; with it, and often in the same specimen, is associated a *yellow jasper*, the red material forming the interior of the balls and the yellow the exterior. *Green jasper* is found at Orsk on the Ural River above Orenburg, and is cut in Ekaterinberg. *Brown jasper* is found as nodules, rounded and polished by blown sand, in the desert near Cairo, and is known as Egyptian jasper. *Riband-jasper* is a quartz-schist with bands of green, brown, and red from the Urals and the Harz Mountains. The bluish-grey *porcelain-jasper* is a clay baked by the burning of coal, and *basalt-jasper* is a clay baked by molten basalt. The former of the varieties of jasper, with their compactness and uniformity of structure, are especially suited for engraving, and they have been used for gems since a early period, the uniformly red stones being especially admired by the Romans. At the present day they are mostly used in Florentine mosaics, or are worked as boxes, bowls, plates, and other objects. The ancient Babylonian cylinder-seal shown in plate 40*a*, fig. 1, is cut in a red and white striped jasper (or perhaps eisenkiesel, compare p. 273).

Tridymite.

In striking contrast to the large and clear crystals of quartz, crystals of tridymite are small and quite inconspicuous. The two substances, though both composed of silica (SiO_2), differ in crystalline form and other characters. Crystals of tridymite have the form of thin, six-sided plates (plate 54, fig. 14), and may be either simple or interpenetration-twins; in size they rarely exceed a few millimetres across, crystals as large as those represented in the figure being quite rare. They are dull and cloudy with a greyish or yellowish colour (the green colour of the crystals shown in the figure is due to a thin coating of chlorite). The specific gravity is considerably lower than that of quartz, being only 2·3. Tridymite is a much less stable form of silica than quartz, and it frequently occurs changed into quartz. The crystals represented in the figure, though possessing the external form of tridymite, have the specific gravity of quartz, and under the microscope are seen to consist of an aggregate of irregularly orientated grains of quartz: they are in fact paramorphs of quartz after tridymite.

Tridymite occurs in the cavities of volcanic rocks, especially trachytes. Localities are the Euganean Hills near Padua (plate 54, fig. 14), the Siebengebirge near Bonn, Mont Dore in the Auvergne, and San Cristobal near Pachuca in Mexico. It has also been recognized in meteorites and described under the special name asmanite.

Chalcedony and its Varieties.

Chalcedony is one of the few minerals which, though crystalline, never presents any external crystal forms. It occurs only in stalactitic (plate 58, fig. 10), botryoidal, or reniform (plate 58, fig. 9) shapes; in the interior it shows a finely fibrous structure and splintery fracture, and small splinters of the material are translucent. The fibres are so very fine and so closely packed together that they can only be recognized when thin sections of the mineral are examined under the microscope in polarized light; the fibres are then seen to posses a radial arrangement about numerous centres. In chemical composition chalcedony is identical with quartz, but the physical characters are different, the specific gravity, for example, being rather lower (2·60), and the optical characters are not quite the same. The colour is mostly grey, bluish-grey, or yellowish, and deeply coloured varieties are distinguished by special names. Some masses of chalcedony are porous and capable of absorbing liquids, and for this reason they adhere to the tongue; other pieces are more compact and not porous. Usually the porous and non-porous materials occur repeatedly interbanded in the same specimen, the thin layers being then alternately lighter and darker in colour (plate 57, fig. 1). Unstriped chalcedony of uniform character and sufficiently porous to absorb colouring matter is known at Idar and Oberstein as "Massikstein", whilst material consisting of porous and non-porous layers is called "striped Serra-stone". These two varieties form a passage from unstriped to striped chalcedony, the well-known agate being a typical representative of the latter.

The *artificial colouring* of chalcedony, which is possible by reason of the porosity of the material, has been practised from early times. The art was for a time lost, and again came into use in Germany about the year 1820. A *black* colour is obtained by soaking the well-dried stones for some weeks in a warm, dilute solution of honey, and then, when they are completely saturated, placing than in sulphuric acid: the honey is thereby decomposed and finely divided carbon separates out in the pores of the stone. By such a process a uniform coloration is not obtained, the porous layers only being blackened, while the non-porous layers remain white, as shown in the specimens of onyx in plate 57, figs. 5 and 6. A more uniform colouring may be obtained by treating the stone with caustic potash before soaking it in honey, but even then the colour only penetrates the outer skin of the stone; material treated in this way is cut into thin slices for making black buttons. A *red* colour is produced by saturating the stone with a solution of an iron salt and then igniting. Yellowish or pale red chalcedony, which already contains some iron, also acquires a red colour when strongly heated. A *blue* colour is obtained by first soaking the stone in a solution of an iron salt and then in a solution of potassium ferrocyanide, the iron then being precipitated as Prussian blue in the pores; and according to the degree of porosity of the different layers these will be coloured a paler or a darker blue. Such blue coloured chalcedony is often sold at watering-places as lapis-lazuli, from which, however, it is readily distinguished by its translucency, greater hardness, and absence of embedded specks of iron-pyrites. Translucent chalcedony is coloured *yellow* by immersing it for a short time in hydrochloric acid. In recent years an artificially *green* coloured chalcedony has been placed on the market in large quantities, the colour here being due to chromic oxide. The stones are saturated with ammonium chromate and ignited, but the exact composition of the chromium solution, whether it is acid or alkaline, is kept a secret. Finally, chalcedony has recently been coloured a rich *brown*, the trans-

PLATE 55.

Quartz IV.

Fig.

1. **"Dendrite"**, chalcedony with delicate tree-like (dendritic) markings caused by the deposition of manganese and iron oxides from solution. Actual size.
   India.
2. **Onyx,** with infiltration canal. Two-thirds actual size.
   Uruguay.
3. **Rock-crystal,** with large and distinct etched figures. The figures being directed upwards to the left indicate that the crystal is left-handed. About one-half actual size.
   Goyaz, Brazil.
4. **Rock-crystal,** with enclosed rutile needles; "Hair-stone". Actual size.
   Goyaz, Brazil.

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lucent stones having much the appearance of some garnets. This colour is obtained by soaking the stones in a solution of brown sugar-candy and then burning. Brown stones of this kind have been prepared and cut in large quantities during recent years, a translucent "Massikstein" of good quality being best suited to give a uniform shade of colouring.

Owing to its compactness and uniformity in texture, chalcedony has always been the principal material used in the glyptic art. According to the differences in colour and the surface patterns of the material, several varietes are distinguished. In the following description of these varieties we shall divide them into two main groups — the unstriped and the striped chalcedonies.

Unstriped Chalcedony includes the varieties:— common chalcedony, plasma, heliotrope, carnelian, and sard.

Common Chalcedony is translucent and of a grey, bluish-grey, or yellowish colour; and is the material mostly employed in the Ionic and Grecian glyptics of the fourth and fifth centuries and of all later times. The carving represented in plate 40*a*, fig. 6, is in such material. Although a mineral of very common occurrence, it is at only a few localities that large pieces of suitable quality for cutting are found. The specimens shown in plate 58, figs. 9 and 10, are from Iceland, where the mineral is found in the vesicular cavities of a volcanic rock. The delicately banded specimen in plate 57, fig. 1, is from Uruguay, which country, together with the neighbouring Brazilian state of Rio Grande do Sul, yields at the present time the largest quantity of chalcedony. In former times India was probably the chief country of supply. The chalcedony amygdales were originally formed in the cavities of an amygdaloidal melaphyre, but this rock being weathered they are now found loose in the ground; they have much the shape of a roll of bread, and may sometimes measure as much as a metre in diameter and weigh several hundredweights. Hollow, kidney-shaped nodules of chalcedony containing water in their interior are found in Uruguay, and are known as *enhydros*. Delicate, stalactitic forms of common chalcedony were formerly found in some of the Cornish mines. A smalt-blue chalcedony pseudomorphous after cubes of fluor-spar is found at Tresztya in Transylvania.

Dentrite (tree-stone) or *Mocha-stone* is chalcedony showing in one plane delicate dendritic or tree-like markings (plate 55, fig. 1; text-fig. 207). Such forms are often popularly thought to be plant remains, but they have really been formed by the percolation of a solution containing manganese along one of the layers in the stone and the deposition of manganese oxide. Similar forms may be readily produced by pressing a drop of ink between two sheets of paper or glass. The stones are so cut and polished that the marking remains covered by a thin layer of chalcedony, through which it can be clearly seen. Large and finely marked stones fetch a high price; the one shown in plate 55 was bought for £3. As a rule, however, the stones are much smaller and the patterns less delicate and plant-like, and they are then of little value; they are usually mounted in brooches and chains. The best specimens come from India, and formerly possibly from Mocha in Arabia, hence the name mocha-stone.

Fig. 207.
Dendrite or Mocha-stone.

Other markings in chalcedony may show a resemblance to gnats, as in the so-called gnat-stone from Montana.

Spotted chalcedony, or St. Stephen's stone, shows red spots of iron oxide. *Moss-agate* is a chalcedony enclosing green, moss-like aggregates of chlorite or actinolite. As these coloured enclosures increase in amount we find a gradual passage to the coloured varieties of chalcedony.

Plasma is a chalcedony uniformly coloured leek-green by the enclosure of green-earth or chlorite; it somewhat resembles green jasper, but is distinguished from this by being translucent on thin edges. It has been supposed to be a cure for stomatic disorders. From the earliest times in Greece it has been engraved as scarabs, and by the Romans it was especially admired. Until comparatively recently this stone was known only as the material of antique gems, but we now know that similar material occurs in the volcanic rocks of the Deccan in India, and it is probable that the Romans obtained it from there. Other localities, such as Oppenau in Baden, are of little importance.

Heliotrope (plate 52, fig. 17) may be described as a plasma marked with spots of red, and since these resemble drops of blood the stone is often called *blood-stone* or blood-jasper. This also occurs in Bombay, but recently it has been found also in Brazil and Australia, and it was formerly quarried in the island of Rum in Scotland. Heliotrope was much used for engraving as gems in later Roman times and especially in the Renaissance; at the present day it is cut for pin-stones and ring-stones.

Carnelian is a red chalcedony, the most valuable material being clear and translucent and of a rich red colour. This colour is due to minute particles of iron oxide enclosed in the stone. Frequently, instead of red, the colour is yellowish-red, owing to the hydrated condition of the ferric oxide; but when such stones are ignited, and the water so driven off, they acquire the desired shade of red. From red jasper, carnelian is distinguished by its translucency, jasper being opaque. Like other varieties of chalcedony, it occurs in the vesicular cavities of volcanic rocks, and when the enclosing rock is weathered the mineral is found loose in the soil. Material suitable for cutting is quite rare. Since early times the best material has come from India, for instance, the Rajpipla Hills at Ratanpur on the lower Narbada river, and several places in the west. A South American locality from which carnelian is exported is the Campo de Maia, fifty miles south of the Rio Pardo.

In ancient times carnelian was a favourite material for engraving as gems, and material of very fine quality is found amongst the Etruscan scarabs and the gems of the Augustan period. At the present day it is also engraved or cut simply as ring-stones and pin-stones.

Sard is an early name for carnelian (antique sard) derived from Sardes, a town through which the material from India was imported into Greece. Now the name is restricted to translucent chalcedony of a pale to dark brown or almost black colour. In the fourth century before Christ it was one of the most valued of stones, but at the present day it is almost entirely replaced by the artificially coloured chalcedony known in the trade as sardonyx.

Striped Chalcedony consists of alternate layers of coloured and white material. When the bands are straight and parallel, the material is known as *onyx*, different names being used according to the colour; thus in onyx proper the bands are alternately black and white, in *carnelian-onyx* red and white, and in *sardonyx* brown and white. These names have, however, not the same meaning now as formerly. The onyx of the ancients is identical with our "oriental alabaster", that is, a fibrous and banded calcite or aragonite; sardonyx was applied to stones with alternating lighter and darker layers, our sardonyx being probably known to the ancients as aegyptilla. Nicolo is a sardonyx with opaque dark brown, almost black, layers, which was especially in vogue during the first century B. C.

PLATE 57.

Agate.

Fig.

1. **Chalcedony,** with bands of grey and white only slightly tinged with colour.
   Uruguay.
2. **Agate,** with horizontal bands; probably artificially coloured.
   Uruguay.
3. **Agate,** with infiltration canal; probably of the natural colour.
   Uruguay.
4. **Brecciated Agate,** natural coloration.
   Schlottwitz, Saxony.
5. **Onyx,** with infiltration canal; artificially coloured.
6. **Onyx,** artificially coloured.
   Uruguay.

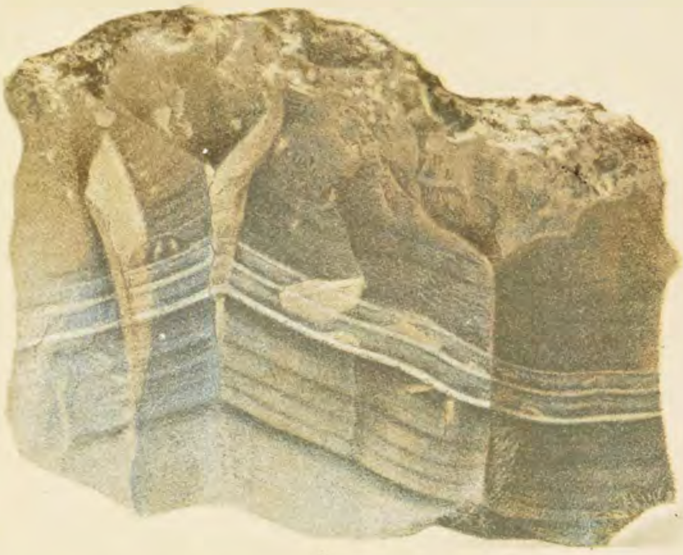

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PLATE 58a.

"Gemma Augustea" in Vienna.

Sardonyx of two layers; the figures are cut in the upper bluish-white layer, whilst the dark under layer forms the background. Size 18·7 × 22·3 cm.

The picture is arranged in two groups, the upper containing the principal figures. On the right is enthroned *Augustus* as Jupiter, partly covered by a mantle; in his upraised right hand he holds the sceptre; at his feet is the eagle, and a shield serves as his foot-stool. In his right hand he holds the lituus of the augur. Above him is his nativity star showing the capricorn. Beside him, on his right hand, sits the goddess *Roma* in chiton and mantle. with a hanging sword, and, in the right hand, a lance. She wears an Athenian helmet with three crests after the pattern of the Athena Parthenos of Phidias. Over the head of Augustus a wreath of oak is held by a woman standing behind the throne; she wears a mural crown with a veil. By the side stands a bearded man, probably representing the celestial god Caelus. Below sits a woman, partly robed and leaning against the throne; in her right hand she holds a cornucopia. Beside her are two children; one of them holding ears of corn, and probably representing Tellus. On the left is to be seen fore-shortened a four-yoked triumphant car (three horses are shown) guided by Victoria; before her is *Tiberius*, about to descend. At the side stands *Germanicus* as a youth with downy beard, clad in a coat of mail; his left hand is on the hilt of his sword, and his right rests on his hip. Both look towards Augustus. Without doubt the intention of the artist was to represent the moment when Tiberius in his triumph, in the year 12 A. D., before he turned towards the Capitol, descended from the car to throw himself at the feet of the father.

In the lower portion of the picture a trophy is being erected by two Roman soldiers in the dress of higher officers. Helping them are two youths clothed in aprons. On the ground are seated two captive Germans — a bearded man in hose with his hands bound behind him, and a mourning woman with her head supported on both hands. Further to the right two other captives, a man and a woman, are being dragged by the hair to the trophy by two men, who are not in Roman dress. These captives are probably Celtic Pannonians, and the men Thracian allies of the Romans in the Pannonian insurrection.

This magnificent example of the glyptic art is probably the work of Dioscurides, the famous sculptor to the court of Augustus. (The above description is taken with some abbreviation from Furtwängler's "Antike Gemmen", vol. II, p. 257.)

Onyx proper with bands of a deep black colour (plate 57, figs. 5 and 6) is of rare occurrence in nature, and most of the material is artificially coloured; the same is true of much carnelian-onyx, which is also artificially coloured or the colour intensified by burning. The brown layers of sardonyx are also usually coloured artificially.

Specimens of the unstriped chalcedonies, carnelian and sard, are often obtained by cutting out the coloured bands of striped chalcedony, which may be either naturally or artificially coloured. And again, the different varieties of onyx do not differ essentially from agate, so that all of them may really be classed under the general term agate.

The varieties of onyx, and especially the sardonyx, have at all times afforded the best material for engraved gems. The large "Gemma Augustea" (plate 58*a*) is cut in a sardonyx of two layers; the Ptolemaic cameo (plate 40*a*, fig. 4) shows nine layers, all of which have been employed to advantage in the engraving. At the present day cameos are still cut in onyx, especially in Italy, but the majority of modern Italian cameos are really shell-cameos, being cut from the thick and variously-coloured shells of certain molluscs. The localities of the varieties of onyx, being the same as the localities of agate, will be mentioned farther on.

Fig. 208.

Agate-amygdale from Göttenbach, Oberstein, Germany.
Viewed from the side: $^2/_3$ natural size.

Agate (plate 57), the commonest and best known of the semi-precious stones, is a striped or banded chalcedony, and its characteristic appearance bears a direct relation to its special mode of origin and occurrence. It occurs principally as a filling material in the vesicular cavities of melaphyre, a rock which has consolidated from a molten lava. When the lava flowed out on the earth's surface the diminution of pressure allowed the water it contained to expand, giving rise to steam cavities in the mass; these cavities would be at first spherical, but with the flowing of the viscous mass they are often drawn out along the direction of flow and become amygdaloidal or almond-shaped (text-fig. 208). The layers of agate in an agate-amygdale follow exactly the outlines of the cavity in which they were deposited, and the aggregate thickness of the several layers is thus the same in all parts (plate 55, fig. 2, and plate 57, fig. 3).

The thickness of the individual layers is often extremely small, 17,000 layers having been counted by Sir David Brewster in the thickness of one inch; usually, however, the apparent layers are much thicker than this. In consequence of this extremely fine, laminated structure, certain specimens, known as *rainbow-agate*, exhibit prismatic colours, the fine bands acting as a diffraction-grating when a plate of the agate is held up to the light: thicker pieces show a wavy reflection of light.

At certain spots the bands of agate do not run parallel to the external surface, but form a sort of channel, called an infiltration canal, through which solutions penetrated into the cavity. During the period of growth of an agate these infiltration canals have several times changed their position; this may be seen in plate 55, fig. 2, where the latest canal is very distinctly shown, and two earlier ones are less conspicuous. In the hollow amygdale shown in text-fig. 209 no less than eight canals may be distinguished; and in a completely filled amygdale they are very numerous, though, of course, they are only to be seen in sections. The latest formed layer in the hollow amygdale of text-figs. 208 and 209 consists of crystallized quartz, the inner surface consisting of crystals closely crowded together and with their apices projecting into the interior of the cavity. Frequently this crystallized quartz is of the amethyst variety; and resting on it may be crystals of calcite or zeolites (harmotome, phillipsite, chabazite, etc.), or needles of manganite or goethite, which represent a still later period of growth. Between the external surface of the agate and the enclosing rock there is frequently a thin layer of a green, earthy chloritic mineral known as delessite. The rocks in which agates are found are always much decomposed.

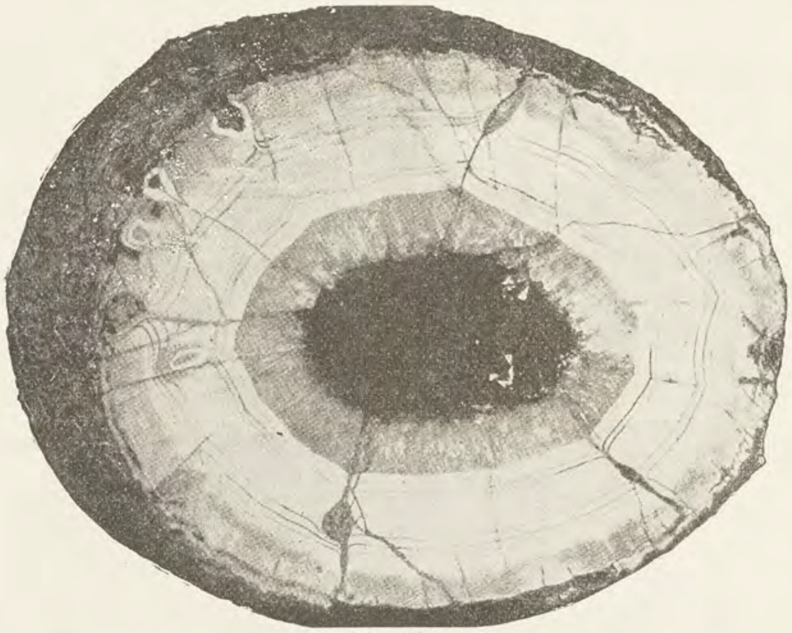

Fig. 209.

Agate-amygdale: cross-section of the specimen shown in fig. 208. Natural size.

In discussing the origin of agate-amygdales we must bear in mind the various points just mentioned. It is certain that the material was deposited from an aqueous solution, and it is probable that the solution was hot. The rock may be assumed to have been saturated with hot water, not doubt soon after its final consolidation, and this would have acted on the rock-forming minerals and taken up material in solution. That such hot solutions are present in the rocks of volcanic districts is well known, as shown by the hot intermittent springs and geysers of Iceland and the Yellowstone Park, and by the materials deposited around them. Such a solution on reaching a cavity in the rock and spreading over its walls will, partly on account of cooling and partly by evaporation, deposit some of the mineral matter it held in solution. The uniformity in thickness of each thin layer over the surface of the whole cavity is perhaps to be explained by the pressure of water vapour inside the cavity, the silica jelly being pressed and consolidated against the walls of the cavity before the next layer was deposited. The crystallization of amethyst in the interior during the later stages of formation may be due the slower rate of growth at a lower temperature. This explanation of the formation of agate is, however, not altogether satisfactory, for while the "infiltration canals" remained open there could not have been an increased pressure of water vapour inside the cavities: and we know that other some minerals (e. g.

malachite) presenting much the same structure have not been formed in districts where geysers are active. It is possible in such cases that the solution simply pentrated the walls of the cavity by capillary attraction and deposited matter from solution as a film on the surface.

Moreover, the bands of agate do not always follow the walls of the cavity. Several agates, especially those from South America, are partly built up of horizontal layers, while in the upper portion the bands follow the walls of the cavity and sometimes show intervening layers of crystallized quartz (plate 57, fig. 2). Here the cavity was no doubt partly filled with the solution and the horizontal layers deposited on the floor; subsequently there was the deposition of crystallized quartz; and finally, the ordinary type of agate formation. In other cases, stalactitic growths of chalcedony (plate 58, fig. 10) may be first formed in the cavity, and the remaining space afterwards perhaps filled up with horizontal layers of agate. In these instances the solutions were clearly influenced by gravity; the pressure of water vapour and the adhesion of a film of liquid to the walls of cavity being without effect.

According to the form of the several layers and the patterns to which they give rise, many trivial varieties are distinguished; for instance, fortification-agate, eye-agate, ring-agate, riband-agate, etc. A special variety is that known as brecciated-agate (plate 57, fig. 4), which consists of fragments of riband-agate broken up by earth movements and cemented together again by a later deposit of quartz.

The natural colouring of agates is usually only dull, pale red and yellowish layers alternating with white and grey translucent layers; and although pronounced red and brown colours do sometimes occur naturally, the bright colours of cut agates are mostly produced artificially (p. 276).

Agate of a quality sufficiently good for cutting is found at only a few localities, but then often in large amounts. Good stones were formely quarried from an amygdaloidal melaphyre in the neighbourhood of Idar and Oberstein on the Nahe in Germany (text-figs. 208 and 209), but now they are only occasionally found; these are characterized by their pure white and bluish-red layers. Veins of riband-agate and brecciated-agate occur in a quartz-porphyry at Rochlitz in Saxony; and very pretty agates, the so-called Scotch pebbles, are fairly abundant at Montrose in Forfarshire and in Perthshire. At the present day the largest amount of agate is obtained from Uruguay and the neighbouring Brazilian state of Rio Grande do Sul. Of some importance also are the Indian occurrences on the Deccan plateau, near Ratanpur on the lower Narbada river, and near Rajkot in the Kathiawar peninsula.

Some of the stones, especially the Indian, are cut in the countries where found, but the Brazilian are largely imported into Germany and cut at Idar and Oberstein or at Waldkirch in Baden. From Germany the cut material is exported to all parts of the world, and there is scarcely a watering-place of any renown where Oberstein agate goods are not offered for sale.

Application. — Agate, more than any other stone, has always been subject to the dictates of fashion, and the remark of Pliny "in magna fuit auctoritate, nunc in nulla" applies at the present day. It was in favour during the Mycenaean epoch and again at the time of Alexander the Great, but later it was unrepresented amongst the antique gems. The present flourishing condition of the agate industry began in the twenties of the nineteenth century, with the re-discovery of the methods of artificial colouring and the discovery in 1827 of the rich deposits in Uruguay, and it reached a maximum in the middle of the century. Later, tiger-eye came more into favour, and at the present time agate is much less worn as a personal ornament (in pins, rings, etc.). On the other hand, it is now largely used for a variety of other objects, either for practical use or for ornaments. It forms, for example, an excellent material for the much used agate mortars, for the supports of the knife-edges of chemical balances and the pivots of magnetic needles. Objects of a more ornamental character include paper-weights, knife-handles, pen-holders, stick- and umbrella-handles, boxes, bowls, seals, etc. Nevertheless, the agate industry at Oberstein and Idar is still very prosperous, and visitors should not fail to see one of the cutting works (fig. 162, p. 199) and the industrial museum at Idar. The whole population is engaged in this special industry to an extent not to be seen at any other place. In addition to agate, all the other varieties of chalcedony are cut, as well as quartz, opal, and all other precious stones, with the exception of diamond.

Opal.

In external appearance, opal differs from chalcedony in the smoothness of its conchoidal fracture (plate 58, fig. 1). It is an amorphous mineral: under the microscope, it shows no trace of crystalline structure, and it is optically isotropic. The stalactitic and botryoidal forms, by which the mineral is sometimes bounded, are the result of gravitational forces and not of any force inherent in the substance itself. Usually, however, freely developed surfaces are wanting, and the material completely fills the cavities and fissures in which it was deposited.

In chemical composition, opal differs from chalcedony and quartz in containing water in addition to silica; but the water is very variable in amount, ranging from one to as much as twenty per cent. The mineral may, indeed, be regarded as a silica-jelly, which was at first soft and contained much water, but became hard on drying. The finely powdered mineral is dissolved by a hot solution of caustic potash. The specific gravity varies from 2·0 to 2·3, and the hardness is $5^1/_2$—$6^1/_2$. The index of refraction is very low, $\mu = 1{\cdot}45$. The transparency also ranges between wide limits, and the mineral may be either perfectly water-clear or quite opaque.

To judge from the characters above enumerated, opal would seen to be mineral scarcely suited for use as a precious stone, were it not for the fact that some specimens are beautifully coloured, whilst others display a magnificent play of colours such as shown by no other mineral. According to the difference in colour or play of colour, different varieties of the mineral are distinguished.

Precious opal, or noble opal, is distinguished from all the other varieties by its fine play of colours. As seen by transmitted light its colour is not a conspicuous feature, this being milk-white in Hungarian and some Australian stones, brownish-yellow in the majority of Australian, and dark blue in the Japanese. By reflected light, however, it shows brilliant flashes of green, blue, and red colours; these may be more or less uniform over a large surface (plate 58, fig. 7), or vary from point to point (fig. 5), or again, run one into another (fig. 6); while with the movement of the stone they vary from brilliant to delicate shades of colour. This peculiar play of colours, characteristic of the opal, is probably due to the presence of cracks of microscopical fineness penetrating the whole substance, at the surfaces of which the colours are produced by the interference of the waves of light passing through the stone. The phenomenon is analogous to that shown by soap-bubbles and other thin films.

Precious opal usually occurs, together with other varieties of opal, as a mineral of secondary origin in rocks of very different kinds: it is found in the volcanic rock trachyte

PLATE 58.

Opal and Chalcedony.

Fig.

1. **Semi-opal,** or common opal.
   Steinheim, Hanau, Germany.
2. **Fire-opal,** on volcanic rock.
   Cerro de Villa Secca, Zimapan, Mexico.
3. **Wood-opal,** wood fossilized by opal.
   Clover Creek, Lincoln Co., Idaho, U. S. A.
4. **Hyalite,** botryoidal.
   Waltsch, Bohemia.
5. **Precious Opal,** in matrix.
   Czerwenitza (= Vörösvágás), Eperjes, Hungary.

6 and 7. **Precious Opal,** in siliceous iron-stone.
Barcoo River, Queensland.

8. **Precious Opal.**
   Mexico.
9. **Chalcedony,** reniform.
   Iceland.
10. **Chalcedony,** stalactitic.
   Iceland.

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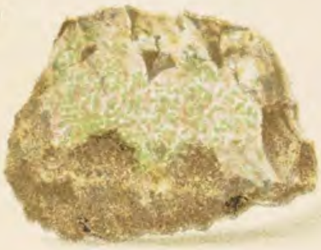

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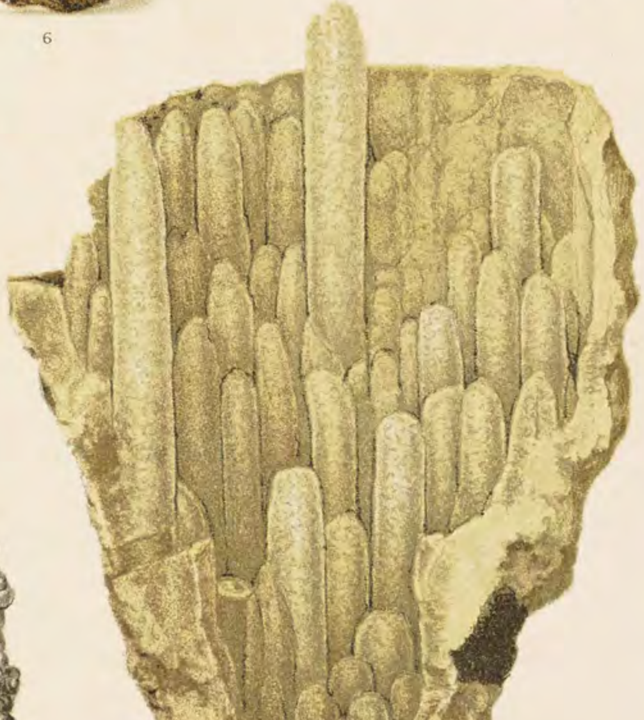

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and in volcanic tuffs, in sandstone and ironstone; also in fossilized wood, and even as the petrifying material of fossil shells. The earliest known locality, whence probably the mineral was obtained by the Romans, is situated near the village of Czerwenitza (Hungarian, Vörösvágás), between Kaschau and Eperjes in northern Hungary. Here the mineral occurs as nests and strings in a much weathered trachyte; and the rock itself is often closely set with specks of enclosed opal, being then known as *mother-of-opal.* These Hungarian opals, which are won by a regular system of mining, are still considered the finest and best, though they are almost equalled by some Australian specimens.

In Australia, precious opal of good quality and in large amounts is obtained from the opal mines at White Cliffs in Yungnulgra Co., New South Wales. It is here found filling veins in a hard quartzose rock, and as a cementing material in sandstone; it sometimes forms the material of fossil wood, shells, and bones, and as pseudomorphs after an unknown mineral. This opal has sometimes the same pale body-colour as the Hungarian opal, and it is not inferior to this in its play of colours. Material of rather a different kind, characterized by blue and green colours extending over large surfaces, is found at several places in Queensland, for example, on the Barcoo river and Bulla creek, where it occurs as nests and strings in a brown, siliceous ironstone (fig. 6 and 7).

In Mexico, precious opal is obtained at Esperanza, to the north-west of San Juan del Rio in the state of Queretaro, but it appears to be of little importance in the European market; and the same applies to the precious opal of Honduras. A small piece of Mexican opal, with brilliant red and green reflections, is represented in fig. 8. In recent years a fine opal of a peculiar kind has come from Japan and has been cut at Oberstein: this is dark brown and opaque, but with the play of colours characteristic of precious opal.

Precious opal has long been a favourite gem-stone. Formerly, it was one of the rarer of precious stones, but since the discovery of the Australian occurrences it has been imported in large quantities, and the market is flooded with material of medium quality, though fine specimens still command a high price. The stone is almost invariably cut and polished with a rounded, convex surface, and only rarely with a flat surface. As a ring- or pin-stone it shows to better advantage when set with a border of small brilliants.

Fire-opal (plate 58, fig. 2) is a transparent to translucent opal with a brownish-red, dark or pale yellow colour; the colour being somewhat similar to that of yellow topaz, but often with a slight milky appearance. It is, however, readily distinguished from topaz, as well as from quartz, by the fact that it feels much warmer, and by its much lower specific gravity. This variety is found in a trachytic rock (fig. 2) at Villa Secca, near Zimapan in Mexico. It is usually cut with facets, and the large table facet is often slightly curved. It is a fiery and effective gem, thought not extensively used, and it fetches a good price.

Hyalite, or glass-opal, is a colourless, glassy variety. It is often bounded by rounded surfaces, being found as single drops, like tear-drops, on other minerals; or it forms a botryoidal encrustation on a rock surface (plate 58, fig. 4), sometimes so thin as to appear like a glaze on the surface. It is met with on basalt at Steinheim near Hanau, on the Limburg, Kaiserstuhl, Baden, and at Waltsch in Bohemia. Very similar to this, but with less transparency and a pearly lustre, is the pearl-sinter, or fiorite, of Santa Fiora in Tuscany.

Semi-opal, or common opal (plate 58, fig. 1), is dull, white or yellowish, and translucent only on the edges: the fracture is conchoidal. It is found in crevices in basalt at Steinheim near Hanau, and many other places. Several varieties are distinguished by special names, according to the colour or other prominent characters, and some of them are used as ornamental stones. *Prase-opal,* which owes its green colour to the presence of nickel, is found, together with the similarly coloured chrysoprase, at Kosemütz, near

Frankenstein in Prussian Silesia. *Pitch-opal*, of a dark brown to black colour, comes from Homberg in Hesse, and Telkebanya in Hungary. *Wax-opal*, distinguished by its wax-yellow colour and waxy lustre, also comes from Telkebanya. *Hydrophane* is a cloudy, brownish opal which becomes clear when immersed in water; this change being due to the absorption of water into the pores of the mineral. Certain specimens even acquire a play of colours when immersed in water: these were formerly known as *"oculus mundi"*.

Wood-opal is an opalized fossil wood, in which the structure of the wood is often plainly visible (plate 58, fig. 3). Other materials consisting of opal are: the siliceous sinter or geyserite, deposited by the hot springs of Iceland and the Yellowstone Park in the United States; and diatomaceous earth, kieselguhr, or tripolite, which consists of the siliceous shells of vast numbers of microscopic algae, or diatoms. These diatoms multiply very rapidly and their remains form thick deposits of white diatomaceous earth, which is largely used commercially. Being a bad conductor of heat, it is employed as a coating for hot-water and steam pipes; and being very absorbent it is used to carry the nitro-glycerine of dynamite.

In addition to the minerals described in this section on precious stones, the following also find an application in this direction: —

Malachite, dioptase, haematite, iron-pyrites, sphene, rhodonite, the felspars (moonstone, sun-stone, amazon-stone, and labradorite), hypersthene, diopside, spodumene, nephrite and jadeite, olivine, cordierite, prehnite, thomsonite, fluor-spar, apatite, and amber.

The first six of the above-named minerals have been already mentioned with the ores, and the remainder will be dealt with in the sections which follow. They are of more importance in other connexions than as precious stones.

* * *

Rock-forming Silicates and allied Minerals.

General.

The minerals which we have so far considered, with the exception of quartz, play no part in forming the large masses of rock of which the earth's crust is composed; they are rather, it may be said, the ornamental portions of the structure. Compared with these, the widely distributed and abundant minerals which constitute the bulk of the earth's crust are unattractive in appearance and lacking in brilliancy of colour and lustre. The precious stones may be looked upon as the princes of the mineral kingdom, the ores as the nobles, and the rock-forming minerals as the people: each of these groups are of importance, and must be considered in their turn.

A rock, as already stated (p. 7), consists of an association of different minerals. The number of minerals so associated together to form any particular kind of rock is always small; and, indeed, there is only a limited number of minerals which are of importance as constituents of the rocks which form the mass of the earth's crust.

Rocks are not only of very different kinds, but their modes of origin are also very different. Some are of igneous origin, having resulted by the consolidation of molten material. The streams of molten lava poured out by the volcanoes of the present day give rise to *volcanic rocks*, and similar rocks were formed in past geological periods. Rocks formed in this way possess many distinguishing features: they are slaggy or cindery, and are frequently largely composed of glassy material. Their minerals are often present as crystals developed on all sides, which are embedded in a more or less compact ground-mass, like the crystal of leucite in plate 62, fig. 1, and of nepheline, fig. 6. Rocks of this kind, with larger crystals set in a finer ground-mass, are said to be porphyritic in structure, and this type of structure is especially characteristic of volcanic rocks. According to the different minerals of which they are composed, the following are the more important types of volcanic rocks to be distinguished: —

Rhyolite, with quartz, potash-felspar, and biotite.
Trachyte, with potash-felspar and hornblende.
Phonolite, with potash-felspar, nepheline, and hornblende.
Andesite, with soda-lime-felspar and hornblende or augite.
Basalt, with soda-lime-felspar, augite, and sometimes olivine.
Tephrite and *basanite*, with soda-lime-felspar, leucite, augite, and sometimes olivine.
Nepheline-basalt and *leucite-basalt*, with nepheline or leucite, augite, and olivine.

Other rocks, also of igneous origin, have been formed from molten material that has not been erupted at the earth's surface, but has consolidated within the crust. These belong the group known as *plutonic rocks*, which often form large mountain masses. Having consolidated slowly under great pressure, their minerals have all been formed together, with the result that the crystals have interfered with each other's development: and we then find, instead of crystals bounded by crystal-faces, an aggregate of irregular grains of the several minerals (quartz, felspar, mica, hornblende, augite, olivine). Although rocks of this class have been formed at some depth in the earth's crust, yet they are often met with at the surface, having been exposed by denudation. The plutonic rocks are typically granular in structure; and according to the essential minerals present, the following more important kinds are distinguished: —

Granite, with potash-felspar, quartz, and mica.
Syenite, with potash-felspar and hornblende.
Nepheline-syenite, with potash-felspar, hornblende, and nepheline.
Diorite, with soda-lime-felspar and hornblende.
Gabbro, with soda-lime-felspar, diallage, and sometimes olivine.

Where cavities and crevices have been formed in the cooling rock-mass, these usually become lined with crystals; for instance, as already mentioned (p. 9), we find in the cavities in granite, crystals of quartz, felspar, mica, rutile, sphene, etc.

The molten magma arising from the depths of the earth is always intimately intermixed with super-heated water; on the cooling of the magma this is set free, giving rise to hot vapours and solutions, which react on the newly-formed minerals of the rock-mass. It is possible that the minerals of the zeolite group have been formed in this way during the early history of the rock, though in some instances they may have been formed subsequently by the processes of weathering. The same hot solutions emanating from the igneous mass may also penetrate the surrounding rocks, dissolving and re-crystallizing a portion of their material, and so giving rise to new minerals of contact origin, such as andalusite, garnet, idocrase, spinel, etc.

The rocks exposed at the earth's surface, being subjected to variations in temperature, become more or less cracked and fissured; into these cracks water penetrates, and when it freezes the rocks are split asunder. Low forms of vegetable life become established on the rock fragments, and by their decay they supply carbon dioxide and humic acids, which, dissolved in water, exert a slow but powerful decomposing action on the minerals constituting the rock. In this way the solid rock gradually becomes transformed at the surface into loose material. This material may then be transported by running water to lower levels, and deposited in the valleys or on the floor of the sea, thus giving rise to new rock masses. Rocks which have originated in this manner are known as *fragmentary rocks* or as *sedimentary rocks*. They are composed of water-worn fragments of minerals or of rock derived from the pre-existing rocks of the earth's surface. Examples of rocks belonging this class are conglomerate, greywacke, sand and sandstone, clay and clay-slate, marl and loam. Finely crystallized mineral specimens are but rarely met with in such rocks; though we may occasionally find crystals of calcite in sandstone, gypsum in clay, and iron-pyrites in clay-slate. It is, however, to be noted that mineral-veins, containing a variety of crystallized minerals, are frequently found traversing the older sedimentary rocks, more especially when these are near some masses of igneous rock.

The rocks of the groups so far considered can be definitely asserted to have had one or other mode of origin; but respecting those of another large group — the *crystalline schists* — we have far less information as to how they have been formed. These have a crystalline structure like that of granite, but at the same time they have a laminated structure as in the sedimentary rocks. Such rocks may originally have been crystalline eruptive rocks, which have acquired a laminated or foliated structure by reason of enormous earth pressures; or they may originally have been bedded sedimentary rocks, which, owing to the action of heat, have acquired crystalline characters. Rocks of this group include: —

Gneiss, with felspar, quartz, and mica.
Mica-schist, with mica and quartz.
Chlorite-schist, consisting mainly of chlorite.
Talc-schist, consisting mainly of talc.

PLATE 59.

Rock-forming Minerals I.

(Micro-photographs.)

Fig.

1. **Magnetite,** skeletal forms of growth, consisting of minute octahedra arranged along the cubic axes; in basalt. Magnification 90.
   Kalsmunt, Wetzlar, Prussia.
2. **Crystallites,** in a glassy rock (pitchstone). × 60.
   Corriegills, Island of Arran, Scotland.
3. **Glass enclosures,** in quartz, with the form of the host: in quartz-porphyry. × 45.
   Baden-Baden.
4. **Quartz,** corroded crystal, penetrated by the ground-mass of the rock; in quartz-porphyry. × 30.
   Grillenburg, Saxony.
5. **Felspar,** with slaggy enclosures arranged in zones; in lava (leucite-tephrite). × 45.
   Vesuvius, Italy.
6. **Apatite,** small hexagonal prisms enclosed in augite; in nephelinite. × 45.
   Löbau, Saxony.

Brauns' "Mineral Kingdom". Stuttgart (Fritz Lehmann).

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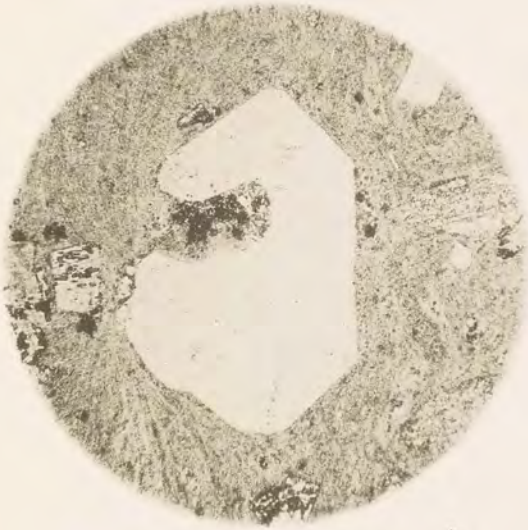

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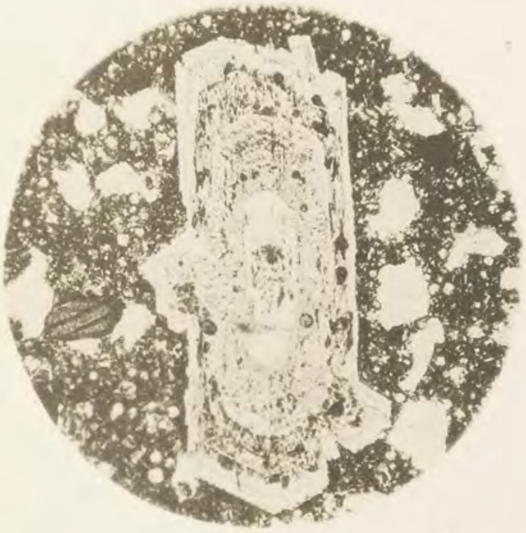

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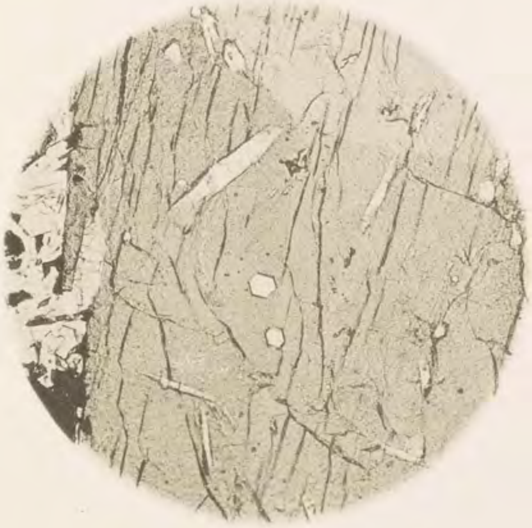

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In the preceding paragraphs a few of the more important types of rocks have been mentioned by name; it is not our purpose in this place to described the characters of the rocks themselves, but rather of the minerals of which they are composed.

In a coarsely crystalline rock, such as granite, the several minerals of which it is composed are visible to the unaided eye, and their characters are sufficently obvious to enable to minerals to be recognized and identified. In most cases, however, for example basalt, the individual minerals are so minute that, to the unaided eye, the rock appears to be compact and homogeneous. It then becomes necessary to examine the rock under the microscope, in order to determine the several minerals that are present. On first consideration a compact, opaque mass of rock does not appear to lend itself to microscopial examination; but when a section of the rock is cut of sufficient thinness that the material is transparent, the constituent minerals will be separately visible under the microscope.

Such *thin sections* of rocks may be prepared by the amateur himself, but a little patience and practice are required, and it usually more expeditious to have them made to order*) or to purchase them ready made from the mineral dealers. The mode of procedure is as follows. A flake of the rock, with an area of about 2—4 square centimetres, is struck off with a hammer, and this is ground down flat on one surface by means of emery or carborundum powder on an iron plate. The ground surface is then polished with very fine emery on a glass plate. The chip is then cemented, with the ground surface downwards, to a slip of glass; this being done with a drop of Canada-balsam, which is warmed on a hot metal plate until it becomes tough but not brittle. A second surface is then ground parallel to the first, and the grinding is continued until the section is quite thin and transparent; the thinner it is made the better will be the finished section. To finish off the slide, the old balsam is scraped away and a thin cover-glass cemented over with Canada-balsam.

The *microscope* used for the examination of rock-sections requires to be fitted with special accessories, which are not often supplied with the more usual pattern of microscopes, such as are used for zoological, botanical, and medical work. These accessories enable the examination to be made with the aid of polarized light, which is of great assistance in determining the characters of the component minerals of the rock (see p. 59). Such a petrographical or mineralogical microscope is represented in fig. 210. As in the ordinary type of microscope, this consists of a stand and tube with an object-glass below and an eye-piece above. Below the stage is a mirror for reflecting light upwards into the tube of the instrument. The coarse focusing adjustment consists of a rack and pinion, and the fine adjustment of a micrometer screw. In the instrument represented in the figure the stand is hinged, so that the tube of the microscope may be placed either in a vertical or in a horizontal position: when in the latter position, the instrument may be used in conjunction with a camera for taking photo-micrographs (such as are represented in plates 59, 61a, and 67). The polarizing accessories consist of two nicol prisms: one below the stage, called the polarizer, and the other in the tube of the microscope just above the object-glass, called the analyser. The polarizer can be moved up or down as required by a lever, and the analyser can be readily slid in or out of the tube. It is, however, more convenient to have the analyser placed above the eye-piece, and in the figure such an additional nicol is shown. The vibration-directions of the light transmitted through the nicols are marked by cross-wires placed in the eye-piece and visible in the field of view of the microscope. The stage is capable of rotation about the optic axis of the instrument, and, being graduated

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*) The best firm for work of this kind is that of Voigt and Hochgesang, of Göttingen.

in degrees of arc, it enables the various directions in the mineral section to be accurately determined.

With such an instrument we can examine in parallel polarized light, not only large mineral sections such as are employed with the polariscope (p. 59), but also the minute mineral grains in a thin section of a rock. If, for example, the mineral is to be tested for dichroism (p. 62), the upper nicol prism is removed and the section is turned with the rotating stage over the lower nicol. If a change of colour is observed in the mineral during this rotation we known that it is dichroic; for example, biotite will display alternately light yellow and dark brown colours, and andalusite will show blood-red and pale green. This is much the most convenient method of recognizing the presence of dichroism in small mineral grains. When determining whether a mineral is isotropic or birefringent, its extinction directions, etc., the two nicol prisms must be in place, and their vibration-directions must be at right angles to one another and parallel to the cross-wires of the microscope: the examination is then said to be made between *crossed nicols* in parallel light.

The same instrument may also be used for observations in convergent polarized light. For this purpose, a system of converging lenses, called the condenser, is placed immediately below the section and above the polarizer, while above the section a high power object-glass is used. On removing the eye-piece (the two nicols being left in place) and looking down the tube of the microscope a small, but sharply defined interference-figure (p. 61 and plate 4) will be visible when a suitably orientated section is on the stage. This figure may be considerably magnified by inserting the eye-piece and at the same

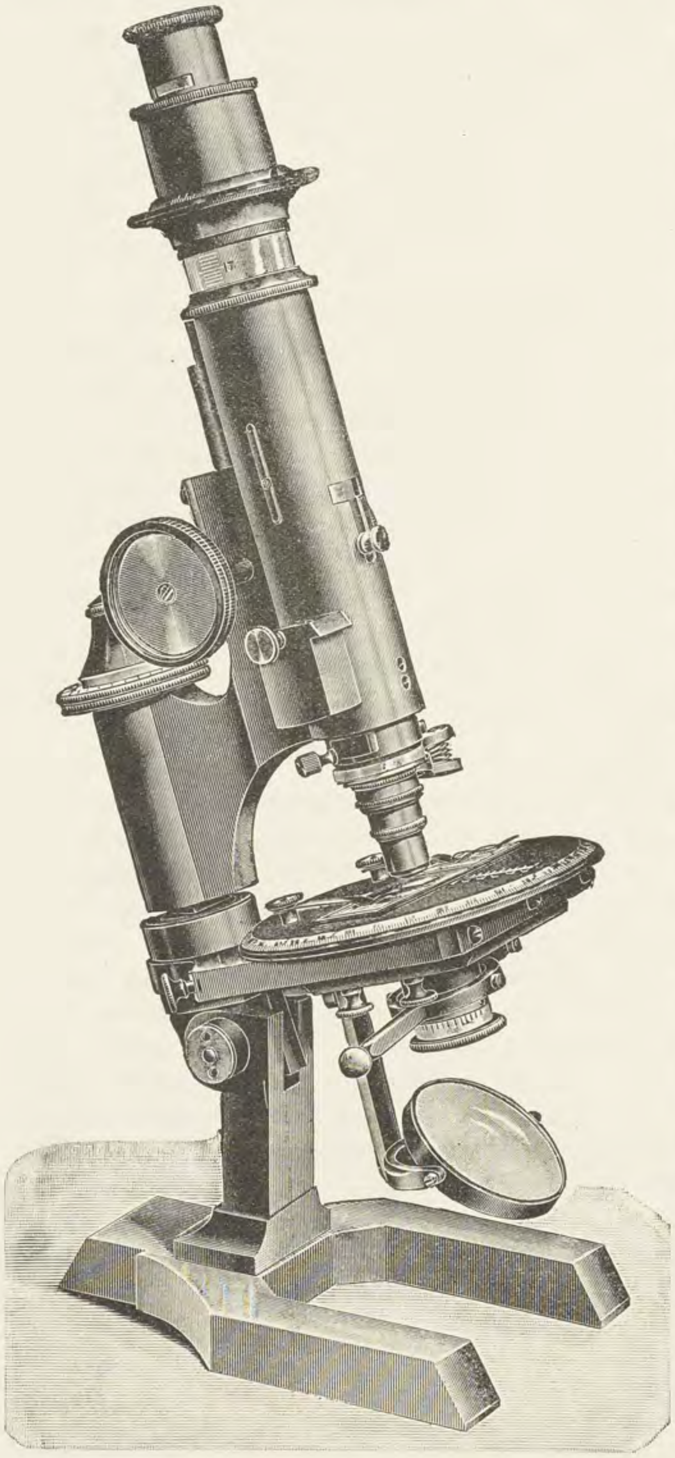

Fig. 210.
Microscope for mineralogical and petrographical work.
(By W. and H. Seibert, of Wetzlar).

time a lens (called a Bertrand lens) in about the middle position in the tube of the instrument.

On some of the preceding pages of this volume we have had occasion to call the microscope to our aid to exhibit certain structures and pecularities which are not visible to the unaided eye. For instance, the enclosures in crystals (text-figs. 96 and 97), the twinning of augite (text-fig. 103), the delicate forms of growth shown in plate 59, figs. 1 and 2, quartz with enclosures and corroded margins in figs. 3 and 4, and felspar with regularly arranged slaggy enclosures in fig. 5 of the same plate. From these observations made with the help of the microscope, we are able to draw conclusions of importance relative to the origin and mode of growth of the crystals and of the rock which they form a part. For instance, the enclosures of glass and slaggy material prove that the minerals have separated from a fused mass; the delicate forms of growth are an indication that the minerals have grown very rapidly; the corroded margins of the crystals indicate that the conditions of pressure or temperature, or that the composition of the liquid, have varied during the period that the rock was formed. Further, the structure of the rock itself is often much more obvious under the microscope than when a hand specimen is examined with the unaided eye. Thus in text-fig. 211, we see very clearly from the lines of flow that the material must once have been in a fluid state: the stream is seen to divide and pass round the square crystal on the right, and to converge and spread out again after passing through the narrow defile between the two larger crystals on the left. From our examination under the microscope of such a section we can safely pronounce that the rock from which it was cut formed part of a lava-flow.

Fig. 211.
Flow structure shown in a thin section of lava.
Magnification 45.

The study of rocks is itself a special branch of mineralogical science known as *petrography*, which owes its present-day position mainly to the examination of thin sections with the aid of the microscope. Indeed, it would not have been possible without the microscope and thin sections to have acquired our present knowledge of rocks and rock-forming minerals. Much can, however, be learnt about the minerals themselves without the aid of the microscope, for these minerals are frequently found as well-developed crystals in the cavities and crevices of rocks of which, as obscure grains, they form a part. Nevertheless, in the following descriptions we shall, where necessary, mention the characters of the rock-forming minerals as they are seen under the microscope.

Some few of the minerals which are of importance as the constituents of rocks have already been dealt with in this volume with the ores and the precious stones; for instance, magnetite, sphene, quartz, tourmaline, and zircon. On the other hand, we shall find that some of the minerals to be now described as rock-forming minerals are sometimes of importance as precious stones.

Felspar.

Felspar is a generic name for a group of minerals, similar to one another in crystalline form and analogous in chemical composition, which are the most abundunt and at the same time the most important of rock-forming silicates. In addition to silica, they contain alumina, together with either potash, soda, or lime, or mixtures of these. The several members can therefore be distinguished chemically as potash-felspar, soda-felspar, lime-felspar and soda-lime-felspar. Others containing baryta, or potash together with soda, are of less importance and need not be further mentioned in this place. Potash-felspar contains, when pure 16·9 per cent. of potash, and, being a widely distributed mineral in the rocks of the earth's crust, it supplies, when weathered, the bulk of the potash present in soils, and so affords nourishment for plants.

Although all the felspars are very similar in their general crystalline form, there is a difference in the symmetry of their crystals: some crystals possess one plane of symmetry and belong to the monoclinic system, whilst others have no plane of symmetry and belong to the triclinic system. The difference between these two kinds of crystals is, however, so slight that it is not at all obvious on inspection. The crystals of felspar represented in fig. 1, plate 60, and fig. 7, plate 61, are so similar that one would naturally conclude that they belong to the same system of crystallization; but in reality the former is monoclinic and the latter triclinic. The difference between the two kinds is more apparent when thin slices are examined in polarized light. There is also an important difference in the angle between the cleavages. All felspars cleave with ease in two plane directions: in the monoclinic felspars the angle between the two cleavages is a right angle (90^{0}); whilst in the triclinic felspars it differs by 3^{0} from a right angle. For this reason, monoclinic felspar is known as *orthoclase* (from the Greek, ὀρθός, right, and κλᾶν, to break), and the triclinic felspars as *plagioclase* (from πλάγιος, oblique). Potash-felspar is either monoclinic or triclinic, belonging to the species orthoclase and microcline described below; while soda-felspar, lime-felspar, and soda-lime-felspar are triclinic, these being the plagioclases described farther on under the names albite, anorthite, etc.

Orthoclase is the most important of the potash-felspars. When pure, it contains: potash (K_2O) 16·9 $^0/_0$, alumina (Al_2O_3) 18·3 $^0/_0$, and silica (SiO_2) 64·8 $^0/_0$, corresponding with the chemical formula $K_2O \cdot Al_2O_3 \cdot 6\,SiO_2$ or $K_2Al_2Si_6O_{16}$. Often a small amount of potash is replaced by an equivalent amount of soda, the potash-felspar being intermixed with some soda-felspar.

Felspar has long been a mineral of interest to crystallographers, and it is now a century ago that C. S. Weiss of Berlin used it as an illustration of his law of zones (p. 15). A crystal of monoclinic felspar (orthoclase) has already been described on p. 39 (text-fig. 83), and several actual crystals are represented on plates 60 and 61.

In the accompanying text-fig. 212 the face lettered *P* is the basal plane $0\,P$ (parallel to which is the best cleavage), *M* the clino-pinacoid $\infty P \grave{\infty}$ (parallel to the plane of symmetry and the second cleavage), *l* and *z* are vertical prisms with the symbols ∞P and $\infty P \grave{3}$ respectively, and *x* is a positive ortho-dome $P \bar{\infty}$. The large crystals shown in fig. 1 of plate 60 and fig. 1 of plate 61 are bounded by the same forms, and differ only in the relative length of the prism faces; in the latter crystal the faces of the prism *z* are coated with green chlorite.

In text-fig. 213 we have again the base *P*, the clino-pinacoid *M*, the unit prism *l*, a steeper ortho-dome $y = 2\,P \bar{\infty}$, and in addition a clino-dome $n = 2\,P \grave{\infty}$ (truncating the edge between *P* and *M*), and a small positive hemi-pyramid $o = P$. This crystal pre-

PLATE 60.

Felspar I.

Common Felspar (Orthoclase).

Fig.

1\. **Orthoclase,** reddish, simple (i. e. untwinned) crystals with smoky-quartz on pegmatite.
Lomnitz, Hirschberg, Riesengebirge, Prussian Silesia.

2\. **Orthoclase,** simple crystal elongated in the direction of the *a*-axis, with dark mica attached; from granite.
Ochsenkopf, Fichtelgebirge, Bavaria.

3\. **Orthoclase,** *Carlsbad twin.* The twin-plane is the ortho-pinacoid (a face of which would truncate the edge on the left common to the two crystals).
Gunnison Co., Colorado, U. S. A.

4\. **Orthoclase,** *Carlsbad twin.*
Carlsbad, Bohemia.

5\. **Orthoclase,** *Carlsbad twin.* The large face to the front in figs. 3—5 is the clino-pinacoid $\infty P \grave{\infty}$, the faces at the side are the vertical prism ∞P and the narrow prism $\infty P 3$; at the end is the basal plane $0 P$, and the steep face behind is the ortho-dome $2 P \bar{\infty}$; in addition there are poorly defined pyramid faces (in fig. 5).
Bärenthal, Titisee, Schwarzwald, Baden.

6\. **Orthoclase,** *Carlsbad twin,* with regular intergrowth of white albite; above is a crystal of fluor-spar; on granite.
Fuchsberg, Striegau, Prussian Silesia.

7\. **Orthoclase,** *Carlsbad twin.* From a pegmatite-vein in granite.
Otani-yama, Kioto, province Omi, Japan.

8\. **Orthoclase,** *Carlsbad twin.* In figs. 6—8 the crystals are terminated by the basal plane and the unit ortho-dome $P \bar{\infty}$, which are both inclined to the vertical axis at about the same angle; in the twinned crystal these two planes therefore nearly coincide, but they differ in their lustre or colour. In fig. 8 the basal planes are white and the ortho-dome faces are reddish, so that the twinning is prominently shown. (The steeper ortho-dome $2 P \bar{\infty}$ in figs. 3—5 does not coincide in this manner with the basal plane in the twinned crystal.)
Baveno, Lago Maggiore, Italy.

9, 10 and 11. **Orthoclase,** *Baveno twins.* The twin-plane is the clino-dome $2 P \grave{\infty}$, a face of which would truncate one of the vertical edges at the side of the figures; the trace of the twin junction coincides with the obtuse edge shown to the front at the top of the crystals.
Baveno, Lago Maggiore, Italy.

12\. **Orthoclase,** *Manebach twin* on granite. The twin plane is here the base $0 P$.
Baveno, Lago Maggiore, Italy.


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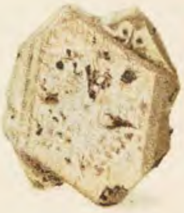
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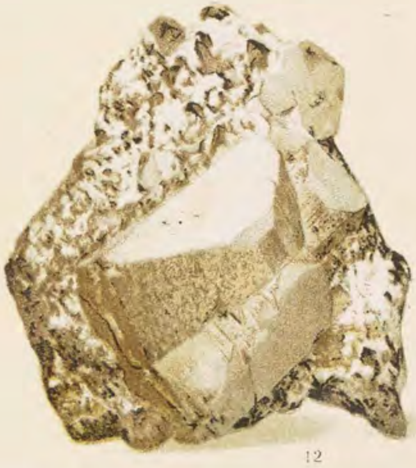
12

sents a prismatic habit in the direction of the edge between P and M, while in fig. 212 the crystal is prismatic along the edge between M and l. The four faces of P and M give a square prism. An actual crystal of this habit is shown in fig. 2, plate 60, where in addition there are narrow faces of the prism $z = \infty P \grave{3}$.

Crystals of orthoclase are usually large enough to allow the angles between their faces to be readily measured with the contact goniometer. The angle between two adjacent prism faces l is $118^3/_4{}^0$, that between the base and the adjacent ortho-dome x (fig. 212) $129^3/_4{}^0$, while from the base to the ortho-dome y (fig. 213) the angle is $99^3/_4{}^0$. The angle between the base and the clino-pinacoid is exactly 90^0, and between the base and the clino-dome n it is $135^0\ 3'$ (not 135^0, as would be the case if the edge between the faces P and M were symmetrically truncated). The faces P and x (fig. 212) are almost equally inclined to the vertical, the angle between these and the front prism-edge being respectively $116^0\ 3'$ and $114^0\ 14'$ respectively. With the help of the angles here given it is possible to identify the prominent faces on a sufficiently large crystal; and any other smaller faces can then be determined from their position in zones on the crystal.

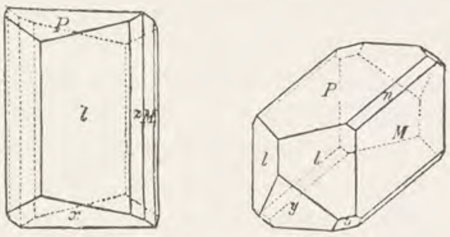

Fig. 212. Fig. 213.
Crystals of Orthoclase.

Although simple crystals of felspar are of common occurrence, yet twinned crystals are perhaps still more common. The different types of twins are named after the localities at which they were first found.

Carlsbad twins were long ago collected at Carlsbad in Bohemia by Goethe, and were described by him in the following words: "There are large masses of the Carlsbad granite in which are found perfect crystals of very complex form. These are double crystals, consisting of two crystals so interlocked that it is impossible to consider one without considering the other. A description of their form is not sufficient to bring it to the imagination, though they may be considered as two rhombic tables united into one another." A glance at figs. 3—5 of plate 60 will suffice to show how well these double crystals were described by Goethe. We can only add that the plane which the two intergrown crystals possess in common is a plane truncating the obtuse edge of the vertical prism. This plane — the ortho-pinacoid — would, if present on the crystals, lie to the side in the three crystals in plate 60 and to the front in text-fig. 214, truncating symmetrically the edge between the two prism-faces lettered m. The twin-plane is thus the ortho-pinacoid, a face which is of comparatively rare occurrence in orthoclase. A characteristic feature of Carlsbad twins is the fact that the basal planes (c) of the two individuals of the twin slope away from the summit in opposite directions. In figs. 3—5 the basal planes are the longer faces sloping to the left and to the right, while the shorter more steeply inclined faces belong to the ortho-dome $y = 2 P \bar{\infty}$. In other twinned crystals in which we have the ortho-dome $x = P \bar{\infty}$, instead of the steeper ortho-dome y, this plane and the base (c) fall together in almost the same plane, since, as already pointed out, the faces c and x are almost equally inclined to the vertical. This coincidence of different faces is shown in text-fig. 215 and in figs. 6—8 of plate 60. A difference in surface character is, however, to be noted between the two portions of what is apparently a single face: in fig. 8 the basal plane is white,

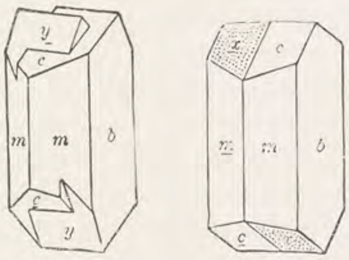

Fig. 214. Fig. 215.
Carlsbad twins of Orthoclase.

while the nearly coincident x face is red; in fig. 7 it is lighter (on the right); and in fig. 6 it is of a purer yellow (the left-hand portion of the large face).

Baveno twins of orthoclase were first found in clefts in the granite of Baveno, on Lago Maggiore in northern Italy; twinned crystals from this locality are represented in figs. 9—11, plate 60. These crystals present the same square prismatic habit as shown in text-fig. 213, the base and the clino-pinacoid being the predominating forms: they are always attached to the rock at one end, while at the free end they show a very obtuse angle with the twin-suture running diagonally across. The twin-plane is a face of the clino-dome $n = 2\,P\,\grave{\infty}$, which truncates the edge between the base and the clino-pinacoid (text-fig. 213): and we can imagine such a crystal cut into two by a plane parallel to n, and one half rotated on the other half through 180° about on axis perpendicular to this plane.

Baveno twins of rather a different type are seen in adularia, a variety of orthoclase from the Alps. A simple crystal is represented in fig. 1, and a complex twinned crystal consisting of several individuals in fig. 2, plate 61. In fig. 3 the small crystal in the centre is twinned on both the upper and the lower portions according to the Baveno law: the two larger portions are thus related to are another by a twice repeated Baveno twinning, or they may equally well be considered to the twinned on one another according to the Manebach law.

Manebach twins derive their name from Manebach in Thuringia. Here the twin-plane is the base, and the prism faces usually form a prominent re-entrant angle on the compound crystal (fig. 12, plate 60; figs. 3 and 10, plate 61). If, however, the prism faces are small, the ortho-domes will extend to the twin-junction and produce a salient angle, as shown in the lower part of fig. 10, plate 60, and in the lower crystal in fig. 8 of the same plate.

These three kinds of twins met with in orthoclase are not confined to the particular localities from which they receive their names. From Baveno in Italy we have, for example, Carlsbad twins (fig. 8, plate 60), Baveno twins (figs. 9—11), and Manebach twins (fig. 12); and, indeed, it is possible to have all three twin-laws represented on the same hand-specimen.

The *cleavage* of orthoclase, as in all the felspars, is a character of considerable importance. There is a perfect cleavage parallel to the basal plane, and a rather less pronounced cleavage parallel to the plane of symmetry; the angle between the two cleavages being 90°. In translucent crystals the perfect cleavage gives rise to a characteristic pearly lustre on the basal plane. In fig. 1, plate 61, the cleavage cracks running across the prism faces are due to the basal cleavage, being parallel to the basal plane (at the back of the crystal; the large face at the top of the crystal being the ortho-dome). A cleavage flake parallel to the basal plane will show on its surface the traces of the second cleavage; and if such a flake be examined in the polarizing microscope between crossed nicols, the light will be cut out when these traces are parallel to the vibration-directions of the nicols. The extinction is therefore said to be straight, and we then know that we are dealing with a monoclinic felspar possessing a plane of symmetry. With other felspars, in which there is no plane of symmetry, the extinction on a basal cleavage is not parallel to the second cleavage, but is oblique.

The hardness of orthoclase is 6 (being taken as No. 6 on Mohs's scale of hardness). The specific gravity varies between 2·5 and 2·6, according to the purity of the material. The refractive indices do not exceed 1·525, and the double refraction is also low. Thin splinters of the mineral are fusible before the blowpipe, but only with difficulty.

Orthoclase is widely distributed as a constituent of various kinds of rocks, and it also occurs as well-developed crystals attached to the walls of rock cavities. According to its mode of origin and occurrence, it presents certain differences in its external appearance, and it is usual to distinguish the varieties now to be described under the terms common felspar, sanidine, and adularia.

Common felspar (plate 60), or simply felspar (i.e. orthoclase-felspar), is cloudy and dull, and in colour may be white, yellow, grey, flesh-red, brick-red, or greenish-grey. Sometimes, as in the felspar of Fredriksvärn in Norway, it shows a change of colours, similar to that to be described farther on under labradorite. Orthoclase occurs as an essential constituent of granite, syenite, porphyry, and gneiss; and it is also present as water-worn grains in some sedimentary rocks (e.g. arkose). In granites it is mostly present as irregular grains; but in certain granites and in porphyries there are larger crystals of felspar set in a finer grained ground-mass consisting of felspar with other minerals. When the rock is weathered, these porphyritic crystals can sometimes be easily picked out from the soft, decomposed mass; figs. 2—5, plate 60, show crystals which have been isolated in this way. The mineral also occurs as crystals in drusy cavities in granites and pegmatite-veins or in clefts in gneiss; the crystals here growing out from the surface of the rock with their base rooted, as it were, in the material of the rock. Such attached crystals are shown in figs. 1, 6—9 and 12 of plate 60; while the crystals in figs. 10 and 11 have been detached from the matrix on which they grew. The large crystal represented in fig. 6 is of special interest in that it shows the yellow potash-felspar (orthoclase) surrounded by a margin of white soda-felspar (albite), the two minerals having grown together in parallel position to form one crystal.

Orthoclase is very liable to alteration by weathering, giving rise to clay, kaolin, or potash-mica.

Common felspar has certain ecomonic uses. On account of the potash it contains, it is sometimes employed as a fertilizer. Larger quantities are used in the manufacture of porcelain and pottery. In the year 1899, Norway alone produced 19,260 tons of felspar; and recently a large deposit has been opened up at Bedford near Kingston in Ontario.

Sanidine. The orthoclase of the younger volcanic rocks (trachyte and phonolite) is a glassy variety known as sanidine. The crystals found attached to the walls of cavities in these rocks are colourless, clear and transparent, with the appearence of glass, and are therefore sometimes known as ice-spar; these are usually quite small, and are not suitable for representing in a picture. More frequently, sanidine is found as embedded crystals. These are colourless, grey, or yellowish, and are often much fissured; they may be prismatic in habit (text-fig. 213), or present the form of tabular Carlsbad twins (text-fig. 214). A fairly large crystal of sanidine, picked out from the trachyte of the Drachenfels in the Siebengebirge, Rhine, is shown in fig. 4, plate 61. On a freshly fractured surface of this rock many smaller crystals of sanidine are seen by the light reflected from their bright cleavages. Large, water-clear fragments of sanidine are found loose in the soil in the neighbourhood of Hohenfels, near Gerolstein in the Eifel; and these were formerly so abundant that they were collected for the porcelain works.

The optical characters of sanidine are of especial interest. The optic axial angle (i.e. the angular distance between the black brushes seen in convergent polarized light, fig. 4, plate 4) is different in different crystals, and the plane of the optic axes is sometimes parallel, and sometimes perpendicular, to the plane of symmetry of the crystal. Further, when a crystal is heated, a progressive change can be observed in the positions of the optic axes, and beyond a certain temperature the change is permanent. These observations indicate that the crystals have at one time been strongly heated and suddenly cooled; a conclusion which accords with the occurrence of sanidine bombs in loose volcanic tuffs. It is probable that the sanidine bombs represent a deep-seated, coarse-grained sanidine-rock, fragments of which have been brought to the earth's surface by volcanic explosions.

Adularia. The purest crystals of orthoclase are those which occur in crevices in the crystalline schists of St. Gotthard; and this variety consequently receives its name from the neighbouring Adula Mountains in Switzerland. Three large crystals are represented in figs. 1—3, plate 61; they are transparent to translucent, and white or yellowish in colour. Sometimes, certain faces, especially those of the prism $\infty P \grave{3}$, are dusted over with green chlorite (fig. 1, plate 61). This crystal (fig. 1) shows in addition large faces of the unit prism ∞P, across which run cleavage cracks parallel to the basal plane; and the large ortho-dome face $P \bar{\infty}$ at the top. The twinned crystals (figs. 2 and 3) have already been referred to (p. 292). The adularia which occurs in the clefts of silicate rocks of the Swiss and Tyrolese Alps is usually associated with crystals of quartz, sphene, chlorite, and other minerals.

Certain specimens of adularia, particularly those from Ceylon, when held in a certain position with respect to the light, exhibit a strong bluish-white reflection comparable with the soft light of the moon. This variety is consequently known as *moon-stone*; and when good, clear specimens are cut and polished with a convex surface (en cabochon) they form a pleasing gem-stone.

Microcline. This is another kind of potash-felspar so similar to orthoclase in external appearance that the two can only be distinguished by an examination of thin flakes or sections under the polarizing microscope. The two are identical in chemical composition and specific gravity, but whilst orthoclase belongs to the monoclinic system, microcline belongs to the triclinic system. Being a triclinic felspar, a flake of microline parallel to the perfect basal cleavage does not give straight extinction (p. 292) between crossed nicols. Furthermore, between crossed nicols it shows a very characteristic grating-like or cross-hatched structure (fig. 2, plate 61a), which is not met with in the other felspars. This peculiar structure is due to repeated lamellar twinning in two directions.

In the colour, habit, and appearance of the crystals, microcline resembles orthoclase very closely. Some crystals are, however, of a bright green colour, and this variety is known as *amazon-stone* or amazonite: the cause of the green colour is not known. The four well-developed crystals of microcline represented in figs. 8—11, plate 61, are of the amazon-stone variety. As in orthoclase, these crystals are bounded by a pinacoid (which must here be called the brachy-pinacoid), vertical prisms, the basal pinacoid, and a macro-dome. It will be seen that the form of fig. 8 compares very closely with that of the crystal in fig. 1 plate 60. In fig. 11 the crystal is bounded below by the large basal cleavage, the large face above being the macro-dome. In fig. 10 we have an excellent Manebach twin: the re-entrant angle is formed by the prism faces, and the faces above and below these are the ortho-domes, the smaller being $y = 2\,P \bar{\infty}$ and the larger $x = P \bar{\infty}$; while at the top is the smaller basal plane parallel to which is the twin-plane. Baveno and Carlsbad twinning is also met with in microcline; and, indeed, it is possible that the crystals represented in figs. 7 and 11, plate 60, may be microcline, for it is not always easy to distinguish between orthoclase and microcline, nor is the distinction of much importance.

Microcline occurs under exactly the same conditions as common felspar (orthoclase), and it has the same technical applications. The bulk of the Norwegian felspar quarried for porcelain manufacture is without doubt microcline. The green amazon-stone is found in the Pike's Peak district of Colorado (figs. 8—11, plate 61), and also in the Ilmen Mountains on the eastern side of Lake Ilmen in the Urals. On account of its colour it is sometimes used for ornamental purposes and for inlaying in mosaics. Ancient Egyptian amulets cut in amazon-stone have been found on rare occasions. In Russia it

PLATE 61.

Felspar II.

Adularia, Sanidine and Triclinic Felspars.

Fig.

1. **Adularia** (a variety of orthoclase), large, simple (i. e. untwinned) crystal. The two large faces at the front belong to the vertical prism ∞P, and the narrow faces at the sides coated with chlorite to the vertical prism $\infty P\grave{3}$. The large face above belongs to the ortho-dome, and the direction of basal plane is indicated by the cleavage cracks.
St. Gotthard, Switzerland.

2. **Adularia,** group of crystals twinned together according to the Baveno law. The small faces of the prism $\infty P\grave{3}$ are here also coated with chlorite.
St. Gotthard, Switzerland.

3. **Adularia,** Manebach twin.
Upper Wallis, Switzerland.

4. **Sanidine** (a variety of orthoclase), from trachyte.
Drachenfels, Siebengebirge, Rhine.

5. **Albite,** twinned crystal.
Left bank of the Nolla, Thusis, Graubünden, Switzerland.

6. **Albite,** several crystals on a rock coated with dark mica.
Radauthal, Harz Mountains, Germany.

7. **Andesine,** with pyrrhotite.
Bodenmais, Bavarian Forest.

8, 9. **Amazon-stone,** from granite.
Pike's Peak, El Paso Co., Colorado, U. S. A.

10. **Amazon-stone,** Manebach twin.
Florissant, El Paso Co., Colorado, U. S. A.

11. **Amazon-stone,** on the large basal plane the cross-hatched microcline structure may be recognized (compare Plate 61*a*, fig. 2).
Florissant, El Paso Co., Colorado, U. S. A.

12. **Labradorite** (or Labrador-spar), with coloured reflection.
Coast of Labrador, North America.

13. **Labradorite,** cleavage fragment showing twin striations.
Coast of Labrador, North America.


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was formerly used to guard against epilepsy, a rounded piece being inserted in the upper arm. This use of the stone is perhaps to be explained by a confusion with the green nephrite, which even to the present day is regarded by the Chinese as a holy stone; further, it must be remembered that formerly the name amazon-stone was applied not only to green felspar but also to nephrite.

Albite, or soda-felspar, is chemically analogous to potash-felspar, differing from it in containing sodium in place of potassium. When pure, it is composed of soda (Na_2O) 11·8 $^0/_0$, alumina (Al_2O_3) 19·5 $^0/_0$, and silica (SiO_2) 68·7 $^0/_0$; but almost invariably small amounts of potash and lime are present. The chemical formula is $Na_2O . Al_2O_3 . 6 SiO_2$ or $Na_2Al_2Si_6O_{16}$. Not only in chemical constitution, but also in the form of the crystals, there is a striking similarity between soda-felspar and potash-felspar: the lie of the faces is much the same, and there is only a slight difference in the angles between corresponding faces; and the modes of twinning are similar. In soda-felspar, however, the crystals do not possess a plane of symmetry, and they are consequently triclinic.

In the crystal of albite shown in text-fig. 216 the two faces *T* and *l*, which together form a vertical prism corresponding with that of orthoclase, are different in character and here belong to different crystal-forms. *M* is the brachy-pinacoid, *P* the basal pinacoid, *x* a macro-dome, and *o* a pyramid; each of these forms consists of only a pair of parallel faces (one of each being visible at the front of the crystal). The faces *P* and *M* are inclined to one another at an angle of 93^0 36′ (the corresponding angle *P M* in orthoclase being 90^0). The crystal shown in text-fig. 217 presents the same faces, with the addition of a steeper macro-dome *r*; the difference in habit being here due to the greater development of the crystal in the direction of the macro-axis *b*. Albite of this habit is known as *pericline*: the crystals usually show signs of a peculiar kind of twinning, the presence of which is indicated by oblique striations on the face *M*.

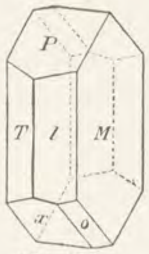

Fig. 216.
Crystal of Albite.

Fig. 217.
Crystal of Albite (variety Pericline).

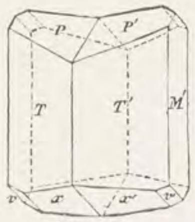

Fig. 218.
Twinned crystal of Albite.

Crystals of the usual habit (text-fig. 216) are invariably twinned according to what is known as the *albite-law* (text-fig. 218). Here the twin-plane is the face *M*, and one half of the twin is turned through 180^0 about a normal to this plane with respect to the other half of the twin. The result of this is that the basal planes of the two portions of the twin (*P* and *P′* in text-fig. 218) are inclined at an angle of 7^0 12′, forming a re-entrant angle at one end of the crystal and a salient angle at the other end. A rotation about the normal to *M* in orthoclase would result in the coincidence of the faces *P* without any re-entrant angle, since here the angle *P M* is exactly 90^0. This albite twinning is a specially characteristic feature of albite, and being often repeated in one and the same crystal it gives rise to a lamellar twinning, which is rendered evident by the fine striations on the basal plane parallel to the edge between *P* and *M*. Twinned crystals of albite are represented in figs. 5 and 6 of plate 61. The crystals may also be twinned according to the Carlsbad-law in addition to the albite-law.

Crystals of albite are usually only small. They may be either colourless and water-clear or white: the name albite refers, in fact, to the typical white colour. The specific gravity is 2·62 to 2·65, and the hardness 6 to $6^1/_2$. Being a triclinic mineral, the extinct between crossed nicols is oblique on all the faces, as also on a basal cleavage flake. The material is not attached by hydrochloric acid.

Albite is usually found as crystals attached to the walls of crevices in crystalline rocks, and is often associated with rock-crystal and chlorite. Sometimes it occurs as a parallel growth on crystals of orthoclase (fig. 6, plate 60). A few localities in the Alps are: the Nolla (fig. 5, plate 61) and Mt. Scopi in Switzerland, Schmirn and Zillerthal in Tyrol, Rauris in Salzburg (here the pericline variety), and Baveno on Lago Maggiore. Other localities are: Striegau (fig. 6, plate 60) and Hirschberg in the Riesengebirge in Prussian Silesia, Radauthal in the Harz (fig. 6, plate 61), Mursinsk in the Urals (as globular aggregates with smoky-quartz, fig. 10, plate 54), Kasbek in the Caucasus, Pike's Peak in Colorado (with amazon-stone, fig. 10, plate 61), Amelia in Virginia, etc.

Anorthite, or lime-felspar. This kind of felspar is, as a rule, very similar to albite in appearance, being found as small, colourless or white crystals with essentially the same form as albite, though sometimes bounded by a profusion of bright faces. Anorthite is, however, distinguished by its higher specific gravity of 2·74—2·76, and by the fact that it is decomposed by hydrochloric acid. The two minerals may also be readily distinguished by their optical characters. For this purpose a thin cleavage flake, taken parallel to the basal plane, is placed on the stage of the polarizing microscope, and the extinction angle is measured with respect to the cleavage cracks which intersect the flake parallel to the brachy-pinacoid. With albite the light between crossed nicols will be extinguished when one or other of the cross-wires is inclined at about 4° to the brachy-pinacoid cleavage cracks, whilst with anorthite this angle is about 40°. This difference may be expressed by saying that the extinction on the basal plane is more oblique in anorthite than in albite.

In chemical composition there is an important difference between albite and anorthite: in the latter we have lime in place of soda, and moreover a much lower percentage of silica. The theoretical composition of anorthite is: silica (SiO_2) 43·3 %, alumina (Al_2O_3) 36·6 %, and lime (CaO) 20·1 %, corresponding with the formula $CaO . Al_2O_3 . 2SiO_2$ or $CaAl_2Si_2O_8$.

Crystals of anorthite are found in the ejected blocks of Monte Somma, Vesuvius, and at Monzoni in southern Tyrol. It is much more frequent as grains in certain basic eruptive rocks, such as gabbro; and it has also been detected in meteorites.

Soda-lime-felspars. Between soda-felspar and lime-felspar there is a series of intermediate felspars with the same general characters as albite and anorthite, and the whole of these (together with the extreme members albite and anorthite) are included in the general term *plagioclase* (p. 290). These are extremely rare as well-developed crystals bounded by faces, but as irregular grains they are widely distributed as constituents of eruptive rocks. Their most characteristic feature, by which they can be recognized, is the fine twin striation on the basal cleavage. This is due to a repeated or lamellar twinning according to the albite-law, the individual lamellae being often no thicker than a sheet of paper. Each lamella is in twinned position with respect to the lamellae on either side of it, whilst the first is in parallel position with respect with the third, fifth, seventh, etc. These striations are often visible with the aid of a hand-lens, and sometimes to the unaided eye (fig. 13, plate 61). In this figure it will be seen that the striations are parallel to the edges of the fragment bounded by the second, less perfect cleavage. On account of this structure the plagioclase felspars are sometimes known as *striped felspars.*

PLATE 61 a.

Rock-forming Minerals II.

(Micro-photographs.)

Fig.

1. **Triclinic Felspar** (Labradorite), showing lamellar twinning in polarized light, Magnification 30.
   Paul Island, Labrador, North America.
2. **Microcline,** showing cross-hatched structure in polarized light. × 45.
3. **Leucite,** showing twin lamellation in polarized light; in leucitophyre. × 20.
   Rieden, Laacher See, Andernach, Rhenish Prussia.
4. **Leucite,** with regularly arranged enclosures of glass; in lava (leucite-tephrite). × 90.
   Vesuvius, Italy. Lava stream of 1861 above the Torre del Greco.
5. **Nepheline,** hexagonal crystal cut parallel to the prism; in nephelinite. × 15.
   Katzenbuckel, Eberbach, Odenwald, Baden.
6. **Nosean,** deeply corroded crystal penetrated by the ground-mass; in leucitophyre (as in No. 3). × 20.
   Rieden, Laacher See, Andernach, Rhenish Prussia.

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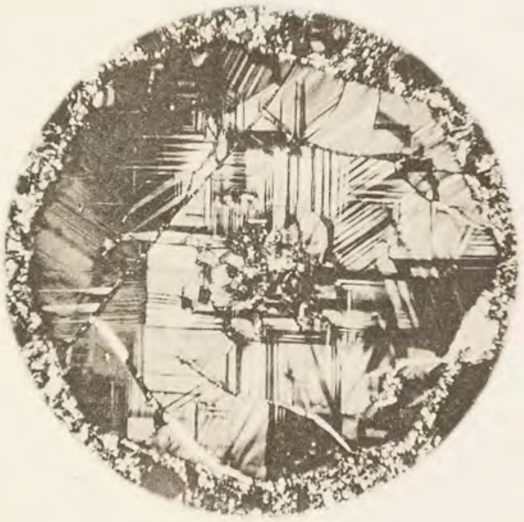

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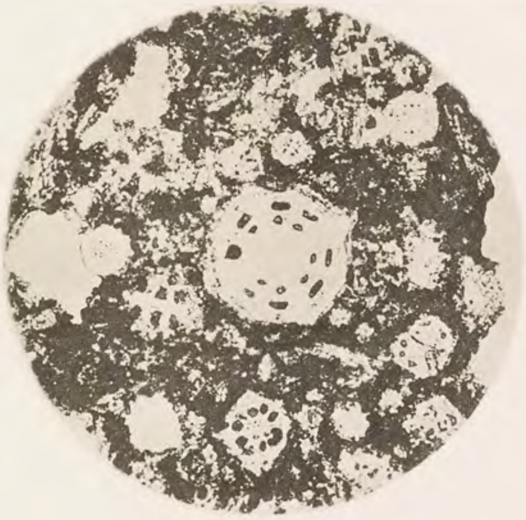

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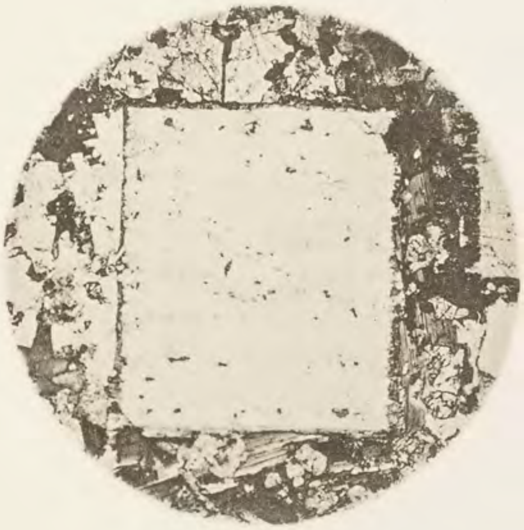

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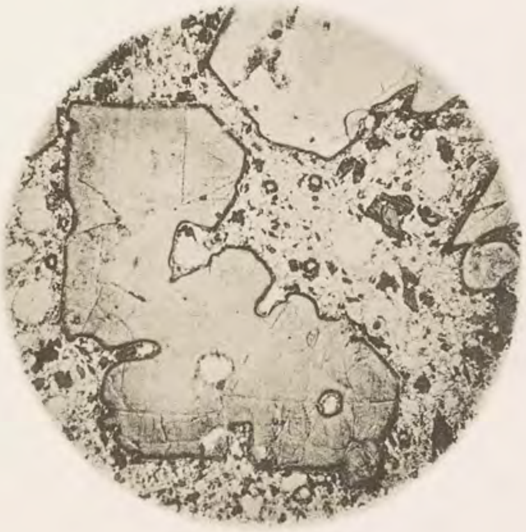

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This banded structure is rendered still more evident when a basal cleavage flake, or a thin section of the material, is examined in the polarizing microscope between crossed nicols (fig. 1, plate 61a). In certain positions the different lamellae appear as alternately light and dark bands; and on rotating the section together with the stage, the light bands become dark and the dark bands become light. If the bands be set parallel to one or other of the cross-wires in the microscope they will be seen equally illuminated; on rotating the stage through a certain angle to the right the alternate bands of one set become dark, and on rotating through the same angle to the left those of the other set become dark. The magnitude of this angle of extinction depends on the relative proportions of soda-felspar and lime-felspar present in the specimen under examination. A long series of careful observations, particularly those made by the late Professor Max Schuster, have demonstrated that an optical examination of this kind will give us an indication of the chemical composition of the felspar.

The results of chemical analyses have proved that the plagioclase-felspars can be ranged in a continuous series starting from albite and ending with anorthite, and that any one member of the series is to be regarded as an isomorphous mixture of the two extremes. Those containing up to 26 % of lime-felspar are included under the term *oligoclase*, up to 50 % *andesine*, up to 76 % *labradorite*, and those with up to 96 % are known as *bytownite*. With an increase in the amount of lime there is a corresponding decrease in the amount of silica: albite contains 68·7 % of silica, oligoclase 62 %, andesine 56 %, labradorite 49 %, and anorthite only 43·3 % of silica. Similarly, there is along the series a progressive variation in the magnitute of the extinction angle on the basal cleavage: in oligoclase this is only about 1°, increasing in andesine to 5°, in labradorite to 17°, and in anorthite to 37°. The same variation is also observed in the specific gravity, which increases progressively with the percentage of lime: the specific gravity of albite being 2·624, of oligoclase up to 2·659, andesine to 2·694, labradorite to 2·73, and of anorthite 2·758. Providing the material is quite fresh, it is thus possible to determine from the specific gravity which member of the series we are dealing with.

These intermediate plagioclase-felspars are common constituents of igneous rocks of various kinds, being often present as irregular grains (as in diorite and gabbro), or as porphyritic crystals set in a finer grained ground-mass (as in basalt and diabase). The porphyritic crystals of lavas often contain slaggy enclosures which are sometimes arranged in a zonal manner (fig. 5, plate 59) showing the stages of growth. A zonal structure of the larger crystals is also often rendered evident by the extinction angles; the nucleus, containing more lime-felspar, has a wider extinction angle, and the outer zones, successively richer in soda-felspar, have smaller extinction angles.

The felspars of coarsely crystalline rocks sometimes contain regularly arranged enclosures of other minerals which impart a special kind of lustre or colour to the host. Thus, the so-called *sun-stone*, a variety of oligoclase from Tvedestrand in Norway, contains large numbers of small, extremely thin scales of haematite, which give rise to a red colour and glittering lustre in the stone. The effect is the same as that seen in avanturine (p. 273), and this variety of felspar is consequently also known as avanturine-felspar. The labradorite or *labrador-spar* of the coast of Labrador contains vast numbers of minute scales and needles, which are doubtless the cause of the brilliant play of colours. The stone itself is of a dull smoky-grey colour, but when it catches the light at a particular angle the surface suddenly lights up with brilliant metallic colours — blue, green, red, or bronze — as but inadequately represented in fig. 12, plate 61. Labrador-spar, particularly that from Labrador, is cut and polished for jewellery and various small ornamental objects, and it is also used for inlaying.

By the alteration of the soda-lime-felspars there may be formed other minerals containing water in addition to the constituents of felspar, which, in a way, may be regarded as hydrated felspars. These form a special group of minerals known as the zeolites to be considered later. Further, when subjected to weathering processes they frequently give rise to calcite, and often to epidote, albite, and quartz: the calcium they contain forms calcite or epidote, the soda-felspar gives albite, while the excess of silica separates as quartz, chalcedony, or opal.

Felspathoid Minerals.

Certain minerals composed of the same chemical elements as the felspars and occurring in the same manner as rock constituents are known as felspathoid minerals. These differ from the felspars in the form of their crystals and they belong to distinct mineral species. We have leucite corresponding with potash-felspar, nepheline with soda-felspar, and scapolite with lime-felspar and soda-lime-felspar. In addition, there are other minerals chemically allied to nepheline, but containing also other salts, namely sodium chloride in sodalite, and sodium or calcium sulphate in nosean, haüyne, and lapis-lazuli. The last of these has already been considered with the precious stones (p. 258).

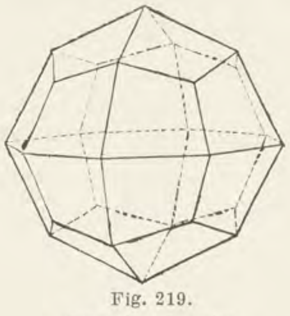

Fig. 219.
Crystal of Leucite.

Leucite occurs only as crystals, and these being always of the same form, they are a very characteristic feature of the mineral. This form is the icositetrahedron 2*O*2 of the cubic system (figs. 1—3, plate 62, and text-fig. 219), which for the above reason is sometimes known as the leucitohedron. Such constancy of crystalline form, or rather habit, is met with in scarcely any other mineral species; on the other hand, some other mineral species, e. g. sphene, are remarkable for the great variation in the form of their crystals.

But although we find this very simple relation in leucite, yet it is a mineral which presents certain difficulties. The form naturally suggests a cubic crystal, which should, of course, be singly refracting. A thin section of a leucite crystal when placed between crossed nicols does not, however, remain dark, but shows the complex structure illustrated in fig. 3, plate 61a. This section is cut approximately parallel to a cube face of the crystal, and as eight faces of the icositetrahedron are intersected, the outline is an octagon. We see in the section a system of light and dark bands approximately at right angles, and others with a diagonal position: the bands are either narrow or wide, sometimes slightly divergent, and they abruptly cease when they meet one of the irregular cracks which intersect the crystal. A comparision of this complex banded structure with the more simple banding shown by sections of plagioclase felspar (figs. 1 and 2, plate 61a) suggests that it is due to repeated twinning. Further, on consideration, it is clear that the banding must be parallel to the faces of the rhombic-dodecahedron. But in a cubic crystal the rhombic-dodecahedron, being a plane of symmetry, cannot be a plane of twinning, and furthermore, as already mentioned, a cubic crystal should not be doubly refracting.

The most satisfactory explanation to this apparent contradiction is that put forward by the late Professor Carl Klein. He found that when a crystal of leucite is raised to a temperature of low redness, the lamellar structure and the double refraction suddenly disappear, the crystal being there truly cubic in its optical behaviour. On cooling again the original conditions reappear without any alteration in the external form of the crystal.

PLATE 62.

Felspathoid Minerals.

Fig.

1. **Leucite,** large, regularly developed crystal (icositetrahedron) in lava.
   Monte Somma, Vesuvius, Italy.
2. **Leucite,** large crystal (icositetrahedron) with smaller crystals attached.
   Capo Sabatenello, east of Resina, Vesuvius, Italy.
3. **Leucite,** large, somewhat distorted crystal (icositetrahedron).
   Rocca Monfina, Naples, Italy.
4. **Nepheline,** hexagonal prism with base and small pyramid faces; in a block ejected from Monte Somma.
   San Sebastiano, Vesuvius, Italy.
5. **Nepheline,** short hexagonal prism with large base.
   Monte Somma, Vesuvius, Italy.
6. **Nepheline,** in rock (nephelinite); showing rectangular and hexagonal cross-sections.
   Katzenbuckel, Eberbach, Odenwald, Baden.
7. **Nepheline** (variety Elaeolite), bluish-grey, with felspar.
   Fredriksvärn, Norway.
8. **Sodalite,** white rhombic-dodecahedra with brown idocrase and black mica in an ejected block from Monte Somma.
   Monte Somma, Vesuvius, Italy.
9. **Nosean,** two greyish rhombic-dodecahedra in an ejected volcanic block.
   Laacher See, Andernach, Rhenish Prussia.
10. **Haüyne,** massive in basaltic lava.
   Niedermendig, Andernach, Rhenish Prussia.

11 *a* and *b*. **Lazurite,** rhombic-dodecahedron with octahedron and three small faces of the icositetrahedron $2O2$.
   Lake Baikal, Siberia.

12. **Lapis-lazuli,** a polished slice.
   Lake Baikal, Siberia.
13. **Scapolite,** tetragonal prisms of the first and second orders with pyramid.
   Laurinkari, Åbo, Finland.

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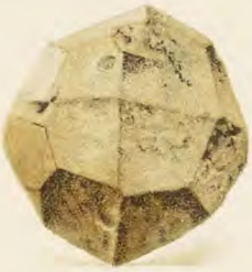

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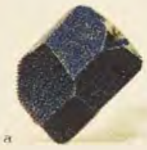

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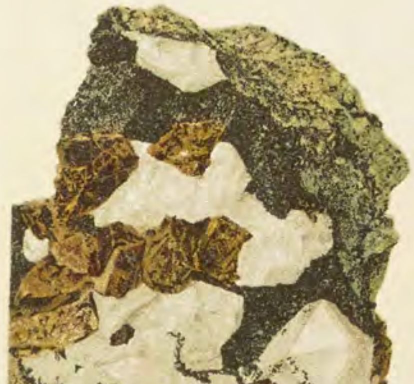

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The change which here takes place is quite analogous to the change of monoclinic sulphur to rhombic sulphur (p. 141), only in leucite the external form of the crystal is not thereby destroyed. The substance of the leucite crystal is cubic only at a high temperature, while at the ordinary temperature it is tetragonal or perhaps rhombic.

Now it is an interesting fact that leucite is found only in lavas and that it is one of the first minerals to crystallize from the molten material. The mineral has thus crystallized at a high temperature in a cubic form, and, as the rock cooled, it underwent a molecular transformation and acquired the characters which we observe at the ordinary temperature. We thus have a paramorph (p. 51) of a special kind, in which the material of the crystal passes from one modification into another when the temperature reaches a certain definite point, and returns again to its original state when the temperature falls. Dimorphous substances which are related to one another in this peculiar manner are known as *enantiotropic*. Another example amongst minerals is given by boracite, which will be described farther on. The same kind of change can be observed in certain artificial salts, such as ammonium nitrate and silver iodide, by using a polarizing microscope fitted with a heating arrangement.

As seen in thin sections under the microscope, leucite presents some other points of interest. It frequently shows enclosures of glassy or slaggy material arranged in a regular manner parallel to the boundaries of the crystal (fig. 4, plate 61a). As may be seen in the several crystals here shown in section, the enclosures vary considerably in their size, shape, and arrangement.

The external appearance of the crystals is well represented in figs. 1—3, plate 62. They are white, grey, or yellowish, and when embedded in the rock they are dull and cloudy; on the other hand, the more rarely occurring attached crystals are clear with a glassy aspect. The refractive index is low (1·508), the specific gravity 2·46, and the hardness $5^1/_2$—6.

Chemically, leucite contains the same constituents as potash-felspar, but these are combined in different proportions. The composition of the pure mineral is potash (K_2O) 21·58 %, alumina (Al_2O_3) 23·40 %, and silica (SiO_2) 55·02, corresponding with the formula $K_2O \cdot Al_2O_3 \cdot 4\,SiO_2$ or $KAlSi_2O_6$. There are thus two molecules less silica than in potash-felspar· The mineral is liable to alteration, taking up water and soda and passing into analcite. Owing to the large amount of potash it contains and to the ease with which it weathers, an attempt has been made to use leucite as a fertilizing material in soils.

Leucite occurs as a constituent of certain recent volcanic lavas and ashes, being especially abundant in the products of Vesuvius (fig. 4, plate 61a, and figs. 1 and 2, plate 62); and at Rocca Monfina near Naples (fig. 3, plate 62). Loose crystals, from the lavas of the extinct volcanoes of the Albanian Hills, can be collected in large numbers at the Osteria del Tavolato on the Via Appia near Rome. It is also found, together with nosean, in the lavas of the neighbourhood of the Laacher See in Rhenish Prussia (fig. 3, plate 61a), at the Kaiserstuhl near Freiburg in Baden, and at Wiesenthal in Saxony.

Nepheline is essentially a sodium aluminium silicate, the formula for which may be expressed as $Na_8Al_8Si_9O_{34}$, or perhaps more simply as $NaAlSiO_4$. The composition is, however, never quite constant, and a small portion of the soda as invariably replaced by potash. Analyses also often show the presence of small amounts of lime, water, and chlorine, but whether these are chemically combined or present as mechanical impurities (crystals and solutions of sodium chloride have been observed as enclosures in nepheline) it is difficult to say.

The crystals are hexagonal, and are bounded by a hexagonal prism and the basal pinacoid (fig. 5, plate 62), sometimes with small pyramid planes in addition (fig. 4). Cross-sections of the crystals, as seen in thin slices or on fractured surfaces of the rock (fig. 5, plate 61a, and fig. 6, plate 62) are rectangular or six-sided. The fresh mineral is colourless and transparent with a glassy lustre, but when weathered it becomes cloudy with a dull white or yellowish colour. The index of refraction is low (1·54), and the double refraction is also feeble. Only rarely are the crystals so large as those represented in plates 61a and 62. Usually they are of microscopic dimensions; and in some cases, where the external form of the crystals is wanting, the mineral can only be detected by chemical means.

The nepheline present in coarsely crystalline rocks is of rather a special character, and this variety is known as *elaeolite*, a name derived from the Greek word for oil, in allusion to the characteristic greasy lustre of the stone. Its colour is greenish, bluish, or reddish. The bluish-grey mineral represented in fig. 7, plate 62, is elaeolite, the yellowish-grey material here shown being felspar.

Nepheline is not always an easy mineral to recognize, and, when the crystal-form or the colour and lustre afford no clue, resource must to made to chemical reactions. When the powdered mineral is warmed with hydrochloric acid it is very easily decomposed with gelatinization: and if the experiment is made with only a small quantity of acid the test-tube can be inverted without the substance being spilt. In a dilute solution of hydrochloric acid the mineral is completely dissolved. Nepheline is especially liable to alteration by weathering, giving rise usually to natrolite.

Attached crystals of nepheline are met with in cavities in the ejected blocks of Monte Somma, Vesuvius (figs. 4 and 5, plate 62), and also at the Laacher See. As embedded crystals, nepheline is widely distributed as an essential constituent of certain volcanic rocks (phonolite and nepheline-basalt); whilst the variety elaeolite is a constituent of the plutonic elaeolite-syenites of Norway, Greenland, Urals, Brazil, etc.

Greenish elaeolite has occasionally been cut as a precious stone, this being the only practical application of the mineral nepheline.

Scapolite. As we have already seen, nepheline is more complex chemically than leucite, and with scapolite the complexity is still greater. In addition to silica and alumina, the mineral always contains lime and soda in variable proportions, and also some chlorine. According to differences in chemical composition, several sub-species or varieties have been distinguished. The crystals of these are practically identical, being tetragonal with prisms of the first and second orders and a pyramid of the first order (fig. 13, plate 62), and they show, in the several varieties, only very slight differences in the angles between corresponding faces. Crystals are either water-clear or cloudy and of a white, greyish, or yellowish colour; the clear crystals are quite small, but the cloudy ones are often of considerable size. The mineral is rather susceptible to alteration, passing into epidote, albite, or mica.

The clear crystals occur in the ejected blocks of Monte Somma, Vesuvius, and of the Laacher See; and the larger, cloudy crystals in the crystalline schists of Arendal in Norway, Malsjö in Sweden, Laurinkari in Finland (fig. 13, plate 62), and other localities.

By reason of its crystalline form and chemical composition, *melilite* is a mineral which finds a place in the scapolite group. It occurs as microscopic crystals in certain basaltic rocks, in which it takes the place of felspar; in thin sections it is seen as colourless laths which give blue polarization colours. It contains more lime (32 % CaO) than any other calcium aluminium silicate.

Another closely allied mineral is *gehlenite* ($Ca_3Al_2Si_2O_{10}$), which occurs as grey tetragonal plates in crystalline limestones at their contact with igneous rock-masses. It is found at Monzoni in southern Tyrol, and the Kaiserstuhl near Freiburg in Baden.

Sodalite Group. The felspathoid minerals of this group are cubic in crystallization, and the usual form of the crystals is the rhombic-dodecahedron (text-fig. 220). They thus show a relation in form to the garnets, and some authors point also to a chemical analogy between these two groups. All contain the nepheline molecule $NaAlSiO_4$ in combination with another salt, the latter differing in the different species. Their hardness lies between 5 and 6, and the specific gravity varies from 2·2 to 2·5.

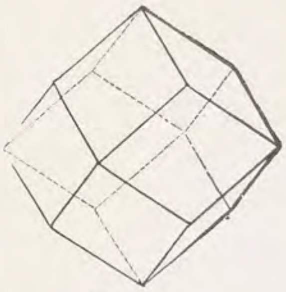

Fig. 220.
Crystal of Sodalite.

Sodalite occurs as colourless rhombic-dodecahedra in the cavities of certain volcanic rocks, particularly in the ejected blocks of Monte Somma (fig. 8, plate 62); or it forms irregularly shaped masses of a white or blue colour in certain plutonic rocks. These two varieties are analogous, in their modes of occurrence, to nepheline and elaeolite respectively, only sodalite is much less frequent. Warmed with acids it gelatinizes like nepheline; and when nitric acid is employed, the solution gives a white precipitate with silver nitrate, proving the presence of chlorine. This presence of chlorine, which amonts to 5 or 6 per cent., is the most characteristic feature of sodalite. The mineral may be considered as a chemical compound of sodium aluminium silicate with sodium chloride, the formula being $3\,NaAlSiO_4 . NaCl$.

Colourless sodalite in found in the ejected blocks of Monte Somma and as a constituent of trachyte in the island of Ischia near Naples. Massive sodalite occurs as a constituent of sodalite-syenite at Ditró in Transylvania, Brevig in Norway, Miask in the Urals, and in Greenland.

Nosean and *Haüyne.* Both of these minerals are named after mineralogists, the latter after the celebrated Abbé Haüy, the founder of scientific crystallography. They are not sharply separated from one another, and for this reason we will consider them together. Ideally, nosean is a compound of sodium aluminium silicate with sodium sulphate, and haüyne of the same silicate with calcium sulphate, their formulae being

Nosean, $3\,NaAlSiO_4 . Na_2SO_4$.
Haüyne, $3\,NaAlSiO_4 . CaSO_4$.

Neither mineral is, however, quite pure; nosean always contains some calcium sulphate, and haüyne some sodium sulphate; and further, in haüyne a portion of the sodium is often replaced by an equivalent amount of calcium. Both are readily decomposed by hydrochloric acid; and when a grain of the mineral is treated with a drop of acid on a microscope slide, and the drop allowed to evaporate, needles of gypsum will separate when haüyne has been used, whilst with nosean these will be formed in only small amount. Both minerals crystallize in rhombic-dodecahedra, and they sometimes differ in colour.

Nosean is usually brown or grey (fig. 9, plate 62); and in thin sections often colourless (fig. 6 plate 61a), but sometimes greyish, owing to the presence of vast numbers of minute gas pores, these being frequently arranged in lines and so giving the appearance of fine striations. The border is often brown and opaque and much indented by the groundmass of the rock, suggesting that the crystals were partly re-dissolved by the magma subsequent to their formation. Under these conditions, nosean occurs, together with leucite, in the phonolites of the Laacher See district, and as a constituent of certain basalts. The attached crystals are found in the ejected blocks of the Laacher See district.

Haüyne is, as a rule, blue in colour, and it is found as large, irregular masses in the millstone lavas of Niedermendig on the Rhine (fig. 10, plate 62). It is also found as small grains and crystals in the ejected blocks of the Laacher See district, in basaltic rocks

PLATE 63.

Zeolites I.

Fig.

1. **Apophyllite,** tetragonal prism of the second order with pyramid of the first order.
   Theigarhorn, Berufjord, Iceland.
2. **Apophyllite,** the same forms with large basal plane.
   Poona, Bombay, India.
3. **Apophyllite,** rose-red crystals.
   Andreasberg, Harz Mountains, Germany.
4. **Apophyllite,** tilted to the front to show the large basal plane; on the edge are the prism of the second order and the pyramid of the first order.
   Nasik, Bombay, India.
5. **Apophyllite,** group of large crystals on basalt; with prism of the second order (large and vertically striated), eight-sided prism $\infty P 2$ (small), pyramid of the first order, and basal plane. Cleavage cracks parallel to the base are shown.
   Poona, Bombay, India.
6. **Apophyllite,** combination of the prism of the second order, pyramid of the first order, and the basal plane, all developed to the same extent, and forming an apparent cubo-octahedron.
   Paterson, New Jersey, U. S. A.
7. **Apophyllite,** thin, platy crystals, tabular parallel to the base.
   Seisser Alp, southern Tyrol.
8. **Chabazite,** isolated rhombohedron.
   Sandö, Færoe Islands.
9. **Chabazite,** rhombohedra on matrix.
   Rübendörfel, Bohemia.
10. **Chabazite,** red rhombohedra.
    Nova Scotia, Canada.
11. **Analcite,** icositetrahedra with native copper.
    Cliff mine, Lake Superior, Michigan, U. S. A.
12. **Analcite,** reddish icositetrahedron.
    Seisser Alp, southern Tyrol.
13. **Heulandite,** crystals on matrix.
    Iceland.


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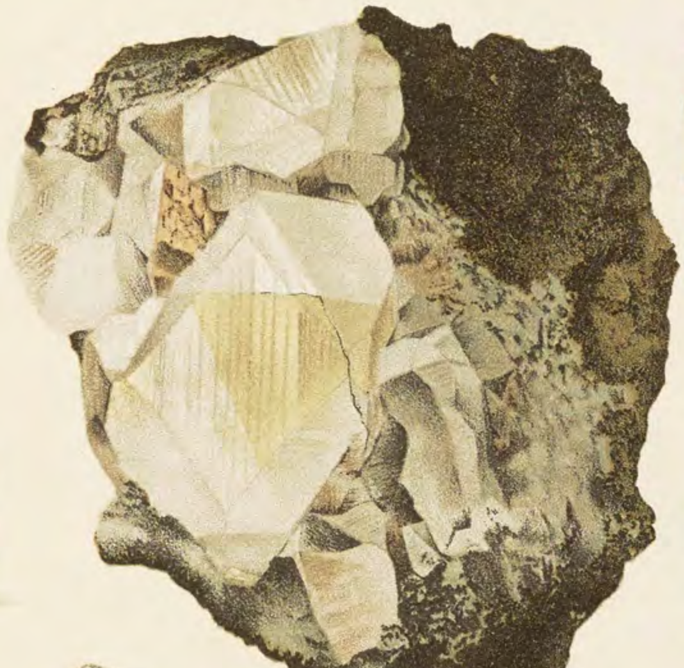
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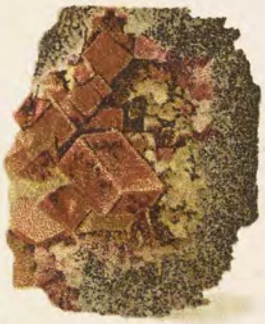
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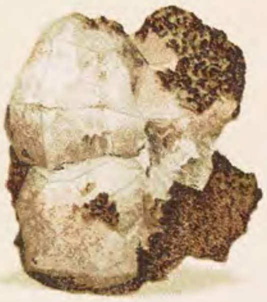
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In its chemical composition apophyllite is somewhat complex. In addition to silica, water, and lime, there is also some potash and usually a little fluorine. Half of the water is expelled at about 240° C., while the remainder, being chemically combined, is expelled only at a red-heat. The formula is consequently written as $H_2(Ca, K_2)Si_2O_6 + H_2O$. When weathered, the mineral gives rise to calcium carbonate, and sometimes the original form of the crystal is not thereby destroyed: such altered crystals are white and dull and have been called *albine*; they are found at Aussig in Bohemia.

As to the physical characters of apophyllite, mention has already been made of the perfect cleavage parallel to the basal plane. On account of this cleavage, the lustre on the basal plane and on cleavage fragments is markedly pearly in character. This whitish pearly aspect, resembling the eye of a fish after boiling, gave rise to the name ichthyophthalmite, or fish-eye-stone. On the other faces of the crystals the lustre is vitreous. A cleavage flake when examined in convergent polarized light shows the interference-figure of a uniaxial crystal, but rings are only seen when the plate is of some thickness, since the double refraction is very low. Further, the rings, as seen with ordinary daylight, are not brilliantly coloured but alternately white and violet-black; this being due to a pecularity in the dispersion. Crystals are colourless, or pale shades of rose-red, yellow, or green. The specific gravity is 2·3 to 2·4, and the hardness between 4 and 5.

Before the blowpipe, apophyllite exfoliates and is readily fused. It is soluble in superheated water; and when the powdered mineral is heated with water in a sealed tube at about 190° C. the material can be re-crystallized. In nature the mineral must have had the same kind of origin in the cavities of volcanic rocks and in mineral-veins; while it has actually been observed as a deposit from the waters of certain hot springs.

In mineral-veins it occurs at the Samson mine at St. Andreasberg in the Harz (fig. 3, plate 63), and at Guanaxuato in Mexico. In the amygdaloidal cavities of eruptive rocks it is found at Aussig in Bohemia, the Færoe Islands, Co. Antrim, Skye, Iceland (Fig. 1), and at Paterson in New Jersey (fig. 6). The largest crystals are those formerly found near Poona in Bombay (figs. 2, 4, and 5).

Chabazite. This mineral may readily be recognized by the characteristic shape and twinning of its crystals. These are cube-like rhombohedra which are usually twinned with interpenetration, corners of one individual projecting from the faces of the other (text-fig. 223, figs. 8—10, plate 63). The twin-plane is the base, and the twin-axis, perpendicular to this, is concident with the principal axis of the rhombohedral crystal: one individual is turned about this axis through 180° with respect to the other individual. Crystals of another habit are also commonly found: these are lenticular in shape, owing to the predominance of a low hexagonal pyramid, and are known as *phacolite*.

Crystals of chabazite, and of its variety phacolite, are colourless, white, yellow, or red (fig. 10, plate 63); the red colour being due to enclosed ferric oxide. They have a vitreous lustre, and are frequently much fissured in their interior. Their specific gravity is 2·1, and their hardness 4—4½.

Fig. 223.
Twinned crystal of Chabazite.

The chemical composition of chabazite is somewhat variable, and must be explained as the result of the mixing together of two compounds in variable proportions. The nature of these fundamental molecules must be deduced from the results of several analyses, and different investigators have come to different results. The following formula assumes one of these molecules to have the composition of lime-felspar, and the other that of soda-felspar but with lime in place of soda, each molecule being combined with eight molecules of water.

$$m\,Ca_2Al_4Si_4O_{16}\,.\,8\,H_2O + n\,CaAl_2Si_6O_{16}\,.\,8\,H_2O.$$

Chabazite occurs in the amygdaloidal cavities of volcanic rocks, and is often associated with phillipsite and calcite, or sometimes with quartz and agate. It is found, for instance, in the amydaloidal basalts at Nidda and many other places in the Vogelsberg, at Oberstein in Germany, in Co. Antrim, and at Kilmalcolm in Renfrewshire. The isolated crystal shown in fig. 8, plate 63, is from the island of Sandö, one of the Færoe Islands; the crystals on phonolite in fig. 9 from Rübendörfel in Bohemia; and the red crystals in fig. 10 from Nova Scotia. The phacolite variety is found at the same localities, and also at Richmond in Victoria, Australia.

Analcite is very similar in the form of its crystals to leucite, and moreover it may be regarded chemically as a hydrated sodium-leucite. The most frequent form is the regular icositetrahedron 2*O*2 (text-fig. 19, p. 23, and figs. 11 and 12, plate 63). Sometimes we find the icositetrahedron in combination with the cube (text-fig. 224). Twinning does not occur, and the crystals are thus quite simple in their form.

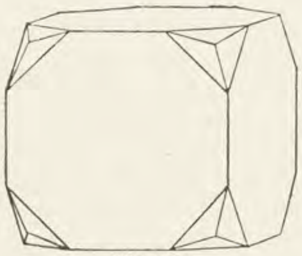
Fig. 224.
Crystal of Analcite.

The chemical composition of fresh unaltered analcite can be expressed by the formula $Na_2Al_2Si_4O_{12}\,.\,2\,H_2O$. A comparison of this with the formula of leucite ($K_2Al_2Si_4O_{12}$) shows the replacement of potash by soda and the addition of water. It is indeed possible by artificial means to convert leucite into analcite, by simply immersing the mineral for a long period in a solution of sodium carbonate. The same process also takes place in nature, for at Kaiserstuhl in Baden we find icositetrahedra which were originally leucite, but now composed of analcite. These two minerals may be distinguished by the following tests: analcite fuses before the blowpipe, whilst leucite does not; heated in a bulb-tube, analcite gives off water, whilst leucite does not; the specific gravity of analcite is 2·2, and that of leucite 2·5.

Crystals of analcite are sometimes colourless and transparent, but more usually they are white and cloudy; sometimes they are reddish, the colour being either uniform in distribution or patchy and veined (fig. 12, plate 63). The mineral occurs principally in the cavities of basaltic rocks, either alone or in association with apophyllite. Water-clear crystals are found in amygdaloidal cavities and also embedded in dolerite in the Cyclopean Islands near Catania in Sicily. Clear crystals are also found at Monti Catini in Tuscany, and Lake Superior in North America (fig. 11). Crystals of especially large size are from the Seisser Alp in Tyrol (fig. 12). The mineral is also common in Co. Antrim and at several places in Scotland. A remarkable occurrence is in clay-iron-stone at Duingen in Hannover; and it has also been found in the mineral-veins of St. Andreasberg in the Harz.

Another cubic zeolite, which may be mentioned here, is the rare *faujasite*; this occurs as small, white or brown, octahedra and spinel-twins in cavities in basalt at Grossenbuseck near Giessen in Hesse, and Kaiserstuhl in Baden.

Heulandite. Crystals of heulandite (fig. 13, plate 63) are monoclinic with usually a thick tabular habit parallel to the plane of symmetry. On this plane the lustre is strongly pearly, since parallel to it there is a perfect cleavage: the other faces of the crystals have a vitreous lustre or are dull. The large faces at the sides belong to the basal pinacoid and the ortho-pinacoid, and the small triangular faces are pyramid faces. The crystals are either white or greyish, but sometimes they are brick-red, owing to the enclosure of haematite (like the crystals of chabazite in fig. 10). The specific gravity is 2·2, and the hardness $3^1/_2$—4.

PLATE 64.

Zeolites II.

Fig.
1. **Stilbite,** large, sheaf-shaped crystals.
   Færoe Islands.
2. **Phillipsite,** white crystals in amygdaloidal cavities in basalt.
   Stempel, Marburg, Hesse.
3. **Harmotome,** twinned crystals with grooved edges.
   Andreasberg, Harz Mountains, Germany.
4. **Natrolite,** radially fibrous with concentric structure; on phonolite.
   Hohentwiel, Würtemberg.
5. **Natrolite,** globular with radially fibrous structure; white inside and yellowish outside.
   Aussig, Bohemia.
6. **Thomsonite,** columnar with radial arrangement.
   Kilpatrick, Dumbartonshire, Scotland.
7. **Prehnite,** globular with internal radial structure.
   Monte Rodella, Fassathal, Tyrol.
8. **Prehnite,** curved aggregates of crystals.
   Bourg d'Oisans, Isère, France.
9. **Datolite,** isolated, colourless crystal.
   Serra dei Zanchetti, Bologna, Italy.

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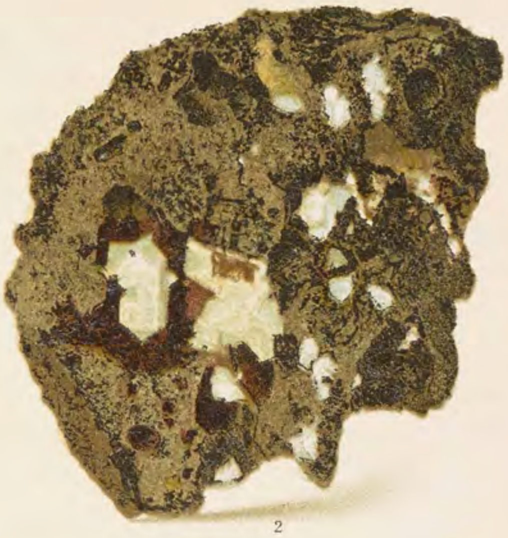

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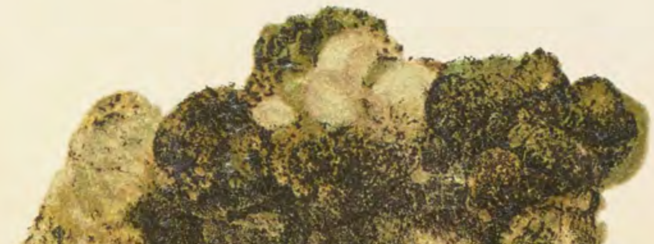

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The chemical composition can here again be best expressed by reference to the felspars, and we may regard the mineral as a compound of the second lime-felspar assumed above for chabazite with five molecules of water, the formula thus being $CaAl_2Si_6O_{16} . 5\,H_2O$. A portion of the lime is usually replaced by a little soda and potash, and less frequently by strontia. The mineral is readily decomposed by acids, and before the blowpipe it fuses to a white enamel.

Heulandite occurs in the amygdaloidal cavities of basaltic rock in Iceland (fig. 13, plate 63), the Færoe Islands, Scotland, and elsewhere. Red crystals are from the Fassathal in Tyrol. In veins in granitic rocks it is found on the Giebelbach in Wallis, Switzerland, and at Striegau in Prussian Silesia; and in mineral-veins at St. Andreasberg in the Harz.

Another zeolite containing the same chemical constituents as heulandite, but combined in different proportions, is *laumontite*. This is noteworthy from the fact that the crystals when exposed to the air soon fall to powder, this change being due to a gradual loss of a portion of the water contained in the crystals. Specimens must therefore be kept in a moist atmosphere over water, or they must be protected with a coat of varnish. The crystals are monoclinic with a prismatic habit and are terminated by an obliquely-placed basal plane. They are found in crevices in granitic rocks at Baveno, Zillerthal, and Striegau.

Stilbite, Phillipsite, and Harmotome. These three species of zeolites, being closely related both in crystalline form and chemical composition, may be conveniently described together in one group. The composition of the silicate portion may, as before be compared with that of the felspars, and in all three minerals this is combined with six molecules of water. Stilbite and phillipsite differ in the relative proportions of their constituents, whilst harmotome contains barium. In all of them a portion of the calcium or barium is replaced by some sodium or potassium. The formulae are: —

$$\text{Stilbite} \;.\;\; . \quad CaAl_2Si_6O_{16} . 6\,H_2O$$

$$\text{Phillipsite} \;. \quad \left\{\begin{matrix} CaAl_2Si_6O_{16} . 6\,H_2O \\ Ca_2Al_4Si_4O_{16} . 6H_2O \end{matrix}\right\}$$

$$\text{Harmotome} \quad \left\{\begin{matrix} BaAl_2Si_6O_{16} . 6\,H_2O \\ Ba_2Al_4Si_4O_{16} . 6H_2O \end{matrix}\right\}$$

From these formulae we see that chemically phillipsite differs from chabazite only in containing six molecules of water instead of eight, and that stilbite is the same as heulandite with an extra molecule of water.

In their crystallization all three minerals show a certain relation to the felspars; they are monoclinic and invariably twinned. The faces shown in text-figs. 225 and 226 are those of the vertical prism *m*, the clino-pinacoid *b*, and the basal pinacoid *c*; those of the two former are striated parallel to their mutual intersection, as indicated in the figures. The angle between the faces of the vertical prism is 118° 50′ (the corresponding angle in orthoclase being 118° 47′).

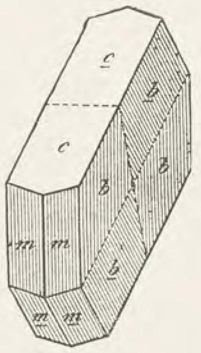

Fig. 225.
Twinned crystal of Stilbite.

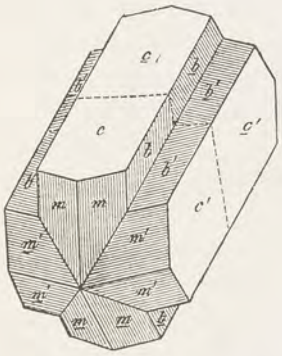

Fig. 226.
Twinned crystal of Phillipsite (or Harmotome).

The twinning is also in part analogous to that of the felspars. The three following twin-laws are to be distinguished. *First twin-law*, with the basal plane as the twin-plane (as in the Manebach twins of felspar). The two individuals are united along the basal plane, and the two portions shown to the front in text-fig. 225 are repeated cross-wise at the back; in the figure the face letters of one individual are underlined. The clino-pinacoid coincides in the two individuals and now bears feather-like striations. Stilbite frequently occurs in crystals with this form. *Second twin-law*, with a clino-dome face as twin-plane (as in the Baveno twins of felspar). Two crystals, each already twinned according to the first law, are twinned together with interpenetration (text-fig. 226) in such a manner that a clino-dome face (a face which, if present on the crystals, would truncate the edge between the faces *b* and *c*) is coincident in the two individuals. The compound crystal produced by this double twinning presents the appearance of a tetragonal prism with grooved edges combined with a pyramid of the opposite order (compare text-fig. 178, p. 227). If the basal plane *c* be more largely developed relatively to the clino-pinacoid *b*, the latter will be suppressed, and in the absence of the grooved edges the compound crystal will appear still more like a simple tetragonal crystal. The presence of twinning will, however, always be rendered evident by the feather-like striations on the prism faces *m*. Twinned crystals of this kind are especially common in harmotome (fig. 3, plate 64) and phillipsite (fig. 2, plate 64). *Third twin-law*, with a face of the vertical prism as twin-plane. Three of the compound crystals produced by the last twin-law are now twinned together with interpenetration on two of the prism faces of one of them. The result is a complex group consisting of twelve simple individuals (text-fig. 227). When the simple crystals are of a thin tabular habit there are several re-entrant angles; but with thicker crystals and when the material so grows that the spaces are filled up, we then have a completely closed crystal, resembling a rhombic-dodecahedron, bounded on all sides by the striated prism faces (text-fig. 228). We have here an excellent example of how the degree of symmetry of a crystal may be apparently increased by twinning. The first twinning (fig. 225) produces a pseudo-rhombic crystal, the second (fig. 226) a pseudo-tetragonal, and the third (fig. 228) a pseudo-cubic crystal, and yet each of these is built up of monoclinic individuals. The presence of this complex twinning is indeed sometimes only suspected when the crystals are closely examined with a lens and the directions of the striations on the faces carefully noted.

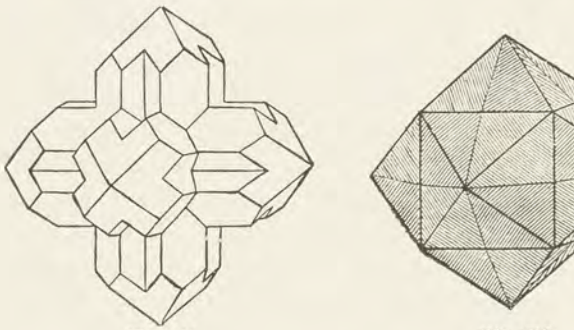

Fig. 227. Fig. 228.

Complex twinned crystals of Phillipsite.

Stilbite is usually found as sheaf-shaped crystals or aggregates of crystals (fig. 1, plate 64), and the name desmine sometimes applied to the species has reference to this form (δέσμη, a bundle). The sheaf-shaped structure is due to a sub-parallel grouping of several of the simple twinned crystals shown in text-fig. 225. Parallel to the clino-pinacoid *b* there is a perfect cleavage on which the lustre is pearly: on other faces the lustre is vitreous. The colour is white or yellowish, or sometimes brick-red or brown. Stilbite is found in amygdaloidal cavities in the volcanic rocks of Iceland, the Færoe Islands, Scotland, Nova Scotia, etc. Brick-red crystals come from Kilpatrick in Dumbartonshire, and large pink crystals with apophyllite from Poona in Bombay. In drusy cavities in granitic rocks it is found at Striegau in Prussian Silesia, and at several places in Switzerland; and in mineral-veins at St. Andreasberg in the Harz.

Phillipsite forms complex twins of the forms shown in text-figs. 226—228; these are usually quite small, rarely exceeding 1 cm. in length. They are white or yellowish, and either brilliant or dull; the specific gravity is 2·2. This mineral receives its name from the English mineralogist William Phillips. It is found in the cavities of basalt in County Antrim, at Stempel near Marburg in Hesse (fig. 2, plate 64), at Richmond in Victoria, Australia, and elsewhere.

Harmotome is popularly known as cross-stone, on account of the characteristic shape of its twinned crystals (text-fig. 226, and fig. 3, plate 64). In some crystals, however, when the grooves are not present, the crossed form is not evident. Since it contains the heavier metal barium, the specific gravity (2·5) of harmotome is higher than that of the other zeolites. The colour is white, grey, or yellowish, and the lustre vitreous. The crystals are usually very sharply developed and may attain a length of a couple of centimetres. Excellent crystals are found in mineral-veins at Strontian in Argyllshire, St. Andreasberg in the Harz, and Kongsberg in Norway. It is also found in agate geodes from the melaphyre of Oberstein in Germany.

Phillipsite and harmotome are extraordinarly similar in the shape of their complex twinned crystals and in external appearance generally: they may be readily distinguished by means of their specific gravity or by a chemical test for calcium or barium. To test for barium, the powdered mineral is decomposed with hydrochloric acid, and to the diluted solution a drop of sulphuric acid is added, when with harmotome a heavy white precipitate of barium sulphate is formed.

Natrolite. As implied by its name, this mineral contains the metal sodium or natrium, the chemical symbol of which is Na. The name sodalite, applied to another mineral (p. 301), has the same meaning. In addition to soda (i.e. sodium oxide), natrolite contains alumina and silica, together with water, the chemical formula being $Na_2Al_2Si_3O_{10} . 2H_2O$. The presence of sodium in the mineral is readily demonstrated by the bright yellow colour which it imparts to the colourless flame of the Bunsen-burner. A fragment of the mineral when held in the flame quickly fuses to a colourless glass, and produces the same yellow flame-coloration as that given by common salt (sodium chloride). Other characteristic chemical reactions of natrolite are the following. The powdered mineral gelatinizes when warmed with a little hydrochloric acid in a test-tube. When heated in a bulb-tube, abundance of water condenses on the cool sides of the tube.

Crystals of natrolite usually have the form of very thin and delicate needles. These are sometimes grouped in small tufts, or they may thickly encrust the surface of the rock. The crystals belong to the rhombic system; but they present quite the appearance of tetragonal crystals, since the angle of the rhombic prism differs but slightly from a right angle, being $91\,^1/_4{}^0$. Further, they are terminated by the four faces of a low rhombic pyramid, which does not differ, so far as can be judged by the eye, from a tetragonal pyramid. Frequently, however, the crystals are closely grouped together to produce compact, radially-fibrous aggregates with a rounded surface, and sometimes also a concentric shelly structure.

The colour is white or yellow, rarely red or green. In the radiating masses there is sometimes a concentric banding of different colours. The hardness is greater than 5; instances in which it is apparently less than this may be explained by the breaking away of the individual fibres of the more or less incoherent aggregate. The specific gravity is 2·2 to 2·25.

Natrolite occurs as a product of the alteration of felspar, and more especially of nepheline and haüyne; and as such it is met with in the steam-cavities of certain lavas, especially basalt and phonolite. Well-known localities are: in the phonolite of Hohentwiel in Würtemberg (plate 64, fig. 4); the Alpstein, near Sontra in Hesse; the Stempel, near Marburg in Hesse (here not now to be found); Aussig in Bohemia (plate 64, fig. 5); as large, rough crystals at Brevig in Norway; as thick growths of delicate needles on the basalt of County Antrim in Ireland; as delicate tufts of hair-like crystals in the Færoe Islands; and as beautiful groups of distinctly-developed, water-clear crystals at the Puy de Marman in the Auvergne. Several other localities might be mentioned, natrolite being, in fact, one of the most abundant of the zeolites, though rarely occurring as distinct crystals.

The prettily coloured and banded natrolite from Hohentwiel (plate 64, fig. 4) has occasionally been cut and polished as a semi-precious stone for ornamental purposes. Being fairly hard and compact, this finely fibrous material takes a good polish. It has been used as a wainscotting in the rooms of the royal palace at Stuttgart. The German poet Joseph Viktor von Scheffel (1826—1886) has given an account of the legend of how the youth Audifax, when rooting up a bush, laid bare the yellow veins which penetrate the grey rock of the mountain.

Closely allied to natrolite are a few other zeolites which may be briefly mentioned in this place. *Scolecite* contains lime in place of soda, and the silicate is combined with three molecules of water of crystallization. Its crystals, although very like those of natrolite in form, are in reality monoclinic, but by twinning they closely simulate the rhombic form. The best crystals come from Theigarhorn in Iceland. *Mesolite* contains the chemical constituents of both natrolite and scolecite. It usually forms finely fibrous masses, which can be distinguished from natrolite only by a determination of the optical characters under the microscope. *Thomsonite* also consists of a calcium aluminium silicate and sodium aluminium silicate with water of crystallization, the formula being $(Ca, Na_2)_2 Al_4Si_4O_{16} . 5H_2O$. This zeolite usually forms radially columnar aggregates (plate 64, fig. 6); but sometimes the aggregates are finely fibrous, with a concentric shelly structure in addition to the radially fibrous. In the latter case the mineral bears a strong resemblance to natrolite (plate 64, fig. 4), although it usually differs from this in colour. Large, radially columnar masses of thomsonite, often with a delicate rosy tinge of colour, have been found at Kilpatrick in Dumbartonshire. Thomsonite showing concentric bands of lighter and darker red, green, and white colours is found in amygdaloidal diabase at Grand Marais, Lake Superior. Small pebbles of this material collected from the shore are polished for use in jewellery.

Prehnite. Although prehnite contains some water and boils up when heated before the blowpipe, it is not as a rule classified with the zeolites, since its water is expelled only at a high temperature. We may, however, consider it in this place because it occurs together with the zeolites, and has been formed like them by the alteration of felspar. If we consider the water to be present as such in the mineral, we see that the formula of prehnite presents a certain analogy to that of natrolite, the two formulae being:

Natrolite . . .	$Na_2O . Al_2O_3 . 3\,SiO_2 . 2\,H_2O.$
Prehnite . . .	$2\,CaO . Al_2O_3 . 3\,SiO_2 . H_2O.$

Usually, however, the formula of prehnite is written in the form $H_2Ca_2Al_2Si_3O_{12}$, in which the hydrogen is basic and plays the part of a metal. When the mineral is heated, this hydrogen is expelled in the form of water, although it does not actually exist as such in the mineral.

That prehnite is not so closely related to the zeolites as these are one to another is also suggested by the colour. Prehnite is always greenish, whilst the zeolites are characteristically colourless or white, although they are sometimes reddish or yellowish, due to the presence of mechanically admixed iron oxide or hydroxide. In prehnite, on the other hand, a small amount of iron oxide is often present in chemical combination replacing an equivalent amount of aluminia.

Crystals of prehnite belong to the rhombic system; when found, which is only very exceptionally, they usually have the form of small rhombic plates flattened parallel to the basal plane. Much more frequently the mineral forms aggregates similar to those of natrolite, with globular surfaces and a radially fibrous structure internally (plate 64, fig. 7). Fan-shaped and cockscomb aggregates of crystals are also characteristic.

The hardness is 6, exceeding that of the zeolites, whilst the specific gravity of 2·8 to 2·9 is considerably higher than for any of the zeolites.

Prehnite is found in the steam-cavities of ancient volcanic rocks and of intrusive igneous rocks, such as diabase and melaphyre. It usually occurs in association with quartz, calcite, albite, less often with datolite, and sometimes with native copper. Less frequently, it is found in veins traversing granite and gneiss. A few of the many known localities for this mineral are: Niederscheld near Dillenburg, and Friedensdorf near Biedenkopf, in Hesse-Nassau; the Radauthal near Harzburg in the Harz; the Fassa valley in Tyrol (plate 64, fig. 7); Bourg d'Oisans, Isère, France (plate 64, fig. 8); as fine specimens in the ancient volcanic rocks at several places in the neighbourhood of Edinburgh and Glasgow; as large masses at Cradock in Cape Colony, where the mineral was first found towards the end of the eighteenth century by Colonel Prehn, after whom it was named.

A peculiar mineral called *chlorastrolite* is sometimes referred to prehnite, although it is perhaps more correctly considered as a variety of thomsonite. This is found as small pebbles, the size of a pea or hazel-nut, on the shores of the Isle Royale in Lake Superior, having been washed out of the amygdaloidal trap rocks of the Island. These pebbles show on their surface light and dark green colours with a peculiar reticulated pattern similar to that on a serpent's skin. In the interior they show a finely fibrous radiated structure. They take a good polish and when cut with a rounded surface often display a kind of cat's-eye effect. They are much sought for by collectors and in America are often worn in jewellery.

Datolite. Our reason for considering datolite with the zeolites is that, like these, it is a mineral of secondary origin in the cavities and crevices of basic volcanic rocks. It also, when heated before the blowpipe, swells up, owing to the expulsion of water, though to not so marked a degree as do the zeolites. In chemical composition, however, it differs very markedly from the zeolites. Like apophyllite (p. 302), it contains no aluminium, an element present in all the zeolites; on the other hand, the elements boron and fluorine present in datolite and apophyllite respectively, do not occur in the zeolites. In its chemical formula, as also in the form of its monoclinic crystals, datolite presents a close analogy to the rare mineral euclase (p. 233). In the datolite formula $HCaBSiO_5$ calcium and boron take the place of beryllium and aluminium respectively in the euclase formula $HBeAlSiO_5$.

Crystals of datolite are usually bounded by a profusion of small, brilliant faces, and they afford excellent material for crystallographic study and measurement on the reflecting goniometer. An isolated crystal with relatively few faces is represented in fig. 9, plate 64. In this crystal the faces set vertically are prism faces; above these and to the front is a large ortho-dome face; at the sides are pyramid faces; and at the top a small basal plane. As a rule the crystals are colourless and transparent with a brilliant glassy lustre, and they occur closely crowded together forming a crystallized crust on the surface of the matrix. Such specimens are little suited for pictorial representation. Larger crystals are also found, and these are frequently tinged with green. The specific gravity of the mineral is 2·9—3·0, and its hardness 5. With hydrochloric acid it gelatinizes, like the zeolites.

Datolite is usually found as crystals lining the crevices of igneous rocks such as diabase, melaphyre, and diorite. Less often it is found in mineral-veins. Localities are:

Andreasberg in the Harz; Baveno on Lago Maggiore in the north of Italy, here as large crystals of tabular habit; Serra dei Zanchetti in the Apennines near Bologna (plate 64, fig. 9); in the neighbourhood of Edinburgh and Glasgow; Arendal in Norway; Bergen Hill in New Jersey.

Kaolin and Clay.

Kaolin. The zeolites (p. 302) may be regarded as intermediate products formed by the alteration of felspars and felspathoid minerals. As proved by experiments, this alteration may have been effected by springs of hot water or by the action of mineral solutions in the earth's crust. The zeolites do not, however, represent the final products of weathering. When felspar is exposed to the prolonged action of water and carbon dioxide, the alkalis and alkaline earths contained in it are removed, and there remains behind the hydrated aluminium silicate known as kaolin or china-clay. The complete decomposition of potash-felspar by the processes of weathering near the earth's surface is accompanied by the leaching out of the potash in a soluble form as carbonate or silicate. This is removed in solution and is of importance as affording nourishment for plants. At the same time a portion of the silica of the felspar is set free, and this often separates as quartz in the immediate neighbourhood. The remainder takes up water, giving rise to the formation of kaolin. This change may be represented in outline as follows:

Felspar	K_2O .	Al_2O_3 .	$6\ SiO_2$	
Removal of	K_2O		$4\ SiO_2$	
Addition of				$2\ H_2O$
Residual product . .		Al_2O_3 .	$2\ SiO_2$.	$2\ H_2O$.

These constituents of the residual product may be written in the form $H_4Al_2Si_2O_9$, representing the chemical formula of kaolin. It is by such a process, at or near the earth's surface, that kaolin has been formed; but in exceptional cases the larger deposits of pure kaolin may have originated by the action of hot springs containing carbon dioxide in solution.

In a pure condition kaolin is a white, earthy, and friable material, which is quite soft and light. It is plastic when moistened with water, and before the ordinary blowpipe it is not fusible. At a still higher temperature it frits together, and is then no longer capable of taking up water. It is on these characters that the use of kaolin in the manufacture of porcelain depends; and the purer the material the more suitable it is for this purpose. Crystallized kaolin, which is sometimes distinguished by the name kaolinite, is of extremely rare occurrence. It has been found in only small quantities as a white, glistening powder in rock cavities at a few localities. Under the microscope these crystals are seen to have the form of thin, six-sided scales.

Deposits of kaolin are of wide distribution in Saxony. That at Aue has been completely exhausted in supplying material for the porcelain works at Meissen. At Meissen itself kaolin occurs in conjunction with pitchstone — a glassy igneous rock — the felspar of which is in places completely weathered to kaolin. Such a crude china-clay contains, for example, 57·46 % of clay substance, 41·11 % of quartz, and 1·43 % of unweathered felspar. The purified china-clay separated from this by washing in water contains 56·15 % silica, 32 % aluminia, 10·81 % water, 0·64 % ferric oxide, 0·33 % lime, and 0·47 % potash. Deposits of china-clay are also found at Passau in Bavaria, at Morl near Halle, etc. Those at St. Yrieix in France, in Cornwall and Devon, and in China are of special importance.

Clay. The conditions under which the processes of weathering take place are such that the resulting kaolin is very liable to be contaminated with other minerals. At its place of origin it is intermixed with fragments of unweathered felspar and grains of quartz in greater or lesser amounts, these having been derived from the same weathered rock mass that gave rise to the kaolin itself. Being in a state of very fine division this kaolin is readily removed by running water, and it so becomes intermixed with quartz-sand, and various other materials of a calcareous, ferruginous, or carbonaceous nature. When such a heterogeneous mixture contains a predominating amount of the kaolin substance it is called *clay*; when sand and iron oxides are largely present it is a *loam* or brick-earth; and when calcareous material is present in larger amounts it is a *marl*. These, being mechanical mixtures, are clearly of the nature of rocks rather than simple minerals; and they only receive mention in this place because of their great economic importance. Marl, although of high value in soils, cannot, on account of its calcareous nature, to put to the some technical uses as clay and loam.

Applications of Clay and Kaolin. — From loam and impure clays bricks and tiles are made, and from clays, according to their degree of purity, the less valuable pottery, earthenware, Delft-ware, and fire-proof vessels. After shaping the clay into the desired form, it is dried and baked. When the vessel is to be impervious to water, it is coated with a material which will produce a glaze during the burning. The glaze has much the same composition as a glass, and by the addition of various metallic oxides it can be produced of any desired colour. Blue is obtained with smalt, yellow with antimony sulphide, brown and black with iron and copper oxides, and white with tin oxide. The majority of these articles being for ordinary use are of a single colour or they are painted with a rough pattern. From the same materials ornamental objects of artistic merit can be fabricated. Examples of work of this kind by Luca della Robbia and of Andrea della Robbia are to be seen at Florence; such as the valuable figures of children on the foundling hospital and the enormous reliefs of the Madonna. The highly-prized Majolica-ware is also made of clay skilfully and artistically glazed.

Fire-proof objects are made from a clay which contains no felspar, lime, or iron, and which does not fuse, but only sinters, at the highest temperature. From such material are made fire-bricks for lining furnaces, and Hessian and Passau crucibles (the latter made of a mixture of fire-clay and graphite) used in glass works and for various other purposes where high temperatures are employed.

The finest kind of ware, known as porcelain, is made from kaolin containing some admixed felspar and quartz. The objects when formed in the white china-clay are first gently baked; then immersed in water and dusted over with powdered felspar; and finally, after drying, they are raised to a white-heat. At this very high temperature the felspar becomes fused and penetrates into the pores between the particles of clay; on cooling it solidifies as a glass, so giving to the porcelain its characteristic translucency. The fire-resisting colouring materials are applied before the second burning, and some others are burnt in subsequently at a more gentle heat.

Pyroxene Group.

All the rock-forming minerals as well as their products of weathering so far considered are free from iron; and for this reason they are, with few exceptions, of pale colours. Those to be now described almost always contain iron, and they are consequently of darker colours. On these lines we can thus distinguish between the lighter and the darker coloured rock-forming minerals. Amongst the latter there are several minerals exhibiting similarities in chemical composition and crystalline form which enable them to be classified into certain well-defined groups. The most important groups of this kind are the pyroxene, amphibole, mica, chlorite, and olivine groups. These will each be considered in turn in the arbitrary order in which they have just been named.

The minerals of the pyroxene group are for the most part silicates of magnesium and iron, and certain members of the group are composed entirely of these (enstatite, bronzite, and hypersthene). The magnesia and iron (ferrous) oxide are present in variable proportions, but their combined molecular ratios is always equal to the molecular ratio of the silica; that is, the ratio of the bases to the acid is as 1 : 1. For example, $MgO : SiO_2 = 1 : 1$, corresponding with the formula $MgSiO_3$. Other minerals of this group contain lime in addition to magnesia and ferrous oxide; and these are present in such proportions that the molecular ratio of the magnesium and iron silicate taken together is the same as that of the calcium silicate (diopside). In other members aluminia may also be present (augite), and it is usual to distinguish between aluminous pyroxenes and those which contain no aluminia. Less closely related minerals of the pyroxene group are those containing alkalis (spodumene and acmite), or lime without magnesia (wollastonite), or manganese (rhodonite). The first-named members are rhombic, the last is triclinic, whilst all the others are monoclinic in crystallization. Collecting these remarks, we may now give the following summary of the minerals of the pyroxene group:

1. Enstatite, Bronzite, and Hypersthene, $MgSiO_3$ (or $Mg_2Si_2O_6$) with a successively increasing proportion of $FeSiO_3$ (or $Fe_2Si_2O_6$): rhombic.
2. Diopside and Hedenbergite, $Ca(Mg, Fe)Si_2O_6$ with an increasing amount of iron: monoclinic.
3. Augite and Diallage, $Ca(Mg, Fe)Si_2O_6 . (Mg, Fe)(Al, Fe)_2SiO_6$: monoclinic.
4. Spodumene, $LiAlSi_2O_6$, and Acmite, $NaFeSi_2O_6$: monoclinic.
5. Wollastonite, $CaSiO_3$: monoclinic.
6. Rhodonite, $MnSiO_3$: triclinic.

Of these, rhodonite has already been described with the ores of manganese (p. 171): and the others will now be described in the order here named. Their relation to the amphiboles will be discussed in that group.

Enstatite, Bronzite, and **Hypersthene** consist of isomorphous mixtures of magnesium silicate with ferrous silicate in varying proportions. Enstatite contains up to 5 per cent. of ferrous oxide, bronzite 5 to 15 per cent. and hypersthene 15 to 30 per cent. The pure magnesium silicate would contain theoretically 40 per cent. magnesia and 60 per cent. silica; and the pure ferrous silicate 54·4 per cent. ferrous oxide with 45·6 per cent. silica. These pure end members of the series are, however, not known as minerals. The colour of these minerals depends on the amount of iron that enters into their composition: enstatite is white, yellowish, or greenish (plate 65, fig. 1), bronzite green or brown, and hypersthene is dark green or blackish-brown (plate 65, fig. 2). In addition to these body-colours, bronzite exhibits a metallic bronze-like lustre, and hypersthene a metallic coppery sheen. These metallic reflections are caused by numerous thin scales of a dark coloured mineral (supposed to be ilmenite) embedded in the material and arranged parallel to certain crystallographic planes (text-fig. 229). As the mineral readily breaks along these directions, the metallic reflection is especially well shown on these surfaces of separation. In addition, there are also two directions of true cleavage parallel to the faces of the vertical prism, which are inclined to one another at nearly a right angle (88°).

The specific gravity of these minerals varies, like the colour, with the amount of iron present; ranging from 3·1 in enstatite to 3·5 in hypersthene. The hardness is between 5 and 6 for all. When weathered they become softer, and pass into serpentine, talc, or steatite. Fig. 1 of plate 65, for instance, represents a crystal of enstatite which has been completely changed to steatite. Material that exhibits a metallic sheen does not lose this when weathered: for example, the bastite or schiller-spar of Baste in Radauthal, Harz, is a bronzite which has been altered to serpentine.

Crystals of these rhombic pyroxenes are of quite rare occurrence. The largest are those of enstatite from Kjörrestad in the parish of Bamle, Norway, where rough crystals exceeding 40 cm. in length have been found. That represented in plate 65, fig. 1, is bounded by the large ortho-pinacoid (to the front), the vertical prism (the faces at the sides), and a rounded basal plane. More usually, these minerals occur in irregular grains as the constituents of igneous rocks, namely: enstatite in andesite, bronzite with olivine in the basic segregations in basalt, and hypersthene in gabbro.

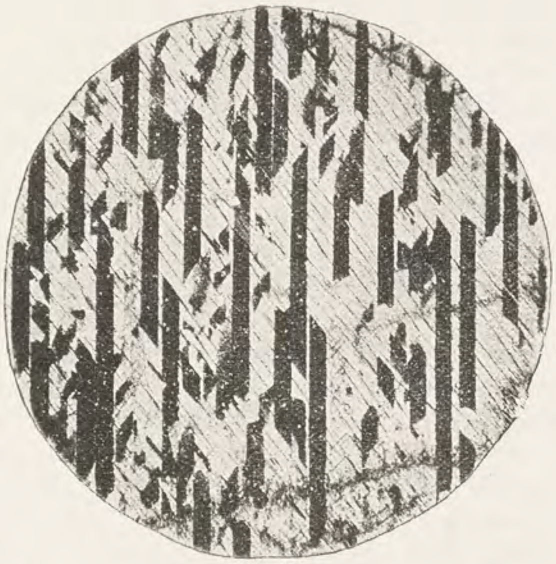

Fig. 229.
Micro-section of Hypersthene with regularly arranged enclosures of a dark mineral.

In thin sections of these rocks the grains of enstatite, etc., show fine cleavage cracks (running diagonally in fig. 229). Dichroism is scarcely noticeable in enstatite, but is stronger in the more ferriferous varieties. The refraction is strong, the mean index for enstatite being 1·669 and for hypersthene 1·702; the birefringence is weak.

Enstatite in its purest form is that found in some meteoric stones; in igneous rocks it is of comparatively rare occurrence. Clear material of a rich green colour and suitable for cutting as gems is found in the "blue ground" of the South African diamond mines. Bronzite is found as large grains at Kupferberg in Bavaria, Kraubat in Styria, and Ultenthal in Tyrol; and as small grains in olivine nodules in the basalts of the Vogelsberg, the Eifel, and many other places. Hypersthene is widely distributed as a constituent of andesite in Transylvania, Auvergne, Nevada, the Andes, etc. Large masses of hypersthene with a fine metallic reflection are found, together with the beautifully coloured labradorite (p. 297), on the island of St. Paul off the coast of Labrador (plate 65, fig. 2). For ornamental purposes this material is cut and polished with a slightly convex surface.

Diopside. In this member of the pyroxene group the magnesium-iron silicate of the enstatite series is combined with are equal molecular amount of calcium silicate, so that the formula becomes $(Mg, Fe)SiO_3 + CaSiO_3$ or $Ca(Mg, Fe)Si_2O_6$. With an increasing amount of iron oxide, isomorphously replacing magnesia, there is a corresponding increase in the depth of colour and in the specific gravity. Typical diopside is transparent and of a pale or darker green colour (plate 65, fig. 4); whilst *hedenbergite*, the member at the iron-rich end of the series, is black and opaque. Sometimes the colour varies in one and the same crystal, one end being pale green or almost colourless and the other end dark leek-green. Alumina is absent or present in only small amount. As an example of the percentage composition, we may quote the following analysis of colourless diopside from the Ala valley in Piedmont: silica (SiO_2) 54·74, magnesia (MgO) 17·02, ferrous oxide (FeO) 2·91, lime (CaO) 26·03 per cent.

Crystals of diopside are prismatic in habit, with usually a large development of the ortho-pinacoid and the clino-pinacoid, which together give a square prism. This square prism has its edges replaced by narrow faces of the unit vertical prism ∞P, and it is terminated by pyramid and dome faces. On the large crystal in fig. 4, plate 65, the large faces of the clino- and ortho-pinacoids are set vertically, and the edges between them are truncated by the unit vertical prism (seen as a narrow face to the front); and the large face at the top is a pyramid face. The faces of the unit vertical prism are inclined to one another at an angle of 87° 10′, and parallel to them there are perfect cleavages. The hardness is $5^1/_2$—6, and the specific gravity 3·2—3·3.

The typical diopside, such as we have just described, occurs as attached crystals, together with crystals of hessonite and chlorite, in veins in serpentine in the Ala valley in Piedmont (plate 65, fig. 4), and also in the Achmatovsk mines at Zlatoust in the Urals (plate 65, fig. 7); and, at the latter locality, together with garnet, chlorite, and titanite (plate 40, fig. 10).

This typical alumina-free diopside passes by insensible gradations into common aluminous augite, and it is not always easy to decide from the composition whether any particular crystal is to be regarded as diopside or as augite. For this reason the intermediate members have been described under several special names (sahlite, baikalite, fassaite, pyrgom, etc.); but here we shall consider them together under the collective name pyroxene and apart from the typical rock-forming augite. A few of such intermediate members of the series are represented in plate 65, figs. 5, 6, and 8. The dark green, almost black crystals in fig. 5 show (e. g. the crystal set vertically in the centre) the two large pinacoids, a very narrow vertical prism not more than a mere line on the front edge, and the dull basal plane dusted over with chlorite. Their dark colour indicates the presence of much iron, as proved by the following analysis: silica (SiO_2) 51·0, magnesia (MgO) 5·9, ferrous oxide (FeO) 17·3, ferric oxide (Fe_2O_3) 1·0, alumina (Al_2O_3) 1·0, and lime (CaO) 22·4 per cent. This specimen is from the iron mines at Nordmark, near Philipstad in Wermland, Sweden.

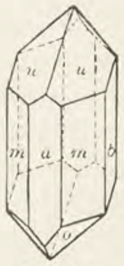

Fig. 230.
Crystal of
monoclinic
Pyroxene.

In fig. 8 the faces of the unit vertical prism are much wider, otherwise the form is the same as in the crystal of diopside in fig. 4. These crystals, which are tilted forward to show the faces at the top, are explained by the accompanying text-fig. 230: *m* is the unit vertical prism ∞P, *a* the ortho-pinacoid $\infty P \bar{\infty}$, *b* the clino-pinacoid $\infty P \grave{\infty}$, and *u* and *o* are pyramids. These crystals are from North Burgess in Lanark Co., Ontario, Canada, and may be regarded as diopside.

The crystal in fig. 6 is again of the same form, but here the faces of the unit vertical prism are still more largely developed. The white matrix is calcite, and the pyroxene has here been formed in the crystalline limestone as a result of metamorphism at the contact with an intruded mass of igneous rock. The locality of this specimen is Pitcairn, St. Lawrence Co., in the State of New York. A similar green pyroxene, called fassaite, occurs as a contact mineral in the Fassa valley in southern Tyrol.

Augite. This is the most abundant of the members of the pyroxene group, and one of the most important of the rock-forming minerals. Like the majority of the rock-forming minerals, it is unattractive in appearance; its crystals are brownish-black and opaque (plate 65, figs. 9—11) — never beautifully coloured, clear, or of large size.

PLATE 65.

Pyroxene Group.

Fig.

1. **Enstatite,** altered to steatite.
Kjörrestad, Bamle, Norway.
2. **Hypersthene,** a polished surface.
Coast of Labrador, North America.
3. **Spodumene,** isolated crystal.
Huntington, Massachusetts, U. S. A.
4. **Diopside,** prismatic crystals with garnet.
Ala valley, Piedmont, Italy.
5. **Pyroxene,** group of crystals.
Nordmark, Wermland, Sweden.
6. **Pyroxene,** in crystalline limestone.
Pitcairn, St. Lawrence Co., New York, U. S. A.
7. **Pyroxene,** parallel growth of prismatic crystals.
Achmatovsk, Zlatoust, Ural Mountains.
8. **Pyroxene,** large, prismatic crystals.
North Burgess, Lanark Co., Ontario, Canada.
9. **Augite,** simple (i. e. untwinned) crystal; ortho-pinacoid, vertical prism, and negative pyramid.
Wolfsberg, Bohemia.
10. **Augite,** twinned crystal; twin-plane the ortho-pinacoid. (The crystal is turned round with the ortho-pinacoid to the side, so that the re-entrant angle may be seen.)
Locality unknown.
11. **Augite,** twinned crystal. (The salient angle at the lower end of the twin is directed towards the front.)
Wolfsberg, Bohemia.
12. **Diallage,** cleavage fragment.
Siberia.
13. **Aegirite** ("Acmite"), isolated crystal.
Eker, Kongsberg, Norway.
14. **Aegirite** ("Acmite"), crystals in quartz.
Eker, Kongsberg, Norway.
15. **Aegirite,** isolated, prismatic crystal.
Kangerdluarsuk, Greenland.
16. **Wollastonite,** fibrous aggregate.
Auerbach an der Bergstrasse, Hesse.


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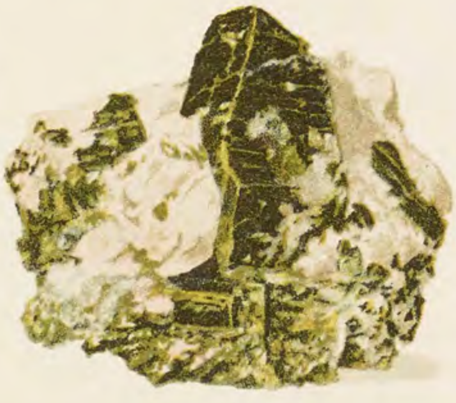
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The simple crystals, as well as the twins, possess a very characteristic form, and it is easy to recognize that they have only one plane of symmetry and are consequently monoclinic. With the unit vertical prism (*m* in text-fig. 231) is combined the ortho-pinacoid *a* and the clino-pinacoid *b*, the two faces of the latter being parallel to the plane of symmetry. The angles between the faces of the unit vertical prism are 87° and 93°, so that the prism-zone of eight faces is a nearly regular octagonal prism. The ends of this prism are closed by two obliquely-placed pyramid faces *s*, which are sometimes briefly spoken of as an augite pair. Sometimes there is in addition a basal plane. Text-fig. 231 corresponds exactly with the crystal represented in plate 65, fig. 9. In the twinned crystals (fig. 232) the two individuals have in common a face of the ortho-pinacoid. If we consider the simple crystal (fig. 231) to be cut into two equal halves by a plane parallel to *a*, and then rotate the front half through 180° about a normal to this plane, we shall obtain the twinned crystal (fig. 232). The characteristic feature of such twins of augite is the presence of a re-entrant angle at one end (plate 65, fig. 10), and of four faces with salient angles at the opposite end (plate 65, fig. 11). Crystals of augite are found embedded in certain rocks (lava, basalt, etc.), and they are bounded by faces on all sides. They are usually of small size, the crystal represented in fig. 10 being an average size, whilst those in figs. 9 and 10 are above the average.

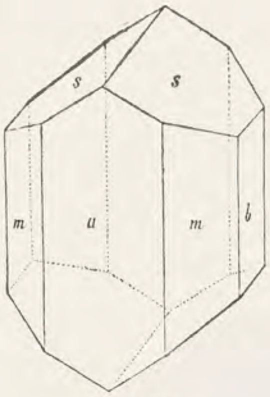

Fig. 231.
Simple crystal of Augite.

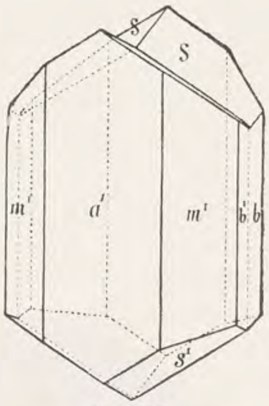

Fig. 232.
Twinned crystal of Augite.

The specific gravity is 3·3—3·4, and the hardness 5—6. There are good, though scarcely perfect, cleavages parallel to the prism faces, and the fracture is conchoidal rather than even. The other characters can only be recognized in thin sections, since the crystals in bulk are quite opaque.

In thin sections the mineral is transparent and of a light brown or violet-brown colour. The crystals show an eight-sided outline in sections perpendicular to the prism, and a six-sided or rhomb-shaped outline in sections parallel to the prism edges. When there are only grains, and not crystals in the rock, the outlines are of course irregular. In these sections the cleavage cracks parallel to the prism faces are always prominently developed, and when the section in perpendicular to the prism these cross at an angle of nearly 90° (plate 67, fig. 1). The darkness of these cleavage cracks and of the outlines indicate that the refraction of the mineral is high ($n = 1{\cdot}72$). The pleochroism is always feeble: when the section is rotated over the lower nicol prism scarcely any change in colour is noticeable.

Between crossed nicols brilliant polarization colours are seen, indicating that the double refraction is strong. Turning a rhomb-shaped section (i. e. one parallel to the plane of symmetry of the crystal) into the position of extinction we see that the angle of extinction (p. 61), as measured to the prism edge, is very oblique, exceeding, in fact, 40°. On account of this oblique extinction, twinned crystals are always readily recognized when examined in polarized light, even if they show no re-entrant angle at their outlines. When one portion of the twin is turned into the position of extinction the other portion is bright (text-fig. 233).

In some instances a twin individual may be present as a very thin lamella inlaid in an otherwise simple crystal. Without examination under the microscope such a twin would be entirely overlooked. As will be mentioned farther on under hornblende, we sometimes see a regular intergrowth of augite with hornblende (plate 67, fig. 3).

The chemical composition of augite is complicated by the presence of aluminia and ferric oxide, and sometimes also of titanic acid and manganous oxide, in addition to the constituents of diopside, and further these constituents may be present in varying amounts. The following figures give the results of analyses of augite from: I, Härtlingen in Westerwald, Hesse-Nassau, and II, Limburg in the Kaiserstuhl, Baden.

	SiO_2.	TiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MnO.	CaO.	MgO.
I.	47·52	—	8·13	5·83	7·77	0·40	18·25	12·76
II.	44·15	4·57	6·90	6·02	3·49	—	22·79	12·26.

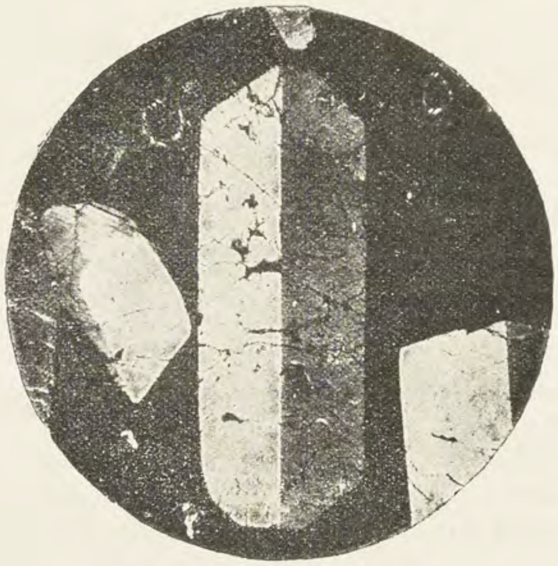

Fig. 233.
Twinned crystal of Augite in polarized light.

Some augites also contain chromic oxide, and others soda, etc. The general chemical formula which expresses these wide ranges in composition has been given above (p. 312). Acids, even hydrofluoric, have scarcely any action on augite, yet in nature it becomes altered by weathering, giving rise especially to chlorite.

Augite with the characters here described occurs as an essential constituent of igneous rocks, such as basalt, diabase, and melaphyre, and their associated tuffs. The loose crystals are mostly collected from the tuffs and ashes of active volcanoes. A few of the many localities are: Vesuvius and Etna; the ancient volcanoes of the Laacher See, Westerwald, Vogelsberg, Rhön, and Kaiserstuhl Mountains in Germany; as well-formed isolated crystals in the basalt-tuffs of the Midland Mountains of Bohemia, e. g. at Schima, Boreslau, and Wolfsberg, near Czernoschin (plate 65, figs. 9 and 11).

Diallage. This member of the pyroxene group is practically the same as augite in its chemical composition, but it differs from this in its structure and occurrence. It is never found as crystals, but only as irregular masses. These possess a characteristic foliated or laminated structure, parallel to which the mineral readily breaks. On these surfaces the lustre is pearly or metallic with a peculiar sheen. This platy separation is very similar to that met with in the rhombic pyroxenes, and, indeed, with the unaided eye it is not always possible to distinguish between diallage and bronzite. In thin sections under the polarizing microscope they are once distinguished, since diallage gives the oblique extinction of augite, whilst bronzite gives straight extinction.

The colour is brown, grey, or greenish, and very often patchy in its distribution (plate 65, fig. 12) due to the partial alteration of the material to serpentine or chlorite. In its other characters diallage is very similar to augite. It occurs as an essential constituent of gabbro, a rock consisting also of labradorite and often olivine. A few localities are: Volpersdorf in Silesia, Radauthal in the Harz, Ultenthal in Tyrol, Prato near Florence, the Lizard district in Cornwall, Lendalfoot in Ayrshire, and the Island of Skye.

Spodumene. To French mineralogists this mineral is known as triphane. From the members of the pyroxene group so far mentioned it differs very widely in chemical composition, for it contains no calcium, magnesium, or iron, or these in only quite small amounts. It is a silicate of aluminium and the rare alkali metal lithium. A crystal from Huntington in Massachusetts, similar to the one represented in plate 65, fig. 3, gave on analysis: —

SiO_2.	Al_2O_3.	FeO.	CaO.	MgO.	Li_2O.	K_2O.	Na_2O.	Total.
63·79	27·03	0·39	0·73	0·21	7·04	0·12	1·10	100·41.

That the mineral contains little or no iron is obvious from its very pale colour. The presence of lithium is readily demonstrated by the characteristic deep crimson colour which a fragment of the mineral imparts to the flame of a Bunsen-burner. Although differing from augite so markedly in composition, yet it has the same type of meta-silicate formula, namely $LiAlSi_2O_6$, and there is further a close similarity in the crystalline form. The crystals are monoclinic, and the faces of the unit vertical prism are inclined to one another at an angle of 87° (as in augite); the ortho-pinacoid is developed as a wide face deeply grooved vertically (the large face to the front in plate 65, fig. 3); and at the end of the crystal is a pair of obliquely-placed faces — the so-called augite pair. Parallel to the faces of the unit vertical prism there are, as in augite, perfect cleavages. Foliated and columnar masses of spodumene are also found.

The colour of the mineral is usually a pale greyish-white, rose-red, yellowish-green, or violet. Clear crystals of a magnificent emerald-green colour, this colour being due to the presence of a trace of chromic oxide, have received the name *hiddenite* (or, erroneously, lithia-emerald); whilst transparent crystals of a beautiful lilac or violet shade of colour are known as *kunzite*. These green and lilac-coloured crystals are strongly pleochroic, and when they are employed as gems it is important that they should be cut in a certain direction to show the colour to the best advantage. The specific gravity of 3·1—3·2 affords a ready means of distinguishing between the green hiddenite variety and emerald.

Spodumene is on the whole a rare mineral, and the crystals are almost exclusively of American origin. It is found, together with mica, beryl, and tourmaline in a quartz vein traversing mica-schist at Huntington (formerly called Norwich) in Massachusetts (plate 65, fig. 3); and with tourmaline and beryl at Goshen in Massachusetts. Enormous crystals, reaching a length of 42 feet and with a cross-section of 3 by 6 feet, have been found in the Etta tin mine at Harney Peak in the Black Hills of South Dakota. The hiddenite variety is found together with emerald at Stony Point in Alexander Co., North Carolina; and transparent, yellowish-green crystals and fragments come from Minas Geraes, Brazil. The kunzite variety is found as clear crystals, sometimes several inches in length, in pegmatite-veins at Pala and elsewhere in San Diego Co., California; and quite recently in the pegmatites near Antsirabe in Madagascar.

The yellowish-green spodumene from Brazil, the emerald-green hiddenite, and the violet kunzite are cut as gem-stones. Of these, hiddenite is especially rare and correspondingly valuable. The large crystals of cloudy spodumene when they occur in sufficient quantity, as in the Black Hills in South Dakota, have been collected for the preparation of lithium salts.

Another mineral of the pyroxene group, and one very closely related to spodumene, is *jadeite*, which will be further mentioned under nephrite when we come to the amphibole group.

Acmite. Crystals of acmite differ considerably in their general form from crystals of augite, and at first sight they would appear to belong to the rhombic series of pyroxenes, rather than to the monoclinic series. Nevertheless, they are in reality monoclinic and their form is essentially the same as that of augite, since the angles between corresponding faces are very nearly the same. In plate 65, figs. 13 and 14, the wide face to the front belongs to the ortho-pinacoid, and the narrow faces on either side are those of the unit vertical prism, the angles between which are 87°, as in augite. The marked difference in appearance from augite is due to the presence of steeply inclined terminal faces, which belong to the pyramid with the Naumannian symbol 6 *P*. These crystals are twinned on the ortho-pinacoid (like the crystal of augite in fig. 11 of the same plate), and for this reason they are terminated by four of the steep pyramid faces equally inclined to the vertical axis, and it is this that produces the apparent rhombic aspect of the crystals. The re-entrant angles between the pyramid faces are not often to be seen, since the crystals are usually broken at this end.

Crystals of the pointed habit just described were named *acmite* (from ἀκμή, a point) by F. Stromeyer in 1821. Later, in 1835, J. Esmark described crystals with obtuse terminations, more like those of ordinary augite, to which he gave the name *aegirite*, after Aegir, a Scandinavian sea-god. The identity of acmite and aegirite was subsequently proved, and unfortunately it is now often customary to adopt the more recent name aegirite for the species rather than the earlier name acmite. It will be seen from the pictures that the obtusely terminated crystal of aegirite (plate 65, fig. 15) is of a blackish-green colour, whilst the acutely terminated crystals of acmite (figs. 13 and 14) are dark brown. These differences are, however, of no real importance, and in all their essential characters the two varieties are identical.

Crystals of acmite (including also aegirite) cleave parallel to the faces of the unit vertical prism, the angles between two cleavage surfaces being 87°. They have a specific gravity of 3·5, and a hardness of 6. In these characters the mineral shows a close relation to common augite. Before the blowpipe it fuses readily, colouring the flame bright yellow and yielding a black, magnetic bead. These reactions indicate respectively the presence of sodium and iron, which are in combination as a silicate with the formula $NaFeSi_2O_6$.

Acmite occurs as long crystals embedded in white quartz (fig. 14) which forms a vein in granite at Eker in Norway. The crystals are often fractured with displacement of the several portions, these being cemented together again by a later growth of quartz and acmite. The aegirite variety occurs as a constituent of nepheline-syenite; and in veins in rocks of this kind it is sometimes found as crystals a foot in length and the thickness of a man's arm. Such crystals are found on the Langesund-fjord in Norway, at Magnet Cove in Arkansas, and at Kangerdluarsuk in Greenland. As a rock constituent it is found in the Kola Peninsula in Finland, the Serra de Tingua in Brazil, and elsewhere.

Many rock-forming augites contain a small percentage of sodium, the presence of which may be ascribed to an intermixture of acmite molecules with the augite molecules. Such intermediate members of the pyroxene group, consisting of an isomorphous mixture of augite and acmite are known as aegirite-augite. They are met with, for example, in the nosean-phonolite of the Laacher See district.

Wollastonite. This mineral receives its name from the English chemist and mineralogist William Hyde Wollaston (1766—1828). Distinctly developed crystals are of rare occurrence and they are mostly only of small size. They are monoclinic with usually a tabular habit, hence the popular name 'tabular spar' for this species. Occasionally delicate tree-like forms of growth are met with, as already represented in plate 2, fig. 5. A more characteristic form of the mineral is as white or grey, platy masses (plate 65, fig. 16) which exhibit a pearly lustre, or as irregular and radially-fibrous masses with a silky lustre. Such material is almost invariably found in granular crystalline limestone, and usually in association with garnet and idocrase. All these minerals are of contact-metamorphic origin, having been formed in an impure limestone by the baking action of an eruptive rock-mass (granite, syenite, or diorite).

Wollastonite is composed of lime and silica in equal molecular proportions, the formula being $CaSiO_3$. The combination of the lime of the limestone with the silica present as impurities in the same has been effected through the agency of heat and hot solutions given off from the intruded igneous rock. This calcium silicate is also present in diopside, but here it forms a double salt with magnesium-iron silicate: in wollastonite is occurs alone. Wollastonite is decomposed by hydrochloric acid with the separation of gelatinous silica; the lime passes into solution, and this solution will impart to the Bunsen-flame a reddish-yellow coloration characteristic of calcium. By this reaction, depending on the ready decomposition of the mineral, wollastonite can be distinguished from all the other members of the pyroxene group.

Massive, fibrous, and platy wollastonite is found in crystalline limestone at Auerbach in Hesse (plate 65, fig. 16), and at Cziklova in Hungary. Dendritic aggregates occur in crevices in a black limestone at Berggiesshübel in Saxony. Blade-like crystals are found in the ejected blocks of Monte Somma, Vesuvius. Recently, well-formed crystals of considerable size have been met with in the Santa Fé mine, in the state of Chiapas, Mexico.

Amphibole Group.

Between the minerals of the pyroxene group, which have been described in the preceding pages, and those of the amphibole group there exist several very close relations; and with certain limitations they might be considered as forming together one great group. Their chemical constituents are the same, although in most cases these are combined together in different proportions in the two groups. This is best shown in the members consisting of magnesium silicate and calcium silicate. In the pyroxene group we have diopside in which magnesium silicate and calcium silicate are combined in the molecular proportion of 1 : 1; whilst in the corresponding member of the amphibole group, namely in tremolite, the ratio is 3 : 1. The simplest formula which expresses the composition of tremolite is therefore $3\,MgSiO_3 . CaSiO_3$ or $Mg_3CaSi_4O_{12}$. In order to being out this relation in the formula of the other members of the group, the amphiboles must be considered as salts of the acid $H_8Si_4O_{12}$. The formula of the simple magnesium silicate would then be $Mg_4Si_4O_{12}$, which only differs from the formula $MgSiO_3$ in being multiplied by four, the ratio of magnesia to silica as found by quantitative chemical analysis being the same for both. This formula merely expresses that the molecule of a member of the amphibole group is larger than the molecule of the corresponding member of the pyroxene group; so that we here have a special kind of dimorphism.

The simple magnesium silicate $Mg_4Si_4O_{12}$ may be intermixed with more or less ferrous iron silicate (anthophyllite), or it may be combined with calcium silicate (tremolite and actinolite). In other members of the group alumina may also be present (hornblende); whilst in others soda may take the place of lime, and ferric oxide the place of alumina. The analogy with the minerals of the pyroxene group is complete, with the exception that in the amphibole group there is no representative rich in lithia.

As in the pyroxene group, so also here the chemically simpler members crystallize in the rhombic system, the others in the monoclinic, whilst the triclinic members are of little importance. All of them possess distinct cleavages parallel to the faces of the vertical prism; but, whilst in the pyroxenes the angle between these cleavages is 87°, in the amphiboles it is 56° (or the supplement of this, 124°). The specific gravity of all the amphiboles lies between 3·0 and 3·2, being lower than for the pyroxenes. When amphibole is fused it consolidates not as amphibole, but as pyroxene with the higher specific gravity.

We can now give the following summary of the minerals of the amphibole group.

Anthophyllite, $(Mg, Fe)_4Si_4O_{12}$	Rhombic.
Tremolite and Actinolite, $(Mg, Fe)_3CaSi_4O_{12}$	Monoclinic.
Hornblende, $(Mg, Fe)_3CaSi_4O_{12} . CaMg_2Al_2Si_3O_{12} . Na_2Al_2Si_4O_{12}$	Monoclinic.
Glaucophane, $Na_2Al_2Si_4O_{12}$	Monoclinic.
Riebeckite, $Na_2Fe_2Si_4O_{12}$	Monoclinic.

Of these minerals *anthophyllite* need be only briefly mentioned, since it is of rare occurrence. It forms brown, fibrous aggregates, with a specific gravity of 3·2. Its formula expressed in the most simple form is the same as that of enstatite (p. 312), namely $MgSiO_3$, and it is here that the dimorphic relation is most clearly shown.

Another member also of minor importance is *glaucophane*. This occurs but rarely as crystals, and it usually forms granular or fibrous aggregates of a dark blue colour. Its strong pleochroism, easy fusibility, and perfect prismatic cleavage are characteristic features. It is of interest as a constituent of certain schistose rocks (glaucophane-schists) met with in a few widely separated districts, namely, the Island of Syra, Zermatt in Switzerland, in Brittany, and on Shikoku in Japan.

The remaining members of the amphibole group, together with some of their more important varieties, will now be described in detail.

Tremolite and **Actinolite.** The first of these two minerals contains little or no iron, and it is consequently white or colourless. Actinolite, on the other hand, contains much more iron, and it is dark green in colour (plate 66, fig. 1). Both of them occur as blades or slender prisms embedded in chlorite-schist or talc-schist, granular limestone or dolomite, and in other crystalline rocks. The crystals are bounded by the faces of the vertical prism with sometimes the clino-pinacoid, but without terminal faces. They may occur singly in the rock, but more frequently they are closely aggregated to form radially disposed masses of needles, or the aggregation may be confused and irregular.

The specific gravity varies from 3·0 to 3·2, according to the amount of iron present, and the hardness is $5^1/_2$—6.

Tremolite and actinolite are characteristically minerals of crystalline schistose rocks and as such are met with in Alpine regions. They are never found as attached crystals on the walls of crevices, the reason for this apparently being that pressure is an agent necessary for their formation. Tremolite receives its name from the Val Tremola on the southern side of St. Gotthard, and the best specimens come from the white crystalline dolomite of Campo longo in the same district. It contains: SiO_2, 58·05; MgO, 27·18; CaO, 13·91; H_2O, 0·34 per cent. Actinolite is of much wider distribution and is found at many places in the Swiss and Tyrolese Alps. Well-known localities are: on the Greiner in the Zillerthal and the Pfitsch valley in Tyrol; the St. Gotthard district, and Pommat in Val Formazza (plate 66, fig. 1) in Switzerland. The actinolite of the Zillerthal contains 6—25 per cent. of iron (ferrous) oxide with correspondingly less magnesia. As rock-forming constituents, both minerals sometimes occur in abundance as tremolite-schist and actinolite-schist.

PLATE 66.

Amphibole Group.

Fig.

1. **Actinolite,** in talc-schist.
   Pommat, Val Formazza, Switzerland.
2. **Hornblende,** simple (i. e. untwinned) crystal.
   Schima, Bohemia.

3, 4. **Hornblende,** twinned crystal; fig. 3 viewed from above, fig. 4 from below.
   Schima, Bohemia.

5. **Hornblende,** isolated, prismatic crystal.
   Roda, Predazzo, southern Tyrol.
6. **Hornblende,** group of black crystals.
   Arendal, Norway.
7. **Smaragdite,** with brown garnet.
   Sau Alp, Carinthia.
8. **Crocidolite,** fibrous. (When altered and replaced by quartz this gives the "Tiger-eye" shown in Plate 52, figs. 13 and 14.)
   Griqualand, South Africa.
9. **Asbestos,** bundle of long fibres.
   Locality unknown.
10. **Nephrite** (Jade). Collected by the Brothers Schlagintweit.
    Central Asia.
11. **Chloromelanite** (a variety of Jadeite belonging to the pyroxene group.) An axe-head.
    Lake Neuchâtel, Switzerland.

Stuttgart (Fritz Lehmann).


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4


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7


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11


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8


10

A compact and microscopically fibrous variety of actinolite is the well-known *nephrite*, which by reason of its special interest will be treated, together with jadeite, in a later section.

An emerald-green variety of actinolite known as *smaragdite* forms, together with grass-green pyroxene (omphacite) and brown garnet, a prettily coloured crystalline rock called eclogite. As a constituent of this rock, smaragdite occurs in the Fichtel Mountains of Bavaria and at Sau Alp in Carinthia (plate 66, fig. 7).

Asbestos. The name asbestos, from the Greek and meaning "unquenched", is applied to minerals which possess a finely fibrous texture and flexibility, so that they can be spun like thread, and which are at the same time incombustible. As shown by their chemical composition such minerals may belong either to tremolite and actinolite (asbestos proper) or to serpentine (serpentine-asbestos), or less commonly to crocidolite (p. 323).

The asbestos proper, or *amphibole-asbestos*, forms white or greenish, fibrous masses from which the single fibres may be easily separated (plate 66, fig. 9). The fibres are sometimes brittle, but frequently they are so pliable and tough that they can be spun and woven. In the variety known as *amianthus* the fibres are so extremly fine that the material has a silky lustre. In some other varieties the fine fibres are matted together to form a felt, such material being variously called, as suggested by its appearance, *mountain-leather* and *mountain-cork*. Although asbestos in larger masses is resistant to high temperatures, yet the fine fibres taken separately can be fused before the blowpipe. That asbestos belongs to the amphibole group is proved by quantitative chemical analysis; for example, a specimen from the Zillerthal, Tyrol, gave: SiO_2, 57·20; CaO, 13·39; MgO, 22·85; FeO, 4·37; H_2O, 2·43. This corresponds closely with the analysis of tremolite quoted above, except that a small proportion of the magnesia is replaced by ferrous iron. The small amount of water often present in asbestos is probably due to incipient alteration.

Asbestos occurs embedded in talc-schist, chlorite-schist, serpentine, or crystalline limestone, and is of wide distribution, but it is not many occurrences that are of economic value. A few of the better known localities are: the Gamskarkogel near Gastein in Austria, where the material occurs in workable quantities; the Knappenwand in Untersulzbachthal, Salzburg, with crystals of epidote (plate 50, fig. 5); the Zillerthal and Pfitsch valley in Tyrol; rich deposits of good quality asbestos are worked in the neighbourhood of Sondrio in Valtellina and in the province of Turin.

The supply of amphibole-asbestos comes mainly from the north of Italy, where the output in the year 1901 amounted to 2000 tons. Of far greater commercial importance than the Italian asbestos is, however, the Canadian asbestos which is a serpentine-asbestos: of the latter the production in 1908 amounted to 65,534 short tons (of 2000 lbs.) valued at about £ 510,000.

The applications of asbestos depend on its incombustibility, its finely fibrous texture, and its low degree of conductivity for heat. It is used as a packing in the pistons and stuffing-boxes of steam-engines and the joints of steam pipes; as an insulating material for covering steam and hot-water pipes; as a filtering material; lamp wicks; loose soles in boots and shoes; imitation snow for theatres and christmas trees; the upper portion of incandescent gas-light mantles. Further, as a fire-proof material for the construction of theatre curtains, boards, and walls. Asbestos fibre coated with platinum (platinized asbestos) is employed in the manufacture of sulphuric acid by the contact process. For spinning and weaving, in the manufacture of asbestos twin and cloth, serpentine-asbestos is on the whole more suitable than amphibole-asbestos, since the fibres of the former are finer, softer, and more flexible.

The practical uses of asbestos date back to very early times. The golden lamp of Minerva at Athens had a wick of asbestos; and the ancient Romans cremated corpses in asbestos shrouds, so that the ashes were kept separate from the ashes of the fire. Karl V, emperor of Germany, had a table-cloth made of asbestos, which, to the amusement of his quests, was cleansed after a meal by being thrown on the fire.

Hornblende. Of all the minerals of amphibole group hornblende shows the best crystals. These belong to the monoclinic system, and in their external shape they present a certain resemblance to hexagonal forms. On this account, hornblende was formerly confused with tourmaline, and the old name schorl was applied indiscriminately to any black crystals of prismatic habit. It was not until the end of the eighteenth century that the two species were distinguished, the name schorl being reserved for tourmaline, while the name hornblende was applied by the German mineralogist Werner to the present mineral. The French mineralogist Haüy gave to it the name amphibole, which signifies that it had been mistaken for other minerals. At the present day the name amphibole is usually applied to the whole group, and hornblende to one member of the group.

The simple crystals (plate 66, fig. 2) are bounded by a rhombic prism parallel to the faces of which there are perfect cleavages enclosing an angle of 124° 10′ (or the supplement 55° 50′): this prism is taken as the unit vertical prism ∞P (*p* in text-fig. 234). The acute edges of this prism are truncated by the pair of parallel faces of the clino-pinacoid (*b*) parallel to the single plane of symmetry of the crystal. At the end of the crystal are three planes; the one (*c*) which is perpendicular to the plane of symmetry being chosen as the basal plane $0\,P$, and the other two (*o*) belong to the pyramid *P*. The angle between an adjacent pair of pyramid faces is 148° 28′, while each of them are inclined at 145° 35′ to the basal plane. This difference of angle is too slight to be detected by the eye without the help of a goniometer. Again the combination of the rhombic prism with the clino-pinacoid produces a six-sided prism with angles of 124° 10′ and 117° 55′, approximating in each case to 120°. The crystal thus presents the appearance of a hexagonal prism terminated by a rhombohedron, as in a crystal of tourmaline (compare plate 48, fig. 1). The fact that hornblende crystals cannot be rhombohedral is, however, at once seen from the cleavages, which are parallel to only four and not all six of the faces. Hornblende crystals are commonly of a short prismatic habit, as in plate 66, fig. 2, but usually they are smaller than the one here represented. Longer prisms, as in fig. 5, are rarely seen. On the black crystals in fig. 6 the only faces present are those of the unit vertical prism and the basal pinacoid: the clino-pinacoid is absent and in consequence the acute edges of the unit prism are developed.

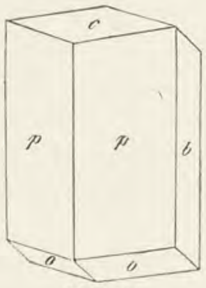

Fig. 234.
Crystal of Hornblende.

Twinned crystals of hornblende are of frequent occurrence. The two individuals of a twin are grown together on a face of the ortho-pinacoid, a face which if developed on the crystal would truncate the front obtuse edge of the prism. The two portions are symmetrical with respect to one another across this plane. Such twins are remarkable in showing no re-entrant angles. At one end there are four pyramid planes (plate 66, fig. 3), and at the other end two basal planes (fig. 4) in juxtaposition. The hornblende crystal now simulates, not a rhombohedral crystal, but a hemimorphic rhombic crystal.

Hornblende is an easy mineral to recognise in thin sections under the microscope. In cross-sections it shows a six-sided outline (plate 67, fig. 2) and in longitudinal sections

PLATE 67.

Rock-forming Minerals III.

(Micro-photographs.)

Fig.

1. **Augite,** cross-section with eight-sided outline; the cleavage cracks parallel to the prism faces intersect at angles of about 90° (actually 87°). In lava (leucite-basanite). Magnification 60.
   Monte Somma, Vesuvius, Italy.
2. **Hornblende,** cross-section with six-sided outline; the cleavage cracks parallel to the prism faces intersect at angles of about 120° (actually 124°). In hornblende-andesite. × 90.
   Altsohl, Hungary.
3. **Augite** and **Hornblende,** in regular intergrowth; a vertical line drawn across the figure would bisect the acute angle of the augite cleavages in the upper part, and would also bisect the obtuse angle of the hornblende cleavages in the lower part. The two minerals have a face of the ortho-pinacoid (the trace of which coincides with the horizontal diameter) in common, and the vertical axes (perpendicular to the plane of the section) are coincident. In amphibole-picrite. × 60.
   Schlierberg, Haiger, Nassau.
4. **Biotite,** or brown mica, with fine cleavage cracks parallel to the base. In hornblende-andesite. × 60.
   Wolkenburg, Siebengebirge, Rhine.
5. **Olivine,** porphyritic crystal with fine cleavage cracks. In basalt. × 45.
   Mosenberg, Manderscheid, Eifel, Rhenish Prussia.
6. **Olivine,** altered to serpentine on the exterior and along cracks in the interior. In palaeopicrite. × 45.
   Schwarze Steine, Dillenburg, Hesse-Nassau.


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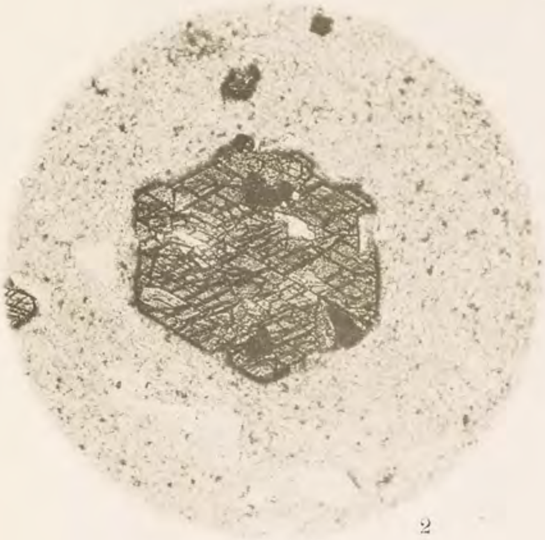
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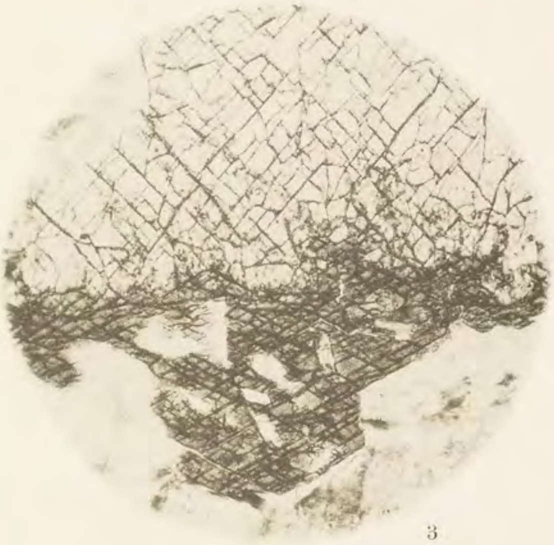
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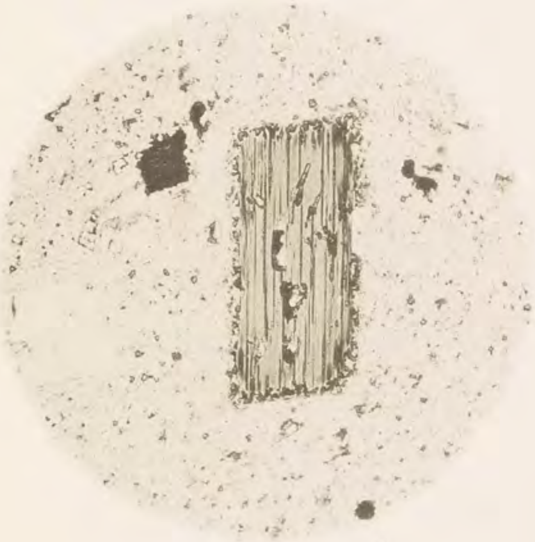
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usually a four-sided outline (plate 67, fig. 4)*): in the former the straight cracks due to cleavage intersect at an angle of about 120°, while in the latter they are parallel to the vertical axis. The colour of the mineral seen in the thin section is brown or green, and the strong dichroism is a very characteristic feature. As the section is rotated with respect to one of the nicol prisms, the colour changes from pale yellow to dark brown or from yellowish-green to dark green, for brown and green hornblende respectively. In sections cut parallel to the plane of symmetry the angle of optical extinction is 12—18°. These characters — the form of outline and the angle between the cleavage cracks, the strong dichroism, and the lower angle of extinction — serve to distinguish hornblende from augite (p. 315) when seen in thin sections of rocks.

The two related minerals hornblende and augite sometimes form parallel intergrowths (plate 67, fig. 3), as already mentioned on p. 46. Another relation shown by the two minerals is in the alteration of augite to hornblende. A crystal of augite, while still preserving its external form, may be altered in substance to hornblende. The cross-section of such an altered crystal will show the eight-sided outline of augite, but the cleavage cracks are at approximately 120° as in hornblende. Pseudomorphous crystals of this kind were first detected by Gustav Rose in the hornblende rocks of the Ural Mountains, and they were consequently named *uralite*.

An important difference between hornblende and augite is in their specific gravity, that of hornblende being 3·1 and of augite 3·3.

Green hornblende, known as *common hornblende* is of wide distribution as a constituent of syenite and diorite, and it also constitutes the greater part of the hornblende-schists of the Alps. In these rocks the mineral is present as grains, the fractured surfaces of which present a fibrous appearance due to the perfect prismatic cleavages. Freely developed crystals attached to the surface of the matrix are found in the iron mines of Nordmark near Philipstad in Sweden, and at Arendal in Norway (plate 66, fig. 6); and in the ejected blocks of Monte Somma, Vesuvius.

Brown hornblende, known as *basaltic hornblende* occurs as a constituent of trachyte, hornblende-andesite, and many basalts. In these volcanic rocks it is found as embedded crystals bounded on all sides by crystal-faces. Very frequently the edges and corners of these crystals are rounded, due to the solvent action of the molten lava under conditions of pressure different from those which subsisted when the crystals first grew. Such crystals of hornblende are especially frequent in basalt-tuffs, and being isolated in the loose material they are easily collected. Localities for good crystals are: Härtlingen in the Westerwald, Ortenberg in the Vogelsberg, Liebhards and Pferdskopf in the Rhön Mountains, Roda near Predazzo in southern Tyrol (plate 66, fig. 5), and especially in the Midland Mountains of northern Bohemia (Schima, plate 66, figs. 2—4, and Wolfsberg near Czernoschin).

Crocidolite. The mineral riebeckite mentioned in the list of amphiboles an p. 320 is of rare occurrence, and is found at but few places as a constituent of igneous rocks. Of more importance is its finely fibrous variety known as crocidolite (plate 66, fig. 8). This forms blue masses with a parallel-fibrous structure, and occurs as a filling in crevices, forming slabs of greater or less thickness, in clay-slates and jasper-schists on the banks of the Orange River in South Africa. The fibres run from side to side of the slabs and are closely compacted; but when the material is rubbed the individual fibres easily separate into a loose woolly mass (hence the name crocidolite). This mineral is also known as *blue asbestos*, and to some extent it is mined for commercial purposes. The cohesion of the

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*) In the explanation to plate 67 the crystal in fig. 4 is incorrectly described as biotite instead of hornblende.

material has at times been increased by the infiltration of silica which is deposited as quartz between the fibres. This may proceed to such an extent that we have a mass of quartz enclosing fibres of crocidolite, as in the blue quartz ("sapphire-quartz") of Golling in Salzburg and the abundant hawk's-eye of the Orange River. With the weathering and alteration of the crocidolite the ferrous oxide it contains is converted into limonite, which impregnating the quartz imparts to it a golden-yellow colour. The result is the well-known tiger-eye (plate 55, figs. 13 and 14), which has already been described (p. 274) as a variety of quartz.

Tiger-eye is employed as a gem-stone and for fashioning small ornamental objects. The finely fibrous crocidolite is put to the same uses as ordinary asbestos, but being much more easily fusible it is not so good for fire resisting purposes.

Nephrite and Jadeite.

These two minerals are so very similar in external appearance and general character that they have always been confused the one for the other; and it was only when they came to be analysed chemically and the specific gravity determined that they were recognized as belonging to distinct species. They are opaque, extremely compact stones with little, save colour, to attract the eye. Nevertheless, they belong to the most interesting of minerals, and since prehistoric times they have been much used for the fashioning of stone implements, personal ornaments, and carvings of various kinds, while at the present day they are highly prized by the Chinese. Compared with the wide distribution of the worked articles in settlements of the greatest antiquity, the rarity of occurrence of the rough material *in situ* is very striking; and the problem as to the origin of the material has been the subject of much inquiry. As a result of mineralogical together with ethnographical and archaeological investigations this problem has now been solved in its main issue.

These stones are known to the Chinese as *yu* or *yu-chi* (yu-stone), and in Persian as *yeshon*. The latter suggests a connexion with the word jasper, under which term the present minerals have no doubt also been included. The name nephrite, first used in this form by A. G. Werner in 1780, is from the old name *lapis nephriticus* or "kidney-stone", since in ancient times the wearing of the stone was believed to be a remedy for diseases of the kidneys. The name *jade*, which is now very often employed to include both nephrite and jadeite, has the same meaning, being derived from the Spanish *ijada* or *piedra de ijada*. When the two species were distinguished by A. Damour in 1863, he proposed for one of them the name *jadeite*.

Nephrite. As previously mentioned (p. 321) this is a member of the amphibole group of minerals essentially identical with actinolite. It forms compact masses with a greenish-yellow, grey, or rarely white colour, and on its broken surfaces it presents a characteristic splintery fracture. This fracture is represented in plate 66, fig. 10, by the lighter-coloured specks and patches, these being due to small translucent splinters partly loosened from the main mass of the stone. The most striking feature of nephrite is its extraordinary degree of toughness.

Some interesting observations respecting the toughness and hardness of nephrite were made by the brothers Schlagintweit, by whom the specimen represented plate 66 was collected in the Gulbashén quarries, situated on the right bank of the Karakash river in Eastern Turkestan (the earliest known locality for Asiatic nephrite). They caused a steel chisel loaded with 50 kilograms to fall from a height of 35 centimetres through a tube onto a block of nephrite, with the result that the chisel was broken whilst the stone remained uninjured. They also remark that when the stone is first taken out of the quarry, especially from the deeper portions, it is softer and more readily worked; this being no doubt due to the presence of moisture, which is lost on exposure to the air. Other more severe tests were made by H. Fischer. He placed a large block of nephrite under a steam-hammer, with the result that the anvil, and not the stone, was broken. The remark of Pliny that diamond cannot be broken on an anvil with a blow from a hammer (p. 205) thus applies much more correctly to nephrite than to diamond. The toughness may be overcome and the stone broken by the application of fire: when a heated stone is thrown into cold water it breaks into small fragments. On this depends the ancient method of fire-setting employed in quarrying the material.

The hardness (H. = $5^1/_2$—6), though greater than that of glass, is not high, being considerably less than that of quartz and of all the precious stones. This character is, however, quite distinct from that of toughness. It is on the latter that the durability of the stone depends. And on this account the material has at all times and in all parts of the world found favour as a material for stone implements, weapons, and personal ornaments. These being regarded as talismans and amulets, came in time to have special superstitions and healing virtues attached to them.

The toughness of nephrite is a consequence of a pecularity of the internal structure of the stone. In thin sections under the microscope the material is seen to consist of extremely fine fibres which are closely and confusedly aggregated to form a compact felt-like mass. That the fibres consist of actinolite is proved by their cleavages and low angle of optical extinction. Different specimens show differences in the size of the fibres and they may be intermixed to a greater or less extent with other minerals. The most frequent of these are grains of diopside. These small differences are, however, of importance, since they enable us to determine the probable source of the material. Thus, Arzruni by a microscopical examination of nephrite objects from Swiss lake-dwellings proved that the material differed from the nephrite from Central Asia, Siberia, and New Zealand, so that it had not, as previously assumed, been brought from these remote regions.

A microscopical examination of the material is only possible when a chip can be removed from the specimen, but this would not allowable in the case of worked articles. The best test then available is that afforded by the specific gravity, the object being weighed in air and in water: the value for nephrite lies between the limits 2·95—3·1, whilst jadeite has the higher value 3·32—3·35. Another ready test for the discrimination of these minerals is given by their fusibility and the colour that they impart to the Bunsen-flame: small flakes of jadeite fuse easily in the flame and impart a bright yellow colour, whilst nephrite fuses only with difficulty.

In chemical composition, nephrite is identical with actinolite or tremolite, the amount of iron actually present varying with the depth of colour of the material. An analysis by E. Schütz of nephrite from Shahidulla in Eastern Turkestan gave: silica (SiO_2), 57·69; alumina (Al_2O_3), 1·58; ferrous oxide (FeO), 2·60; lime (CaO), 13·81; magnesia (MgO), 22·55; water (H_2O), 1·75 per cent. (Compare with this the analysis of tremolite given on p. 320.)

Occurrence of nephrite.— Although worked articles of nephrite are found in many parts of the world, it is only at a few places that the rough material has been found *in situ*. Until year 1884 no occurrence in Europe had been discovered; and Heinrich Fischer, the author of the authoritative work "Nephrit und Jadeit" (2nd edition, 1880), had expressed the opinion that the all the material found amongst prehistoric remains in Europe had been brought from Asia, either along trade routes or with the migration of the early tribes. On the other hand, Andreas Arzruni pointed out that all the objects of nephrite found in the neighbourhood of the Alps, although similar amongst themselves in microscopical character, differed appreciably in this respect from Asiatic nephrite. He consequently believed that the material was not of exotic origin, in spite of the fact that up to that time no Alpine occurrence was known. In the year 1884, however, nephrite was discovered by Hermann Traube *in situ* at Jordansmühl in Silesia. It here forms a band between granulite and serpentine, and is also present as rounded nodules in the serpentine; that occurring in the band being dark green in colour, whilst the nodules are light green. Traube also later recorded the occurrence of nephrite at Reichenstein in Silesia, whilst quite recently (J. Uhlig, 1910) veins of nephrite have been observed in the gabbro-serpentine rocks of the Radauthal in the Harz Mountains. "Henckelius in Mineralogia redivivus" (1759, p. 30) mentions *lapis nephriticus* from the serpentine quarry at Zöblitz, Saxony. It is quite likely that this was only a compact serpentine; but still this early mention, hitherto overlooked, is of interest. The presence of isolated boulders of nephrite in northern Germany (e. g. at Schwemal near Düben in the Leipzig district) in without explanation.

In Asia, the occurrence of nephrite *in situ* was first recorded by the brothers Schlagintweit, who in 1856 and 1857 visited the Konakán and Karalá quarries in the neighbourhood of Gulbashén and Shahidulla-Chodja on the right bank of the Karakash river in Eastern Turkestan. This locality is situated on the northern slopes of the Kuen-Lun Mountains: other occurrences are known on the southern slopes of this range, to the westward in the Pamir region, and to the east in the Chinese province of Kan-su. The occurrences *in situ* are always in the neighbourhood of gneiss and crystalline schists. Boulders and pebbles of nephrite are abundant in the river beds throughout the whole region. In the villages on the northern slopes of the Nan-Shan an extensive trade in nephrite is carried on, the peasants collecting it for sale to Chinese merchants. Large boulders of nephrite are also found in the river beds in government Irkutsk in Siberia. Worked articles as well as the rough material are also met with in Alaska. In New Zealand, nephrite is abundant, being found on the west coast *in situ* and as pebbles in the river beds and on the sea beach. This is the well-known New Zealand greenstone, or *pounamu* of the Maoris.

Jadeite. This is a member of the pyroxene group and is analogous to spodumene in chemical composition (p. 316). As already mentioned, jadeite is strikingly similar in its general appearance to nephrite, though perhaps it is more often of a fine green, sometimes emerald-green, colour, than the latter. Usually, however, it shows just the same yellowish-green, greyish-green, and white colours as does nephrite. Even experts fail to distinguish the two minerals by sight alone. Distinguishing features of importance are the higher specific gravity (3·32—3·35) of jadeite, its much lower degree of fusibility, and the yellow coloration which it imparts to the Bunsen-flame. This characteristic flame-coloration is due to the presence of sodium in the mineral. An analysis by Lemberg of jadeite from Burma gave: silica (SiO_2), 58·95; alumina (Al_2O_3), 25·17; soda (Na_2O), 14·70; lime (CaO), 0·41; magnesia (MgO), 0·47; water (H_2O), 0·30 per cent. The mineral is thus a silicate of aluminium and sodium with the formula $NaAlSi_2O_6$, a formula analogous to that of spodumene but with sodium in place of lithium.

Not only do the specific gravity and chemical composition indicate that jadeite belongs to the pyroxene group, but so also do the microscopical characters. When thin sections of the material are examined under the polarizing microscope, it is seen to possess a granular, rarely fibrous, texture, and the individual grains show the cleavage and wide angle of optical extinction characteristic of the pyroxenes. As a rule the individual particles are rather larger in jadeite than in nephrite; and some pale coloured jadeites have somewhat the aspect of marble, although of course they are much harder, tougher, and heavier than this.

The jadeite of Upper Burma is perfectly pure, no trace of any another mineral being intermixed with the jadeite grains. In this respect it differs widely from the jadeite of worked objects found in Europe, in which other minerals are sometimes present in considerable amount.

Some jadeites contain iron oxide and are consequently darkly coloured, this being especially the case in the variety *chloromelanite*, so called from its greenish-black colour. This variety is found in Europe only as worked objects, especially axe-heads (plate 66, fig. 11); most of these are found in France, and a few in Switzerland, that represented in the picture being from the lake-dwellings on Lake Neuchâtel. Worked objects are also occasionally found in Mexico, Guatemala, Colombia, New Guinea, and elsewhere. Chloromelanite is said to occur *in situ* in New Guinea.

The hardness and toughness of jadeite are slightly greater than of nephrite. The mineral is put to exactly the same uses as nephrite, as will be described farther on.

Occurrence of jadeite. — In Europe, jadeite is not known with certainty to occur *in situ*; the only rough material so far found consists merely of pebbles which have not been traced to their original bed. All the jadeite which comes into the trade is from Asia, but even of Asiatic occurrences (probably in Tibet and Eastern Turkestan) the only one of which we have any definite particulars is that in Upper Burma. Until comparatively recently this remote region was practically unknown to Europeans. It was examined geologically by F. Noetling in 1892, and more recently by A. W. G. Bleeck in 1907.

The jadeite-mining district of Upper Burma is of limited extent, and is situated in the Kachin Hills, about 120 miles from Mogaung. The material is quarried from the solid rock at the village of Tawmaw; and as pebbles and boulders it is collected from the bed and banks of the river Uru, a tributary of the Chindwin. Although the alluvial deposits have been worked since a remote period, they are not yet exhausted. Deposits of laterite in the valley also contain a few blocks of jadeite; these are iron-stained and of a rich reddish-brown colour, which is much admired by the natives and by the Chinese. The occurrence of the mineral *in situ* at Tawmaw was first known about the year 1880. Here in the midst of the jungle a low isolated hill composed of dark green serpentine projects through the surrounding sandstone. The jadeite forms a thick bed, or perhaps dyke, in this serpentine rock. Hundreds of the natives work in an enormous quarry loosening blocks of the tough intractable stone by the primitive method of fire-setting. The bulk of this jadeite is a snow-white, fine-grained stone resembling marble, in which irregular patches of the beautiful emerald-green material are enclosed. The latter is the more valuable material specially sought for by the Burmese and Chinese. The larger part of the output remains in Burma or is exported into China; only a small amount being sent to Europe.

Applications of nephrite and jadeite. — *Nephrite* was employed in prehistoric times as the material for stone implements and weapons; these are often beautifully finished, and were perhaps used only for ceremonial purposes. The axe-head represented in plate 66, fig. 11 was fixed in the crown of a deer's antler and this mounted on a wooden stick. In Europe, such nephrite implements are found principally in the neighbourhood of the Alps, in Switzerland, southern Baden, and Bavaria. In southern Asia and more especially in the east, nephrite remains to the present day a favourite material for all kinds of ceremonial and ornamental objects, such as amulets, ring-stones, rings, bowls, vases, boxes, cups, sword- and knife-handles. Elaborate designs and groups of men and animals, similar to those cut in agalmatolite, are also carved with infinite patience. Spheres, ovoids, discs, and cylinders are bored for use as necklets. The cylinders are bored in the direction of their length, and resemble the ancient Assyrian cylinder-seals and the Trojan rolls. In western countries nephrite is coming more and more into favour for ornamental objects. Umbrella- and knife-handles, and even bowls, are now cut at Oberstein in Germany. Owing to the toughness of the material, the working consumes much time, and consequently even these modern reproductions are costly. A number of ancient nephrite objects, artistically worked and ornamented with gold and valuable precious stones, are preserved in the Green Vaults at Dresden.

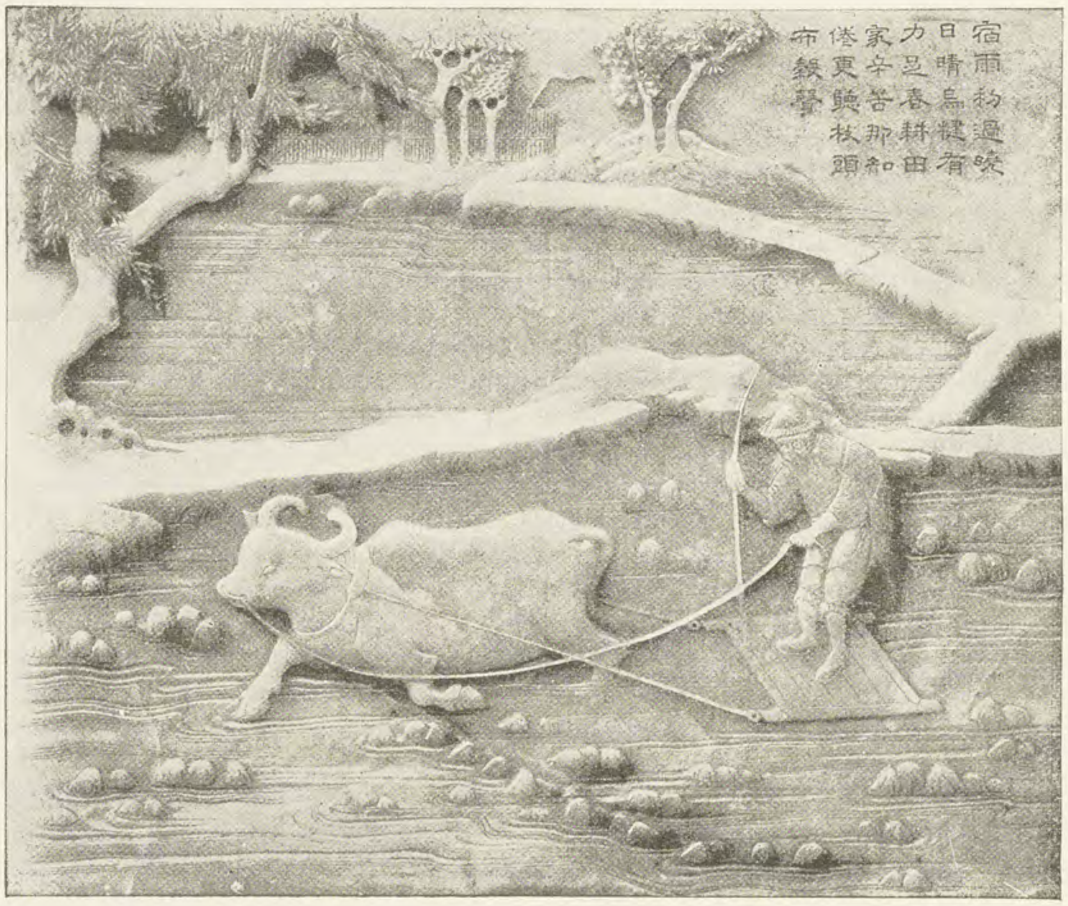

Fig. 235.
Chinese carving in Jadeite.

Jadeite is put to practical the same uses as nephrite, only it is less abundant. Worked objects, more especially flat axe-heads, of jadeite are found mostly in the north-west of France, whither they were carried as charms against evil. They were built into the foundations and walls of some of the huts as a protection against lightning. Ancient jadeite objects are also of wide distribution in North, Central, and South America. Some of these have the form of plates and long thin rods, which when struck emit a musical note. The famous Aztec ceremonial axe in the Berlin Museum was brought from Mexico by Alexander von Humboldt.

A valuable example of Chinese carving in jadeite is represented on a reduced scale in the accompanying text-fig. 235: the original measures 25·2 by 21·7 centimetres. The work is of the finest quality, and we marvel at the skill and patience of the artist. The text-figure suggests a reproduction of a painting rather than a carving executed in a particularly hard and tough stone. In the corner is engraved a verse of Chinese poetry*) in praise of the peasant.

Attention may be here called to the remarkable work entitled "Investigations and Studies in Jade" (New York, 1906), descriptive of the unique collection of the late Heber R. Bishop, which was presented by him to the New York Metropolitan Museum of Art. In two huge and sumptuous volumes nephrite and jadeite are dealt with from every possible point of view, whilst the numerous plates are veritable works of art. An edition of one hundred copies was privately printed and distributed amongst the important libraries of the world.

Mica Group.

The minerals belonging to this group possess a cleavage in one direction so perfect that their material can be readily split into the thinnest sheets. All of us are familiar with the mica windows of oil-stoves and the mica chimneys of incandescent gas-burners. If the metal binding of one of these chimneys be removed we shall see that the mica springs back from its curved cylindrial form into a flat sheet. Thin sheets of mica are thus elastic as well as flexible. Some other minerals, e. g. chlorite, which possess a cleavage like that of mica, are flexible but not elastic: the sheets can be bent, but when released they do not spring back to their original position. With the sheet of mica which we have taken out of the lamp chimney we shall be able to demonstrate the other characters of the mineral.

When the sheet is placed in the polariscope we see, using convergent light, a good optical interference-figure, as represented in plate 4, figs. 3 and 4. With most sheets of mica the two black hyperbolic brushes will be widely separated in the field of view; whilst with other specimens, particularly of brown mica, these brushes are very close together in the centre of the field. We thus see that mica is optically biaxial, and that the optic axial angle may be either large or small. This observation proves that mica must belong to either the rhombic, monoclinic, or triclinic system of crystals. It cannot belong to the hexagonal system as is usually suggested by the external form of the crystals (plate 68, figs. 1—6), since hexagonal crystals give a uniaxial interference-figure (plate 4, fig. 1).

In which of these three systems mica crystallizes is not so easily determined. It has, however, been found that etched figures artificially developed on the cleavage surfaces are symmetrical with respect to only one line (text-fig. 236). There can thus be only one plane of symmetry, and the crystals must therefore be monoclinic. We may take the cleavage direction as the basal plane of the monoclinic crystal. Approximately perpendicular to this are six faces, four of which may be taken as belonging to the unit vertical prism, and the remaining two as the clino-pinacoid parallel to the plane of symmetry (and consequently truly perpendicular to the basal plane). In the crystal shown in plate 68, fig. 2, the two narrow faces to the front are prism faces, and those to the right and left (not visible in the picture) belong to the clino-pinacoid. On very perfectly developed crystals the angle between the prism faces has been measured on the goniometer as 120° 11′. When

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*) In the German original a transcription and translation are given of this and compared with a fragment of Haydn's "Seasons".

the prism faces are more largely developed than the clino-pinacoid, the crystal may present a rhombic outline.

If the point of a darning-needle or nail is placed against a sheet of mica and struck a short, smart blow with a hammer, there is developed around the central hole a star of six rays. This is known as a "percussion-figure" and is shown in text-fig. 237 by the continuous lines. Two of these rays are parallel to the clino-pinacoid (*b*), and the four others each parallel to the four prism faces. We can now distinguish between the former and the latter by examining the starred cleavage plate in convergent polarized light. The narrower dark band joining the two eyes of the interference-figure (plate 4, fig. 3) is either perpendicular to or parallel to one pair of rays of the percussion-figure: these rays are then the ones parallel to the clino-pinacoid, that is, parallel to the plane of symmetry. It is thus possible, by means of the percussion-figure and the interference-figure to determine the orientation of any irregularly bounded sheet of mica or of a sheet which has been squared and cut with shears.

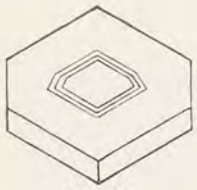

Fig. 236.
Etched figure on cleavage surface of Mica.

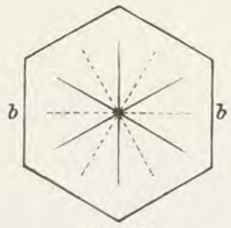

Fig. 237.
Percussion-figure on cleavage surface of Mica.

Those micas in which the narrower dark band of the interference-figure, that is, the plane of the optic axes, is perpendicular to a line of the percussion-figure are known as micas of the *first class*; those in which it is parallel are known as micas of the *second class*. This is more briefly stated by saying that in micas of the first class the plane of the optic axes is perpendicular to the plane of symmetry; whilst in the second class the optic axial plane is parallel to the plane of symmetry.

Another set of cracks is developed on a cleavage sheet of mica by pressing against it a blunt point. This is known as the pressure-figure, and is shown by the dotted lines in text-fig. 237; two of the six rays are perpendicular to the clino-pinacoid *b*, and the others perpendicular to the prism faces. Lines of this kind, probably developed in the mica by earth pressures, are shown in plate 68, fig. 4; the four shorter edges are here the prism edges, and the longer pair those of the clino-pinacoid.

The crystal-faces so far mentioned are those which are perpendicular or approximately perpendicular to the basal plane. In some crystals (plate 68, fig. 1) these faces are replaced by steeply inclined pyramids and dome faces. Although the cleavage surface is so bright and smooth, the other faces of mica crystals are generally dull and rough, and it is only rarely that more than approximate angles can be measured between the faces. Twin intergrowths of mica are of frequent occurrence, but as these are not easily recognized they need not be further mentioned in this place.

According to differences in chemical composition, several varieties of mica may be distinguished. They all contain silica, alumina, alkalis (potash, soda, or lithia), and the constituents of water; in addition, some contain fluorine, magnesia, and iron oxides. It is thus possible to distinguish as chemical varieties: potash-mica, soda-mica, lithia-mica, and magnesia-mica, each of which with now be described in turn.

Potash-mica or **Muscovite.** This contains no iron and is consequently of pale colours. In thin cleavage flakes it is transparent and almost or quite colourless. Thicker crystals may be grey (plate 68, fig. 2), greenish-grey (fig. 1), yellowish, brown, rarely green (fig. 3), or rose-red (fig. 7). The last-named colour is especially characteristic of lithia-mica, and the mineral of the occurrence represented in fig. 8 was formerly assumed to be a lithia-mica until it had been examined more closely. On the cleavage face the lustre

PLATE 68.

Mica and Chlorite Groups.

Fig.

1. **Muscovite** (potash-mica), prismatic crystal with basal cleavage, in quartz.
   New Jersey, U. S. A.
2. **Muscovite,** tabular crystal; prism, clino-pinacoid and basal cleavage.
   Bamle, Norway.
3. **Muscovite,** green, tabular crystals.
   Lincoln Co., North Carolina, U. S. A.
4. **Phlogopite** (magnesia-mica), large crystal viewed from above on the basal plane. The lines are the traces of slip-planes.
   Hull, Ottawa Co., Quebec, Canada.
5. **Biotite** (magnesia-iron-mica), cleavage flake.
   Ortenberg, Vogelsberg, Germany.
6. **Biotite,** thin, attached crystals.
   Monte Somma, Vesuvius, Italy.
7. **Muscovite,** of rose-red colour (and on this account formerly considered to be lepidolite).
   Goshen, Massachusetts, U. S. A.
8. **Zinnwaldite** (lithia-iron-mica), with zonal banding.
   Zinnwald, Erzgebirge, Bohemia.
9. **Chlorite,** variety Leuchtenbergite.
   Shishimskaya Mountains, Zlatoust, Urals.
10. **Chlorite,** variety Penninite. Prismatic crystal with basal plane.
    Zermatt, Switzerland.
11. **Chlorite,** variety Clinochlore. Group of tabular crystals.
    West Chester, Pennsylvania, U. S. A.

Stuttgart (Fritz Lehmann).


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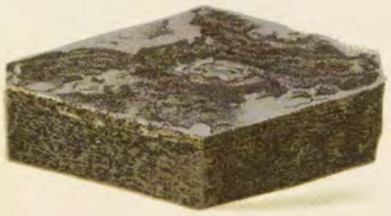
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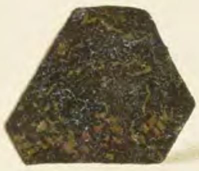
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is bright and pearly, while other faces are dull and rough. The hardness is low (H. = 2), and the specific gravity about 3.

The cleavage flakes show in convergent polarized light a biaxial interference-figure (plate 4, figs. 3 and 4) with the two hyperbolic brushes widely separated, the optic axial angle being large. This angle in air varies from 60° to 70°. The plane of the optic axes is perpendicular to the plane of symmetry, so that muscovite is a mica of the first class. The strength of the double refraction differs greatly in different directions: on the basal cleavage it is low, whilst in sections across this it is strong. The reason for this is that while two of the principal indices of refraction have very nearly the same value, the third is widely different. Thus the values for sodium-light were determined as 1·6068, 1·6011, and 1·5718. The difference between the first and second of these is only 0·0057, but between the first and third the difference amounts to 0·0350. Thin cleavage flakes therefore give in parallel polarized light interference-colours of low orders, whilst thin sections across the cleavage polarize in colours of high orders.

Potash-mica when of ideal purity contains: silica (SiO_2), 45·3; alumina (Al_2O_3), 34·4; potash (K_2O), 11·8; water (H_2O), 4·5 per cent., corresponding with the formula $H_2KAl_3Si_3O_{12}$. Often, however, it contains also small amounts of soda and fluorine. Before the blowpipe the mineral is fusible only with difficulty; and the flame is coloured violet by reason of the potash present.

Hydrochloric and sulphuric acids have scarcely any action on potash-mica, neither have the waters and solutions which percolate through the rocks of the earth's surface. For this reason the mineral is very resistant to weathering. On the contary, it often occurs as a secondary product of the weathering of other minerals, such as felspar, andalusite, garnet, tourmaline, corundum, and many others. It is, at the earth's surface, the most stable of the micas, and for this reason is of wide distribution. In association with quartz and felspar it occurs as an essential constituent of many granites, gneisses and mica-schists; and when these rocks are broken down by weathering agents it forms part of the debris of which the sedimentary rocks are built up. Only in lavas is it conspicuous by its absence: in these rocks its place is taken by magnesia-mica.

As a rock constituent muscovite usually has the form of small irregular scales often measuring not more than a few millimetres across. In the coarser grained rock known as pegmatite the sheets of mica are occasionally of considerable size—several feet across. Crystals of muscovite bounded by crystal-faces are of much rarer occurrence. They are usually embedded in the quartz of the rock (plate 68, figs. 1 and 7) or attached to the walls of cavities (plate 68, fig. 3).

Enclosures of other minerals in muscovite are frequent and of special interest. Growing along with the mica between its planes of lamination these foreign minerals have been constrained to take a thin, flattened form. Thus crystals of garnet, which are so characteristically rounded or grain-like in form, when found embedded in sheets of mica have the form of thin plates with an almost circular outline. Tourmaline is found as thin, flattened prisms, and quartz as mere films; whilst magnetite is usually so thin that it is brown and transparent. That mica is capable of exerting some influence over the crystallization of other substances is shown by the following simple experiment. An aqueous solution of potassium iodide when allowed to crystallize on a glass plate produces a crop of thick cubes. If, on the other hand, the solution is crystallized on a clean, fresh cleavage sheet of mica, the crystals of potassium iodide take the form of flattened octahedra: and not only this, but the tiny crystals are all regularly orientated in the same direction on the sheet of mica, one of their triangular edges being parallel to the optic axial plane of the mica.

As a rock constituent potash-mica is of such wide distribution that is possible to mention only a few of the more important localities. Attached crystals are found with rock-crystal in cavities in the granite of St. Gotthard, especially in the neighbourhood of the hospice; at Abühl in the Sulzbachthal, Salzburg; Mursinsk in the Ural Mountains; as crystals 25 centimetres in length and 15 cm. thick in the Ilmen Mountains; as beautiful green crystals in Lincoln Co., North Carolina (plate 68, fig. 3). Embedded crystals are more common; for example, in quartz from New Jersey (plate 68, fig. 1); the isolated crystal from Bamle, Norway (fig. 2); rose-red crystals from Goshen, Massachusetts (fig. 7). Plumose mica, often with very delicate forms, is found in the granite at Aschaffenburg, Heidelberg, Pressburg in Hungary, and near Dublin. Large sheets, occasionally measuring as much as 10 feet across, are found in the Indian mica mines in Bengal and Madras. The production of Indian mica in 1908 amounted to 2310 tons, valued at £73,124. Considerable amounts used for technical purposes are also produced at various places in the United States. The commercial mica obtained in large quantities from Canada and Ceylon is a magnesia-mica and not potash-mica.

Applications.— Mica (or perhaps gypsum, or both of them) was known to the Romans. According to Pliny it was used in place of glass for the windows of foundries and beehives. At the present time it is much used for the windows of oil-stoves, lamp chimneys, eye shields, and in fact for any purpose where a transparent material capable of withstanding considerable changes in temperature is required. Being a bad conductor of electricity, and on account of its flexibility, mica is now used in large quantities for the construction of electrical machinery of various kinds. For this purpose scraps of mica are often cemented together to form a material known as "micanite" or "micanite cloth". The preparation of mica for the market is quite a simple operation. The "books" of mica taken from the mines are easily split into sheets of the required thickness, and these are trimmed to size with shears.

A popular name for mica is *Maria-glass* (*glacies Mariae*), because spangles of mica have long been used for decorating statues of the Virgin. In popular usage it is often called talc, but this is quite a distinct mineral (p. 342). Again, clear sheets of gypsum are often mistaken for mica, but this is not flexible and elastic like mica, and when exposed to heat it becomes white and opaque.

Soda-mica or **Paragonite.** This is analogous to potash-mica in composition but with sodium in place of potassium. As small scales it forms a white, glimmering rock called paragonite-schist. This is found at Monte Campione, near Faido on the southern slopes of St. Gotthard; and is represented in plate 51, fig. 1, as the matrix of crystals of cyanite and staurolite. The mineral is also met with on the Island of Syra, and on Lake Superior in North America. It always occurs as a constituent of crystalline schists and is not of wide distribution.

Lithia-mica. Two kinds of mica contain lithium as an essential constituent: these are distinguished by the absence or presence of iron, the former being known as lepidolite and the latter as zinnwaldite. Both are easily fusible before the blowpipe and impart a crimson coloration, characteristic of lithium, to the flame. Lepidolite is more closely related to the micas described above, whilst zinnwaldite is more allied to the magnesia-micas.

Lepidolite is usually met with as scaly aggregates, and on this account it receives its name, from the Greek, λεπίς, λεπίδος, a scale. The words lepidoptera, lepidodendron, and many others are derived from this root. Distinctly formed crystals are of quite rare occurrence. In colour the mineral shows a wide range, being white, grey, greenish, rarely blue, but as a rule of a delicate shade of rose-red or peach-blossom-red. This characteristic red colour is due to the presence of a little manganese. A fine scaly aggregate of lepidolite is represented in plate 48, fig. 8, as the matrix of rose-red tourmaline.

Of the alkalis contained in lepidolite, potash always predominates (9—12 per cent.); the lithia ranges from 3 to 6 per cent.; and in addition some specimens contain rubidium (up to 3·7 per cent. of rubidia Rb_2O, but usually much less) and caesium (up to 0·5 per cent. Cs_2O). Further, lepidolite almost always contains some manganese ($1—5^1/_2$ per cent. MnO); and fluorine is always present (4—8 per cent.). The percentage of silica ranges from 49 to 52, and of alumina from 20 to 30. The mineral is thus very variable in chemical composition, and only in part is it represented by the formula $(K, Li)_2Al_2Si_3O_9(F, OH)_2$. The best test for recognizing the mineral is to hold a small flake in the Bunsen-flame; it fuses quite readily to a white bead and imparts a crimson colour to the flame. The specific gravity is 2·8—2·9.

Lepidolite always occurs in connexion with granitic rocks, more usually in veins of granite-pegmatite, in which it is usually associated with red tourmaline (rubellite). It is not a mineral of wide distribution. A few of the more important localities are: Penig in Saxony; Rozena in Moravia; Schuttenhofen in Bohemia; Alabashka in the Urals; Mount Mica near Paris, and elsewhere in Maine, where blocks of a hundredweight have been found; Madagascar, etc. The largest deposits are those mined at Pala in San Diego Co., California (plate 48, fig. 8), where in 1901 the output of 1750 tons was valued at 43,200 dollars.

Applications. — The pretty rose-red spangled lepidolite from Moravia has occasionally been cut and polished in small slabs for making boxes, etc. The mineral is the most important source of lithium salts, which are used mostly in medicine. Rubidium and caesium salts are also extracted, but these are now mostly obtained from the mother-liquors of the Stassfurt potash-salts. These two rare alkali metals are present as traces in many mineral-waters, and it was in the mother-liquor from the brine of the Dürkheim spring that R. Bunsen discovered these chemical elements. From 240 kilograms of the mother-liquor, remaining from 44,200 kilos of the brine, he obtained 9 grams of rubidium chloride and 7 grams of caesium chloride. These metals give very characteristic flame-spectra, and it was during his classic work on spectrum analysis that Bunsen detected their presence in such small quantities. Lithium, the commonest of these three elements, is remarkable in being not only the lightest metal, but the lightest of all kinds of solid matter, its specific gravity being only 0·59. It is a silver-white metal which so far has found no practical application.

Zinnwaldite is a kind of lithia-mica containing iron. It receives its name from its most important locality, namely Zinnwald in the Bohemian Erzgebirge. It is sometimes found as large six-sided plates, but more often as small crystals grouped in fan-shaped aggregates. Containing a considerable amount of iron, the crystals are coloured yellowish-grey or brown, the colours being often arranged in zones, as is well shown in plate 68, fig. 8. In the crystal here figured we also see a series of fine lines perpendicular to the outer edges. Since this crystal is only a fragment taken from a close aggregation with other crystals, only two of the six possible edges are present, and correspondingly there are only two sets of the fine lines, and also only a portion of the zoning shown. This fine striation is the result of an intimate twin intergrowth.

The chemical composition of zinnwaldite may be explained by the mixture of the lepidolite molecule with a molecule of iron silicate, as expressed by the formula $(K, Li)_2Al_2Si_3O_9(F, OH)_2 + Fe_2SiO_4$. An analysis of zinnwaldite from Zinnwald gave the following results:

SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MnO.	K_2O.	Li_2O.	F.	H_2O.
46·44	21·84	1·27	10·19	1·57	10·58	3·36	7·62	1·04 per cent.

Traces of rubidium, caesium, and thallium are also sometimes present. Before the blowpipe the mineral fuses readily to a black slag, and it imparts a crimson coloration to the flame. Specific gravity 2·9—3·1. The most important locality for zinnwaldite is Zinnwald in Bohemia, where it is found grown on quartz, together with cassiterite, fluorspar and scheelite, in the veins of tin ore. The crystals are not often so large as the one represented in plate 68, fig. 8, being usually 1—2 cm. across.

Magnesia-mica or **Biotite.** As a rule this mica is darkly coloured, either dark brown or dark green, and it is then readily distinguished from potash-mica: sometimes, however, the colour is as pale as that of potash-mica. Of the specimens represented in plate 68, the dark brown crystal in fig. 5 could not be mistaken for any other kind of mica; whilst the crystals in fig. 6 are so pale in colour that they might readily be confused with potash-mica, if one did not recognize the specimen as one of the very characteristic ejected blocks of Monte Somma, Vesuvius, in which potash-mica never occurs. The large crystal in fig. 4 might also from its light colour be mistaken for potash-mica, and only on closer examination would it be found to be a magnesia-mica.

The contrasting of potash-mica and magnesia-mica as done in the last paragraph is not quite correct, for both of them contain a considerable amount of potash, only the latter contains magnesia in addition. To avoid misunderstanding it is best to use the name muscovite in place of potash-mica. Of the magnesia-micas, those of a dark colour and rich in iron (magnesia-iron-mica) are distinguished as *biotite*, whilst the paler coloured with little iron are called *phlogopite*. The crystals in plate 68, figs. 5 and 6, belong to biotite, and that in fig. 4 to phlogopite. Many mineralogists regard phlogopite as a distinct species, and not as a variety of biotite.

These two kinds of magnesia-mica can be readily distinguished from muscovite by their optical characters. In convergent polarized light the black hyperbolic brushes of the interference-figure are very close together; in other words, the optic axial angle is small. In some brown biotites this angle is practically zero, so that the interference-figure instead of being as in plate 4, fig. 4, very closely resembles that in fig. 1. Such mica had for long been regarded as optically uniaxial, but closer investigation proved that, like all other micas, it is really biaxial and monoclinic. Another distinction is that biotite and phlogopite are micas of the second class, the optic axial plane being parallel to the plane of symmetry, whilst muscovite is a mica of the first class (p. 330). Darkly coloured biotite is strongly dichroic; this dichroism is not observable on the cleavage planes, but only in sections across the cleavage. To cut a cross-section from an isolated crystal would not be possible because of the perfect cleavage; nevertheless, we have plenty of opportunities of observing cross-sections in thin slices of rocks. These have a rectangular outline, often with frayed ends, and show sharp cleavage cracks parallel to their length. They sometimes very closely resemble longitudinal sections of hornblende*) crystals, but differ from these in always giving straight or very nearly straight extinction with respect to the cleavage cracks. When the section is rotated with respect to one of the nicol prisms, the strong dichroism in evident by the change in colour from pale yellow to dark brown.

Cleavage sheets of phlogopite sometimes show a peculiar optical effect when a small flame is viewed through them. Radiating from the centre of the source of light a bright six-rayed or twelve-rayed star is seen. This phenomenon, known as ***asterism***, is caused by the presence of vast numbers of microscopically minute needles of rutile embedded in the mica along three or six directions.

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*) In the explanation of plate 67, fig. 4, the crystal shown in thin section has been, in fact, incorrectly described as biotite, instead of hornblende. (Compare p. 323.)

Magnesia-mica, of all the micas, occurs in the best crystals. Those of biotite (plate 68, figs. 5 and 6) are mostly small with the form of thin, six-sided plates. The small faces on the edges are sometimes (on crystals from Monte Somma) so smooth and bright that the angles between them can be accurately measured, and the crystals so proved to possess monoclinic symmetry. On the other hand, crystals of phlogopite are usually of large size and with rough faces: they not infrequently show lines of the pressure-figure, as in plate 68, fig. 4. An enormous crystal of phlogopite, found in a mica mine near Sydenham in Frontenac Co., Ontario, measured $1^{1}/_{2}$ by 2 metres on the cleavage surface, while perpendicular to this the crystal had a length of over 5 metres ($16^{1}/_{2}$ feet). Such a crystal would be rather too large for a private collection of minerals.

The chemical composition of the magnesia-micas is very variable, since magnesia and ferrous oxide, and alumina and ferric oxide are mutually replaceable. A general formula expressing this is $(K, H)_2(Mg, Fe)_2(Al, Fe)_2Si_3O_{12}$, which is in agreement with the analysis of many biotites. An analysis, by F. Berwerth, of biotite from Monte Somma, Vesuvius, gave:

SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MgO.	K_2O.	H_2O.	F.	
39·30	16·97	0·48	7·86	21·89	7·79	4·02	0·89	per cent.

Here the percentage of ferric oxide is low, but in some other biotites this may be as high as 20. In phlogopite the iron is low, and the ratio of silica to bases is rather different than in biotite.

Biotite is the most widely distributed of all the micas. It occurs not only in granite, gneiss, and mica-schist, like muscovite, but also in volcanic rocks. In granites, etc., it takes the form of irregularly bounded scales or sometimes larger plates; whilst in volcanic rocks the small plates have regular six-sided outlines. Sharp crystals of brown biotite are especially found in volcanic ashes and sands; for example, in the Vogelsberg (plate 68, fig. 5), Westerwald, and Laacher See district in Germany, and in the Midland Mountains of northern Bohemia. The best crystals are those in the ejected blocks of Monte Somma, Vesuvius (fig. 6). Large crystals of phlogopite occur at South Burgess in Ontario, Hull in Quebec (fig. 4), and several other localities in Canada.

Besides occurring as a constituent of granite, syenite, diorite, minette, trachyte, porphyry, and basalt, gneiss and mica-schist, biotite is also developed in various rocks by the result of the contact action of igneous rocks; and phlogopite is especially characteristic of crystalline limestones. At the earth's surface, biotite is not so stable as muscovite. When exposed to atmospheric weathering it becomes bleached and is altered to muscovite or to a green chloritic substance.

Chlorite Group.

The minerals of the chlorite group, like those of the mica group, possess a perfect cleavage in one direction, and their crystals are six-sided in outline. Like the micas, they are also monoclinic in crystallization, but here it is possible that some of them may be really rhombohedral. The cleavage flakes, though flexible, are not elastic: and another important difference from the micas is in the absence of alkalis and fluorine. All the chlorites contain silica, alumina, magnesia, and water; in some species the magnesia is replaced by variable amounts of ferrous oxide, and the alumina by ferric oxide. Those containing iron are green or bluish-green in colour; and on this account the name chlorite is applied — from the Greek χλωρός, green. According to differences in chemical composition and crystalline form the following more important varieties are distinguished.

Penninite. In its external form penninite shows rhombohedral symmetry. The simplest crystals (plate 68, fig. 10) are bounded by a very steep rhombohedron and the basal pinacoid. Parallel to the latter there is a perfect, pearly cleavage, but the natural crystal-face is rough, as shown in fig. 10. The angle between the rhombohedral faces is $114^1/_2{}^0$, and these form an angle of 104^0 with the base.

The optical characters of penninite are also in agreement with the rhombohedral form. Cleavage flakes show in convergent polarized light a uniaxial interference-figure (plate 4, fig. 1), but owing to the very low double refraction the rings are widely separated. In spite of this, many investigators hold that penninite is monoclinic, and they explain the uniaxial character by the presence of repeated twinning. The mineral is strongly dichroic: a transparent crystal when viewed through a rhombohedral face shows a deep blood-red colour, but when viewed through the basal plane the colour seen is bluish-green. Sections cut perpendicular to the basal plane show in the dicroscope brownish-red and green pairs of colours.

The hardness of penninite is low — about $2^1/_2$ on the scale. The specific gravity of a crystal from Zermatt was determined as 2·65. Analysis, by Hamm, of material from the same locality gave:

SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MgO.	H_2O.	
33·71	12·55	2·74	3·40	34·70	12·27	per cent.

This composition can be expressed by the formula $H_8(Mg, Fe)_5(Al, Fe)_2Si_3O_{18}$. The mineral is decomposed by hydrochloric acid with the separation of silica.

Penninite occurs as attached crystals, which are often aggregated together in druses, in crevices in chlorite-schist and similar rocks. The locality of the typical mineral is Zermatt in Switzerland (plate 68, fig. 10): here, on the Rympfischwäng on the Findelen glacier, and on the Gornergrat, it is found as crystals, 3 to 4 cm. in length and thickness, in crevices in actinolite-schist and chlorite-schist, and is associated with crystals of magnetite, garnet, and calcite. Other localities are in the Binnenthal in Switzerland, the Ala valley in Piedmont, and the Zillerthal in Tyrol.

A variety of penninite coloured a rich peach-blossom-red by chromium (5 per cent. Cr_2O_3) is known as *Kaemmererite*. This is found on chromic iron-ore at Lake Itkul in the Urals, at Kraubat in Styria, and Texas in Lancaster Co., Pennsylvania.

Clinochlore. In external appearance clinochlore (plate 68, fig. 11) does not differ from penninite. The name signifies that the crystals belong to the monoclinic system; this degree of symmetry is sometimes suggested by the form of the crystals, but it can only be determined by goniometric measurement. A cleavage flake gives in convergent polarized light a good biaxial figure (plate 4, figs. 3 and 4), thus differing from penninite. All the other characters, however, resemble those of penninite. The colour is bluish-green. For comparison with the penninite analysis quoted above, the following, by Clarke and Schneider, is given of clinochlore from West Chester in Pennsylvania.

SiO_2.	Al_2O_3.	Fe_2O_3.	Cr_2O_3.	FeO.	MgO.	H_2O.	
29·87	14·48	5·52	1·56	1·93	33·06	13·60	per cent.

Calculating the ferric oxide and the chromic oxide with the alumina, and the ferrous oxide with the magnesia, this analysis gives the formula $H_8Mg_5Al_2Si_3O_{18}$, similar to that of penninite.

Clinochlore occurs as attached crystals, as large lamellar masses, and as fine scaly aggregates. In the last-named form it is abundant as a constituent of chlorite-schist, which as the matrix of magnetite is represented in plate 29, fig. 1, and of perovskite in plate 40, figs. 1 and 3. The attached crystals are usually associated with garnet, magnetite, and occasionally with sphene (plate 40, fig. 10). They are sometimes placed singly on the matrix, or again they may be closely crowded together on the rock surface. By the approximately parallel grouping of small scales, rosettes and vermicular forms result.

The largest crystals of clinochlore are from West Chester in Chester Co., Pennsylvania; these have the form of six-sided plates (plate 68, fig. 11) or of thick crystals with triangular basal planes. Fine crystals are also found at Achmatovsk in the Urals, and smaller ones on the Mussa-Alp in the Ala valley in Piedmont, on the Schwarzenstein in the Zillerthal and near Pfitsch in Tyrol, at Kupferberg in the Fichtelgebirge in Bavaria, etc.

A variety of clinochlore containing but little iron, and of a yellowish-white or greenish-white colour, from the neighbourhood of Zlatoust in the Urals, is known as *leuchtenbergite* (plate 68, fig. 9). The close similarity between the crystals here represented and those of clinochlore in fig. 11 is at once evident. This mineral was so named, after Maximilian, Duke of Leuchtenberg, in the belief that it represented a distinct species.

Besides the few varieties of the chlorite group here described there are many others which have been distinguished by special names.

Chlorites often occur as secondary minerals resulting from the weathering of biotite, garnet, augite, etc. Earthy chlorite is sometimes used as a green paint; and the "green earth" of Monte Baldo near Verona, used for the same purpose, is in part composed of chlorite.

Olivine.

Olivine is a mineral of interest from several points of view. It occurs as an essential constituent of rocks of various kinds; and by its weathering it gives rise to certain widely-distributed secondary minerals. When found as clear, transparent pieces it has been used since early times as a gem-stone. Again, its presence in meteoric stones and irons, sometimes as bright crystals rich in faces, proves to us that the laws of chemical combination and crystalline structure are the same in other parts of the universe as in our own world.

The chemical components of olivine are silica, magnesia, and iron (ferrous) oxide, the two latter being present in variable and mutually replaceable proportions. An olivine specially rich in iron, found in the glassy basalt at Limburg in the Kaiserstuhl, Baden, has received the special name *hyalosiderite*. A small amount of nickel is frequently present in olivine; and it is a noteworthy fact that nickel ores often occur in association with olivine-bearing rocks—for example, the important nickel ore garnierite (p. 174). Traces of manganese and aluminium are also sometimes present, although these do not appear in the following analyses of olivine.

	SiO_2.	MgO.	FeO.	NiO.
I. Olivine from the Vogelsberg, Hesse .	40·09	50·49	8·17	0·37
II. Olivine from "The Orient"	39·73	50·13	9·19	0·32
III. Olivine from the Pallas meteoric iron	40·86	47·35	11·72	—
IV. Hyalosiderite from Limburg, Baden .	36·72	31·99	29·96	—

In all cases the composition of olivine can be expressed by the formula $(Mg, Fe)_2SiO_4$. The member of the series containing little or no magnesium, and with the formula Fe_2SiO_4, is known as *fayalite*; this is found in cavities in a glassy volcanic rock in the Yellowstone National Park in the United States, and in a granitic rock in the Mourne Mountains in

Co. Down, Ireland. The member at the other end of the series, and consisting of nearly pure magnesium silicate, Mg_2SiO_4, is known as *forsterite*; this is found as almost colourless crystals in the ejected blocks of Monte Somma, Vesuvius, and in some crystalline limestones of contact-metamorphic origin. These two extremes of the olivine group are, however, of exceptional occurrence, and they need not be further mentioned in this place.

The name olivine is applied to this mineral on account of its characteristic olive-green colour, which is often to be seen in the grains and nodules found embedded in basaltic rocks (plate 69, fig. 4). The isolated, clear crystals are usually pale yellowish-green (plate 69, figs. 1 and 2), and as gem-stones (fig. 3) are known as *chrysolite* and *peridot.* The name chrysolite as used by Pliny was applied to some other mineral, which was perhaps yellow topaz—really a more appropriate application of the term. Peridot is a name that has long been employed by French jewellers, and it is also adopted by French mineralogists instead of the name olivine.

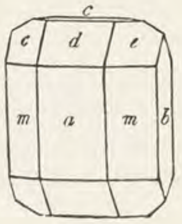

Fig. 238.
Crystal of Olivine.

Crystals of olivine belong to the rhombic system, and it is only exceptionally that they show more than a few faces. In text-fig. 238, *m* is the unit vertical prism ∞P, *a* the macro-pinacoid $\infty P \bar{\infty}$, *b* the brachy-pinacoid $\infty P \breve{\infty}$, *c* the base $0 P$, *e* the primary pyramid P, and *d* the unit macro-dome $P \bar{\infty}$. These faces correspond with those seen on the crystal in plate 69, fig. 6, though here the base and the brachy-pinacoid are absent. The small crystals in figs. 1 and 2 are bounded by the large ortho-pinacoid, and in addition a brachy-dome in here largely developed.

Of much more frequent occurrence than crystals are irregular grains embedded in the rock; and these are usually easily to be recognized as olivine by their characteristic olive-green or oil-green colour. They are clear and transparent or only translucent, and possess a glassy lustre. The smaller grains show an irregular or sub-conchoidal fracture; but larger ones sometimes show even fractures, or cleavages, parallel to the faces of the two pinacoids. The hardness is about the same as that of quartz, and the specific gravity (3·3 — 3·4) near that of augite. When finely powdered, the mineral is completely decomposed by hydrochloric acid with the separation of gelatinous silica. The refractive power and the double refraction are high; the greatest and least indices of refraction being 1·697 and 1·661 for sodium-light.

The characters last named are of great assistance in the recognition of olivine when thin sections of rocks are examined under the microscope. A form of cross-section frequently seen is that represented in plate 67, fig. 5; in this figure the fine lines are cleavage cracks. In thin sections the mineral is colourless and transparent, and, owing to the high index of refraction, the surface appears rough and pitted. This roughness of surface is best seen when the nicol beneath the stage of the microscope is lowered in its holder (but for fig. 5 this was not done, in order that the clearness of the picture might be preserved). As a consequence of the strong double refraction, thin sections of olivine show brilliant polarization-colours between crossed nicols. Being a rhombic mineral the sections give straight extinction: the light is cut out when the longer (vertical) edges in fig. 5 are parallel to the vibration-direction of one or other of the nicols. Enclosures of other minerals in olivine are often to be seen under the microscope, grains and rounded octahedra of picotite (p. 226) being especially frequent.

Olivine is readily altered by weathering processes; water is taken up, and the mineral passes into serpentine. The large crystals represented in figs. 5 and 6, plate 69, though presenting the form of olivine, no longer consist of olivine substance, having been completely altered into serpentine: they are, in fact, pseudomorphs of serpentine after olivine. The crystal in fig. 5 is a simple one with its original form well preserved. The two large crystals in the upper portion of fig. 6 are united in twinned postion along the brachy-dome $P\breve{\infty}$; but such twins are of extremely rare occurrence in olivine. The grains of olivine found embedded in rocks are very frequently more or less altered to serpentine; and in thin sections all the stages of the process can be followed. The olivine crystal in plate 67, fig. 6, with the same characteristic outline as that in fig. 5, shows an outer zone of serpentine, and the penetration of the same material along a network of cracks in the interior of the crystal. Some of the olivine still remains unaltered, but as isolated grains embedded in the network of serpentine. As the weathering proceeds the serpentine continues to grow at the expense of the olivine, until the whole crystal is transformed into the serpentine substance $H_4Mg_3Si_2O_9$. This chemical change is accompanied by the separation of iron in the form of magnetite or other oxide of iron, which collects along the network of cracks. By such a process rocks rich in olivine have given rise to serpentine-rocks.

Other modes of alteration of olivine are also known. For example, when the mineral is rich in iron, as in hyalosiderite and the olivine of some basalts, the product of weathering is limonite (hydrated iron oxide). In some rocks containing much calcium the olivine may be replaced by calcite; and in some diabases of Upper Devonian age this in the usual mode of alteration of the olivine.

Olivine forms an essential constituent of basalt and of other related rocks, occurring as embedded grains and small crystals (plate 67, fig. 5), either uniformly distributed throughout the rock or aggregated in nodular masses (plate 69, fig. 4). These aggregations in basalt consist mainly of olivine, together with pale-brown and grass-green augite and grains of black picotite. Bombs of such aggregated material are ejected by some volcanoes, and are found in abundance in the ancient crater of the Dreiser Weiher, in the Eifel. In rocks of another class, olivine is the predominating constituent; for example, in peridotite and picrite (plate 67, fig. 6), the latter being so named because of the large amount of magnesia, or bitter-earth, it contains. A rock known as dunite, from Dun Mountain in New Zealand, consists almost entirely of olivine. Isolated crystals of olivine are found at a few places loose in volcanic ash; for example, at Forstberg in the Laacher See district, and in the Auvergne.

The source of the clear olivine suitable for cutting as gems has long been shrouded in mystery; such specimens have usually been vaguely stated to be from "The Orient" or from Egypt. The locality of the specimen in plate 69, fig. 3 is given as Spyrget Island in the Arabian Gulf. Recently, however, a description has been published of the occurrence of clear crystals of olivine in an altered dunite on the small island of St. John in the Red Sea. Most of the gem-material probably comes from this island, where the mining, a monopoly of the Khedive of Egypt, is jealously guarded. Clear fragments and crystals of olivine are also picked up in the deserts of Arizona and New Mexico, particularly from the ant-hills. The large pseudomorphs of serpentine after olivine (plate 69, figs. 5 and 6) are from Snarum, near Modum in Norway. The typical iron-rich hyalosiderite is found in a glassy basalt at Limburg in the Kaiserstuhl, Baden. As a constituent of a meteoric iron, olivine is represented in plate 31, fig. 7.

Application. — Clear olivine is cut for use as a gem-stone, being then often known as chrysolite or peridot. It is remarkable for its perfect transparency and strong lustre, but owing to its yellowish-green colour and comparative softness it is not a stone of great value. From coloured glass of similar appearance it may be readily distinguished by its higher specific gravity: in bromoform olivine sinks, whilst glass floats.

Serpentine.

As already mentioned in the description of olivine, serpentine is an alteration product of that mineral, although at times it also arises by the weathering of some other minerals. It possesses no distinct crystalline form, but occurs as fibrous, columnar, foliated, or compact masses.

Fibrous serpentine is yellow of various shades, and on account of this colour and the fibrous texture it receives the name *chrysotile* (not to be confused with chrysolite, p. 338). It occurs as veins in compact serpentine (plate 69, fig. 7), the fine fibres being arranged perpendicularly to be walls of the vein. The close aggregation of the fine fibres gives to the mass a beautiful and very characteristic silky appearance. When, however, the mass is rubbed, the fibres are readily separated, and being very flexible they form a wool-like mass. Such material possesses the external characters of asbestos (that is, the true asbestos or hornblende-asbestos, p. 321) from which it is distinguished by the name *serpentine-asbestos*. It forms, in fact, the bulk of the commercial asbestos, which is obtained largely from the serpentines in the province of Quebec in Canada. Chrysotile is found in serpentine-rocks at many localities; for example, at Reichenstein in Prussian Silesia (plate 69, fig. 7), Friedensdorf in Nassau, and the Lizard district in Cornwall.

The columnar and foliated varieties, known respectively as *metaxite* and *antigorite*, are of less importance. The purer varieties of massive serpentine occur as separations in veins and crevices. Such material is usually pale in colour — grey, or yellowish-green to dark-green — with a banded arrangement of different tints; it has a splintery or conchoidal fracture, and in thin sections under the polarizing microscope is seen to consist of an aggregate of very fine fibres. This form is known as *picrolite* (plate 69, fig. 8) or precious serpentine, and is identical with the material of the pseudomorphs after olivine already mentioned. Compact serpentine also largely occurs as a constituent of the rock masses in which it has originated, being then intermixed with other minerals, such as augite, pyrope, etc., which have resisted the weathering processes. Such material is distinguished as common serpentine.

The formation of serpentine from olivine can be observed at any of the places where ancient igneous rocks rich in olivine crop out at the earth's surface. It is seen that the alteration takes place quite close to the surface and along fissures, and is evidently brought about by atmospheric agencies as in ordinary weathering. The appearance of the partly altered material as seen under the microscope has already been described (p. 339), and in this place it will only be necessary to say a few words as to the chemistry of the process. This may be represented schematically by the following equation: from two molecules of olivine we deduct one molecule of magnesia and iron oxide and add two molecules of water:

$$\underset{\text{Olivine}}{2\,(\mathrm{Mg,\,Fe})_2\mathrm{SiO}_4} - (\mathrm{Mg,\,Fe})\mathrm{O} + 2\,\mathrm{H}_2\mathrm{O} = \underset{\text{Serpentine}}{\mathrm{H}_4(\mathrm{Mg,\,Fe})_3\mathrm{Si}_2\mathrm{O}_9}.$$

The magnesia that separates combines with carbon dioxide to form magnesite, a mineral which as compact, white nodules is sometimes found in association with serpentine. The iron (ferrous) oxide becomes in part oxidized with the production of magnetite. The water that is taken up is not merely absorbed, nor is it present as water of crystallization, but is enters into chemical combination with the magnesium silicate, and it can only be expelled again at a red-heat. For this reason the formula of serpentine is written in the form as given in the equation above, rather than as $(\mathrm{Mg,\,Fe})_3\mathrm{Si}_2\mathrm{O}_7 \,.\, 2\,\mathrm{H}_2\mathrm{O}$.

PLATE 69.

Olivine, Serpentine, Talc, Cordierite, Ilvaite.

Fig.

1. **Olivine** (Chrysolite), large crystal, somewhat water-worn.
   Egypt.
2. **Olivine** (Chrysolite), small, clear crystal.
   Egypt.
3. **Olivine** (Chrysolite), faceted.
   Spyrget Island, Arabian Gulf.
4. **Olivine,** a large crystal with cleavage surface, and granular masses; in (so-called blue) basalt.
   Langsdorf, Lich, Upper Hesse.
5. **Olivine,** altered to serpentine. Group of crystals; the two larger are in twinned position.
   Snarum, Norway.
6. **Olivine,** altered to serpentine; simple crystal.
   Snarum, Norway.
7. **Serpentine,** variety Chrysotile. Fibrous veins in common serpentine.
   Reichenstein, Prussian Silesia.
8. **Serpentine,** variety Picrolite. From palaeopicrite.
   Mornshausen, Biedenkopf on the Lahn, Germany.
9. **Ilvaite** (or Lievrite), isolated, prismatic crystal with pyramid and narrow macrodome.
   Rio la Marina, Island of Elba, Italy.
10. **Cordierite** (or Dichroite) portion of a large crystal with a little copper-pyrites on the surface.
    Orijärvi, Finland.
11. **Talc,** variety Steatite. Pseudomorphous after quartz.
    Thiersheim, Wunsiedel, Fichtelgebirge, Bavaria.
12. **Agalmatolite,** Chinese carving.
13. **Talc,** lamellar aggregate.
    Zillerthal, Tyrol.


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When free from iron, serpentine contains: silica (SiO_2) 43·5, magnesia (MgO) 43·5, and water (H_2O) 13 per cent. The amount of iron may reach 10 per cent., but only rarely exceedes this. By the addition of alumina, serpentine may become altered into chlorite — and this mineral may also be formed by the weathering of an aluminous magnesium silicate such as augite. A rock consisting originally of olivine and augite may thus be altered by weathering into a mixture of serpentine and chlorite.

Massive serpentine, often penetrated by veins of chrysotile, is of wide distribution. In Germany, it is met with in the Vosges, at Todtmoos in the Black Forest, at Biedenkopf and Dillenburg in Nassau, the Fichtelgebirge in Bavaria, as large masses at Zöblitz in Saxony, and at Reichenstein and Kosemitz in Silesia. In the Austrian Empire, at Pressnitz in Bohemia, Kraubat in Styria, etc. Other localities are Zermatt and elsewhere in Switzerland; Prato near Florence in Italy; near Ekaterinburg, etc., in the Urals. The greater part of the Lizard peninsula in Cornwall is composed of serpentine; and serpentine-rocks are also found in Anglesey and at several places in Scotland.

The olivine-rocks from which serpentine has been derived are frequently the home of useful minerals of various kinds; for example, diamond and pyrope, mispickel, magnetite, chromite, platinum, chrysoprase, and nickel ores.

Applications. — Serpentine-asbestos finds the same applications as the true asbestos (p. 321), but it is not capable of resisting high temperatures to the same degree, since it loses water and becomes brittle. Common serpentine is carved and turned into vases, lamp-stands, bowls, and a variety of ornamental objects, large numbers of which are made in Cornwall from the Lizard serpentine. Being compact and not very hard (H. = 3, as of marble) it is easily worked, and it takes a good polish. Formerly it was believed that serpentine acted against poisons, especially the vemon of serpents; and on this account apothecaries used mortars made of serpentine in preference to those of other materials.

Meerschaum.

In the worked form of bowls for tobacco-pipes and cigar- and cigarette-holders, meerschaum is known to everybody as a compact, white material with dull lustre and somewhat the appearance of ivory. It is well adapted for these uses, being fairly soft and readily cut, compact though light, and at the same time sufficiently porous to absorb moisture. Meerschaum is a German word meaning "sea-froth" or in French *écume de mer*. Mineralogists sometimes call this mineral by the name sepiolite, as suggested by a resemblance to the light, porous material known as the bone of the cuttle-fish or sepia.

Rough meerschaum is found in nature as irregular nodules. It is opaque and white, pale grey, or creamy in colour; and so porous that it adheres to the tongue and floats on water. On a fresh fracture it is dull and earthy in appearance; but when rubbed, even with the finger-nail, the surface becomes smooth and shining. The reason for this is that the particles of the soft, porous material become more closely pressed together.

The nodules, as found, are scraped free from earthy material with a special kind of knife, yielding peculiar shaped masses with rounded surfaces. The pieces are then air-dried, polished with wax, and sorted into various grades according to size and quality. Pieces too small and impure for carving are crushed and made into a paste with water. In this paste a sort of fermentation is set up by the addition of suitable organic matter, and in this way the earthy impurities are separated. The purified paste is then pressed into moulds. The presence of organic matter in such articles of compressed meerschaum is demonstrated by the fact that when heated they blacken, and finally become white when more strongly burnt.

In its chemical composition meerschaum is closely related to serpentine; it contains the same constituents, but these are combined in other proportions, the formula being $H_4Mg_2Si_3O_{10}$. Like talc and serpentine, it is thus a hydrated magnesium silicate. Further, like serpentine, it is a product of weathering, representing perhaps a more advanced stage in the alteration; at any rate it is always found in association with serpentine.

Practically all the meerschaum that comes into the market is obtained from the plain of Eski-Shehr in Asia Minor, where it is dug from a number of shallow pits by the inhabitants of the Turkish villages. According to K. E. Weiss, a large part of the production at the present day is from the mines of Sarysu and Sepetchi situated between 20 and 30 kilometres to the east of Eski-Shehr at the foot of the hills bordering the wide valley of the Pursak-Chai (or Tembris river). The meerschaum-bearing rock is a soft, tuff-like breccia, which contains, in addition to the nodules of meerschaum, numerous fragments of serpentine and some of limestone. The majority of the meerschaum nodules are not larger than a medium-sized apple, and only exceptionally are they as large as a man's head. The pits vary in depth from 3 to 40 metres.

Other localities for meerschaum are of little importance. It is found in the Lyubic Mountains in Bosnia, and at Hrubschitz in Moravia.

The chief manufacturing centre of meerschaum goods is Vienna, but there is also a flourishing industry at Ruhla near Eisenach in Germany, whence smokers' requisites made of meerschaum and amber are sent to all parts of the world.

Talc Group.

Talc. Whilst some minerals are distinguished by their high degree of hardness, talc is remarkable for its softness; it is, in fact one of the softest of minerals, and is chosen to represent No. 1 in the mineralogist's scale of hardness (p. 51). For this reason it is greasy to the touch; and it is easily scratched, even by the finger-nail. The foliated or lamellar masses possess a perfect cleavage parallel to their large surface, and thin scales may be readily detached. These cleavage flakes are easily bent, and when released they do not spring back to their original position; so that the mineral, although flexible, is not elastic like mica. On the cleavage surfaces the lustre is markedly pearly in character. Distinctly developed crystals of talc are not known: the mineral occurs only as foliated (plate 69, fig. 13), scaly, or compact masses. The colour is white, yellowish, or more often a delicate shade of apple-green with a silvery appearance, as represented in the picture. The specific gravity is about 2·7. Thin cleavage flakes are transparent, and when examined in convergent polarized light they exhibit a biaxial interference-figure. In many of its characters talc shows a resemblance to the micas and chlorites, and, like these, its system of crystallization is probably monoclinic.

In chemical composition talc is related to serpentine and meerschaum in that it contains the same elements, but these are combined in other proportions. It is a hydrated magnesium silicate with the formula $H_2Mg_3Si_4O_{12}$, which corresponds with the percentage composition: silica (SiO_2) 63·52, magnesia (MgO) 31·72, and water (H_2O) 4·76. A small portion of the magnesia may be replaced by an equivalent amount of ferrous oxide (up to 2 per cent. FeO). Like serpentine, talc is also a mineral of secondary origin produced by the alteration of other magnesium silicates. For this reason it is usually found in association with serpentine and chlorite, together with various other minerals (magnesite, dolomite, magnetite, and actinolite) formed as by-products by the same processes of alteration. Alone it forms the rock called *talc-schist*, and when intermixed with more or less chlorite it constitutes the scaly or compact *potstone*.

Talc is found in the crystalline schists of mountainous districts; for example, in the Zillerthal in Tyrol (plate 69, fig. 13), Mautern in Styria, the St. Gotthard district in Switzerland, in the Urals, etc.

Applications. — Owing to its smoothness and softness, powdered talc is much used as a toilet-power; for smoothing the floors of dancing rooms, and as a dry lubricant. Potstone may be turned in the lathe, and fashioned into fire-proof vessels or pots, and into fire-proofs slabs. In former times talc was used as a medicine.

Steatite. This is a compact, massive variety of talc, which owes its name to the fact that it is greasy or fatty to the touch: the popular German name Speckstein ("lard-stone") also has the same meaning. It is white, pale yellowish, or greyish in colour, and sometimes shows marble-like markings. It has a dull, earthy fracture, but when rubbed the surface becomes smooth and shining.

Although showing no crystalline form of its own, it not infrequently assumes the forms of the crystals proper to some other minerals. Such pseudomorphous crystals are of interest, and more especially so when we find that the original mineral which the steatite has replaced is the very resisting quartz. The six-sided pyramids shown in plate 69, fig. 11, have exactly the same characteristic form as the crystals of quartz represented in plate 51, yet the material of which they consist is opaque, dull, and quite soft: they are, in fact, pseudomorphs of steatite after quartz. Steatite also forms pseudomorphs after many other minerals; for example, dolomite, enstatite (plate 65, fig. 1), topaz, etc. A well-known locality for these pseudomorphs, and one which has yielded sharply defined specimens after a variety of minerals, is Göpfersgrün near Wunsiedel in the Fichtelgebirge, Bavaria. They occur in a bed of limestone, which, near its contact with granite, has been largely replaced throughout the whole of its mass by steatite, and the minerals contained in it have likewise suffered the same alteration. It is probable that the changes have been effected by hot solutions containing magnesium salts that emanated from the intruded granite.

Applications. — Steatite is the most suitable material for making the tips of gas-burners, since it can be readily cut into the required shape, and in the flame it does not fracture or fuse, but only becomes harder. The annual production in the Fichtelgebirge amounts to about 2500 tons of the value of £14,500. In Griqualand, South Africa, steatite is carved by the natives into tobacco-pipes.

Agalmatolite. This is a collective term applied to a variety of compact but quite soft minerals which are used by the Chinese for carving into idols and grotesque figures (plate 69, fig. 12). The name means in Greek "statue-stone"; and pagodite, another name applied in the same sense, was suggested by the miniature pagodas carved in these materials. These terms are thus descriptive of the uses of the material, rather than as defining the kind of mineral. They are analogous to the term asbestos (p. 321), which is often applied generally to any flexible mineral fibres that can be spun and are not combustible. As a matter of fact, at least three distinct kinds of minerals are employed for these Chinese carvings, and thus to be included under the general term agalmatolite.

One of these belongs to the species pyrophyllite, a hydrated aluminium silicate related to kaolin. Another is identical with steatite, a hydrated magnesium silicate. A third has the same chemical composition of muscovite or potash-mica (p. 330). This variety of mica is composed of extremely fine scales and has been produced by the alteration of other minerals.

All these possess in common a close, compact structure, and yet they are so soft that they are very easily cut with a knife. In colour they are usually grey or greenish-grey, with splashes and veins of more pronounced red or green colours. These variations in the colour of the material are often skillfully utilized in the carving (plate 69, fig. 12).

Nothing is known as to the mode of occurrence of these materials; and indeed we known very little about the minerals of the vast Chinese Empire.

Cordierite.

In certain gneissose rocks there are sometimes to be seen yellowish and bluish, translucent to transparent grains possessing a glassy lustre, which at first sight might very well be mistaken for the common mineral quartz. When, however, these grains are examined more closely it will be found that one and the same grain shows a bluish or yellowish colour according to the direction in which it is viewed. The mineral is thus strongly dichroic, and cannot therefore be quartz. This peculiar character is exhibited much more strikingly by the rolled pebbles of the mineral from Ceylon; these show, when viewed successively in three different directions at right angles, one or other of the three colours dark-blue, pale-blue, and pale-yellow. When a dichroscope is employed any two of these colours can be seen simultaneously in the instrument. On account of this strong dichroism (or rather trichroism) the mineral is often known as dichroite. The name cordierite is after the French mineralogist P. L. Cordier, who was the first to notice the dichroism of this mineral.

In some of its characters, besides in its general appearance, cordierite shows a resemblance to quartz; the mean refractive index of 1·54, the low double refraction, the hardness of about 7, and the specific gravity of 2·6 all being very nearly the same as for quartz. These similarities are, however, accidental, for the two minerals are not in the least related to one another.

Crystals of cordierite (plate 69, fig. 10) have the form of short, stout prisms terminated by a large basal plane. Their faces are rough and the edges rounded; and good, sharply-developed crystals are very rare. The prism is often six-sided with quite the appearance of an hexagonal crystal; but measurement of the angles between these faces shows that we are dealing with a combination of a rhombic prism and a brachy-pinacoid. The angle of the rhombic prism is 119° 10′; and the crystals belong to the rhombic system. In the picture other prisms are also present, and all the faces in the prism-zone are deeply striated vertically: at the top, and perpendicular to the prism, is the large, rough basal plane.

Cordierite consists mainly of silica (51·36 per cent.), alumina (34·96 per cent.), and magnesia (13·68 per cent.); but a portion of the magnesia is always replaced by an equivalent amount of ferrous oxide (FeO 1—9 per cent.), and there may also be a small quantity of water present. The last constituent is probably due to a slight alteration of the mineral, for cordierite is very readily attacked by weathering processes, yielding potash-mica as a final product. Altered cordierite has at different times received a variety of names (pinite, gigantolite, fahlunite, aspasiolite, etc.) in the belief that distinct species were represented. The chemical formula of pure, unaltered cordierite is as yet not exactly known; the percentages given above correspond to $Mg_2Al_4Si_5O_{18}$.

In thin sections cordierite is colourless and transparent, and, the dichroism being now scarcely perceptible, the mineral may easily be mistaken for quartz. Cordierite is, however, frequently associated with the fibrous mineral sillimanite; and along fissures it usually shows a cloudiness due to a finely fibrous aggregation of altered material: quartz, on the other hand, is always perfectly fresh. Another characteristic feature of cordierite is the presence of pleochroic halos around spots in the crystal: these yellow halos are seen to come and go as the stage of the microscope with the section is rotated over the lower nicol-prism (the upper nicol being removed).

As already remarked, cordierite occurs as a constituent of certain gneisses, and as water-worn pebbles, clearly derived from the same rocks. It is also sometimes found in pyrites deposits in gneissose rocks. A well-known locality is near Bodenmais in the Bavarian Forest, where crystals associated with greyish-green felspar (plate 61, fig. 7) are found in pyrrhotite on the Silberberg. The large crystal represented in fig. 10, plate 69, is from Orijärvi in Finland, where cordierite occurs with copper-pyrites and iron-pyrites, specks of which still remain attached to this crystal. Other localities are: Cabo de Gata in Spain; Kragerö, Arendal, and Tvedestrand in Norway; Haddam in Connecticut; and, as smooth, rounded pebbles, in the gem-gravels of Ceylon.

Application. — The transparent, blue pebbles are cut as gem-stones, but care must be taken that the direction of cutting is such that the blue colour will be shown to the best advantage. On account of this colour, the mineral is also known as *water-sapphire* or *lynx-sapphire*, the former name being applied to pale coloured stones and the latter to those of a deeper blue. From the true sapphire (blue corundum) it is easily distinguished by its much lower hardness and specific gravity; it also possesses much less brilliancy of lustre, and is more strongly dichroic than sapphire.

Ilvaite.

The last mineral to be described in this section does not properly belong to the rock-forming minerals, for it is of quite exceptional occurrence. It is, however, a silicate, and as it is met with in very fine crystals it deserves mention in this place. As seen from fig. 9, plate 69, and text-fig. 239, the crystals belong to the rhombic system. They are bounded by two rhombic prisms ($M = \infty P$ and $S = \infty \breve{P}2$) the faces of which are striated vertically; a rhombic pyramid ($o = P$); and a macro-dome ($P = P\bar{\infty}$) which truncates the front edges of the pyramid. A small basal plane and a second macro-dome are also shown in fig. 9.

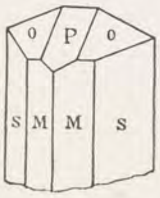

Fig. 239.
Crystal of Ilvaite.

The colour is iron-black, and fresh crystals display a very brilliant lustre. The mineral, however, weathers rather easily, becoming dull and brown, and finally passing into limonite. This alteration suggests the presence of iron; and, in fact, the mineral is richer in iron and poorer in silica than any of the silicates that we have considered. The essential constituents are silica, iron (ferrous and ferric) oxide, and lime, and in addition there are small amounts of manganese oxide and water. An analysis by Städeler of ilvaite from Elba gave:

SiO_2.	Fe_2O_3.	FeO.	CaO.	MnO.	H_2O.	
29·34	20·84	34·12	12·78	1·01	2·43	per cent.

corresponding with the formula $H_2Ca_2Fe''_4Fe'''_2Si_4O_{18}$. Before the blowpipe, the mineral readily fuses to a black, magnetic bead. The specific gravity is 3·9—4·1.

The best crystals of ilvaite come from Rio Marina on the Island of Elba; and it is from the old name, Ilva, of this island that the mineral receives its name (another name, also in common use, is lievrite). The crystals are found in pockets in the iron ore, taking the place of haematite. The finest crystals are preserved in the Senckenberg Museum at Frankfurt-on-Main, and were long ago collected in Elba by the famous German traveller E. Rüppell: that represented in fig. 9 is one of this set.

Radiating and compact masses of ilvaite with small, thin crystals have been found in the neighbourhood of Herborn in Nassau. The two localities mentioned are the only ones of any importance for this mineral.

◆

Mineral Salts.

General.

Amongst the minerals which we have so far considered there are many that are regarded by the chemist as salts, although they do not fall in with the popular idea of a salt. None of them have a salty taste and none (with the exception of copper-vitriol, p. 112) are readily soluble in water. The latter will now be dealt with, commencing with the indispensable common salt, the salt of salts; and then the potash-salts and saltpetre, of such importance as artificial fertilisers. Next we have the lime salts, which also are of importance in that they enter largely into the composition of the hard parts, the shells and bones, of animals. Finally, there are some other salts that find a variety of useful applications in technical processes.

We thus see that the minerals of this chapter are to a large degree necessary for the nutrition of plants and animals; and they are utilised in the great chemical industries, supplying, either directly or indirectly, products that are now almost necessities in everyday life.

The mineralogist, who attaches so much importance to crystalline form, will find in some of the minerals to be described very little of interest, since they occur only as unattractive, granular masses, and the enumeration of their essential characters need only be brief. Such salts may, however, play an important part in industry and agriculture, and they will consequently be treated here at somewhat greater length than in many of the textbooks on mineralogy.

If we consider for a moment the many and far-reaching applications of rock-salt and the potash-salts we begin to perceive the enormous extent to which these are utilized in the chemical industries. The raw materials of little value are converted by human intelligence, organisation, and work into products of greatly increased value; and when these products of chemical industry are utilized in connexion with agriculture they bring to a country more wealth than is yielded by the richest gold mines. Results such as these stimulate scientific research, and thereby the well-being and wealth of nations are increased.

Rock-salt.

When in ordinary life we speak of salt we mean the white, granular powder with which we savour our food, little thinking, perhaps, that it is one of the stones of the earth's crust. It is, indeed, a direct mineral product of nature, and may be obtained by simply crushing rock-salt: it is the only mineral that, without further preparation, forms part of our nutriment.

The pleasant saline taste is, of course, a characteristic feature of this substance; but there are several other characters which are of interest to the mineralogist, to whom, by the way, the mineral is often known as halite. The clear, spar-like masses obtained in salt-mines are seen to possess perfect cleavages in three plane directions at right angles to one another, along which the mass is readily broken when struck with a hammer. The resulting fragments have the form of cubes; and further, we find that the three cleavages are equally perfect and not to be distinguished the one from the other. We may, therefore, conclude that these cleavage fragments are true cubes, and consequently that rock-salt crystallizes in the cubic system.

Natural crystals of rock-salt of a distinct form are not of frequent occurrence. A simple cube bounded by natural crystal-faces (not cleavage surfaces) is represented in plate 70, fig. 1: the fine cracks parallel to the edges of the cube indicate the presence of the cubic cleavage. Crystal-forms other than the cube are rare. Small octahedra (plate 70, fig. 3) are found embedded in carnallite; and on crystals obtained artificially from solutions containing urea a hexakis-octahedron has been observed. Such forms are, however, quite exceptional, and the simple cube is a highly characteristic form for rock-salt. Artificially formed crystals frequently show sunken areas on the cube faces, and in extreme cases the crystal may be shaped like a hopper or funnel (text-fig. 241, p. 354). As a rule, however, the mineral is found as cleavage and granular masses, often penetrated by strings of gypsum and anhydrite. Crevices in such massive material are sometimes filled by a fibrous form of rock-salt, the fibres being set perpendicularly to the walls of the crevice (plate 70, fig. 2). When intermixed with clayey material we have salt-clay.

In the cleavage cube of blue rock-salt shown in plate 70, fig. 4, there is seen at the upper right-hand corner a diagonally-placed surface perpendicular to the front face of the cube. This surface has the position of a face of the rhombic-dodecahedron, but it is not a natural crystal-face. It is a surface of secondary separation produced by the pressure of earth movements when the rock-salt was still buried in the rocks of the earth's crust. The same result can, indeed, be produced artificially by the application of pressure. To effect this a clear cleavage cube is placed diagonally in a vice so that two cube edges are held by the jaws: on turning the screw, the cube falls into two pieces along a diagonal parallel to a face of the rhombic-dodecahedron. One of the halves so obtained by artificial means is shown in plate 70, fig. 5; the striated and diagonally-placed surface (perpendicular to the front face of the cube) is the surface of separation. The separation has been brought about by the slipping of one half over the other along this surface, which is therefore known as a plane of gliding or *glide-plane*. This is quite distinct from a cleavage-plane; and any attempt to produce a separation in this direction by placing a knife diagonally across a cube face of rock-salt, and striking a sharp blow with a hammer, results only in the production of the usual cubic cleavage. There is, however, a very simple test which may be applied to ascertain whether a mineral possesses glide-planes. A blunt point — a nail often serves the purpose, or better still a steel punch with a rounded point — is placed on the surface to be tested, and the punch is struck a smart blow with a small hammer. On a cleavage face of rock-salt there are thereby produced two clean cracks perpendicular to the surface and each parallel to a diagonal of the cube face; the two cracks forming a four-rayed star about the point of percussion. The surfaces of these internal cracks are thus parallel to two faces of the rhombic-dodecahedron, and consequently have the same direction as the glide-planes produced by a simple pressure. This test is known as the punch test, and the figure produced is called a *percussion-figure*. A figure of the same character, but six-rayed instead of four-rayed, may be similarly produced on a cleavage surface of mica (p. 330).

When exposed to a moist atmosphere, rock-salt attracts water to itself; and this is especially the case when the salt contains some admixed magnesium chloride. The film of moisture so deposited on the surface dissolves some of the salt, and there are then formed, on a natural cube face or a cleavage surface, a number of small pits closely crowded

PLATE 70.

Rock-salt, Sylvite, Cryolite, Boracite.

Fig.

1. **Rock-salt** (or Halite), a clear cube.
   Wieliczka, Galicia, Austria.
2. **Rock-salt,** fibrous.
   Berchtesgaden, Bavaria.
3. **Rock-salt,** octahedron.
   Leopoldshall, Anhalt, Germany.
4. **Rock-salt,** blue cleavage mass.
   Stassfurt, Prussia.
5. **Rock-salt,** cleavage fragment with glide-faces produced by pressure.
6. **Rock-salt,** with zonal enclosures of petroleum.
   Storunia, Galicia, Austria.
7. **Sylvite,** cube with octahedron.
   Stassfurt, Prussia.
8. **Cryolite,** crystals on the surface of massive cryolite.
   Ivigtut, Greenland.
9. **Boracite,** rhombic-dodecahedron with cube and tetrahedron.
   Lüneburg, Hannover. Prussia.
10. **Boracite,** cube with rhombic-dodecahedron and both tetrahedra.
    Lüneburg, Hannover, Prussia.
11. **Boracite,** cube with rhombic-dodecahedron and one tetrahedron.
    Lüneburg, Hannover, Prussia.
12. **Boracite,** rhombic-dodecahedra in gypsum.
    Lüneburg, Hannover, Prussia.

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together. These pits, or *etched figures* (fig. 240), have the form of square pyramids sunk into the surface, each being bounded by four triangular planes inclined to the cube face at only a small angle. These new planes have the position of the faces of a flat tetrakis-hexahedron; and when they are abundantly developed on the edges of the cube they may produce a bevelling of these edges. The form is then a combination of the cube and a tetrakis-hexahedron, as shown in text-fig. 28. Such a form does not occur on a growing crystal of rock-salt, but only on a partly re-dissolved crystal. These forms of the etched figures prove that rock-salt possesses the full degree of symmetry of the cubic system.

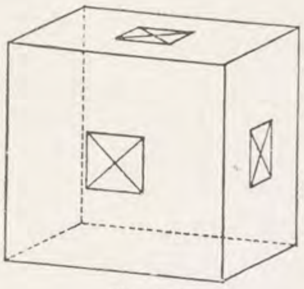

Fig. 240.
Etched figures on Rock-salt.

Chemically, rock-salt is sodium chloride and consists of 60·6 per cent. of chlorine combined with 39·4 per cent. of sodium, corresponding to the formula NaCl. In the colourless flame of the Bunsen-burner it fuses readily (at 775° C.) and colours the flame an intense yellow. This affords a simple test for distinguishing between the minerals rock-salt and sylvite, which are very similar in appearance: the latter gives a violet coloration to the flame. The yellow light of the sodium-flame is a homogeneous or monochromatic light, containing no rays of other wave-lengths. For this reason the sodium-flame is used as a source of light in determining the refractive indices and other optical constants of crystals. The intereference-figures represented in plate 4 were photographed in sodium-light, since they are shown much more sharply in monochromatic light than in white light. A good sodium-flame may be obtained with a bead of fused sodium chloride supported in a loop of platinum wire; or still better by supporting the salt on a sheet of asbestos card, through a round hole in which the flame of the Bunsen-burner passes.

The fact that salt possesses a taste indicates that it is soluble in water; and it is indeed one of the most readily soluble of minerals. 100 parts of water are capable of dissolving 36 parts of salt. Unlike many other substances, the degree of solubility is only slightly influenced by the temperature: a boiling solution contains no more than 39 parts of salt in 100 parts of water.

It is well known that when salt is scattered on snow the latter becomes melted; and it is also common knowledge that when ice and salt are mixed together the mixture becomes extremely cold — such a freezing mixture being often used for making ice-cream. In a mixture of three parts of ice with one of salt the temperature falls to — 18° C.; this being the freezing point of a solution of sodium chloride in water of these particular proportions. With some other salts still lower temperatures are reached; for example, a mixture of calcium chloride and ice cools to — 37° C.

Being a cubic mineral, rock-salt is singly refracting and optically isotropic. This can be readily demonstrated by placing a clear cleavage fragment in the polariscope between crossed nicols: it remains dark in all positions. If a piece should show here and there feeble double refraction, this is the result of strain and proves that the fragment has been subjected to pressure. The index of refraction is low, being 1·5442 for sodium-light. Clear cleavage blocks of rock-salt are perfectly transparent, not only to light rays, but also to heat rays — in other words, the material is diathermanous to a high degree.

Amongst the colours shown by rock-salt, the blue presents points of special interest. It may range from a deep, intense blue to bright sky-blue (plate 70, fig. 4), or at times it may be of a purple shade. The intensity of the coloration often varies in different parts of the same piece of rock-salt, and sometimes shades off into colourless portions. When the salt is dissolved in water the colour disappears, and the same happens when the mineral is heated. Chemical analyses have failed to reveal the presence of any known colouring matter in the material. The blue colour may be produced artificially by exposing colourless rock-salt to the action of cathode rays or by heating it in a vapour of metallic sodium. Attempts have been made by numerous investigators to solve this curious problem; much has been written on the subject, and various explanations as to the cause of the mysterious blue colour have been offered, but the matter has not yet been finally settled. According to one explanation, the colour is due to the presence of sodium subchloride Na_2Cl.

Other colours than the blue shown by rock-salt are due to the presence of mechanically enclosed impurities, which separate as a deposit when the salt is dissolved in water. Thus a red colour in rock-salt is due to intermixed ferric oxide, grey to clay or anhydrite, and brown to organic matter. These finely divided particles produce a cloudiness, or even opacity, in the rock-salt. Usually they are distributed throughout the mass without any orderly arrangement; but sometimes they are collected in layers parallel to the faces of the cube, so marking out a zonal structure in the crystal. A quite exceptional example of this is shown in the cleavage plate of rock-salt represented in plate 70, fig. 6. Here the mineral encloses crude bituminous petroleum, in alternately greater or lesser quantities as shown by the darker and lighter bands of colour. We see also that during the growth of the crystal there have been slight variations in its form: at times the edges of the cube were quite sharp, while at other times they were truncated. (A similar variation in form during growth is shown by the crystal of barytes in plate 76, fig. 2.) Rock-salt and petroleum are frequently found together in nature; and it has been assumed that salt plays some part in the formation of petroleum.

Enclosures of colourless liquid and of gas are also frequent in rock-salt. The cavities containing a liquid and a bubble of gas are sometimes of appreciable size, and the movement of the enclosed bubble can be readily seen as the specimen is turned about in the hand. The walls of these cavities are parallel to the cube faces of the enclosing crystal, and the cavities themselves are sometimes square or long and rectangular in shape. The liquid is a concentrated aqueous solution of salt, and the gases consist mainly of hydrocarbons; they are sometimes confined under a considerable pressure — corresponding to the pressure under which the rock-salt was formed. When such rock-salt, enclosing gases under pressure, is dissolved in water, the gas escapes with a crackling noise owing to the bursting of the cavities. Or when the salt is heated, the expansion of the gas causes the mass to burst, scattering fragments in all directions. Salt that behaves in this manner is called decrepitating salt (German, *Knistersalz*). When free from enclosures, salt does not decrepitate, even when heated to its melting point.

The specific gravity of rock-salt is quite low, being only 2·15. The hardness is also low, being slightly higher than that of gypsum.

Pseudomorphs after rock-salt, having the form of cubes with sunken faces, are not infrequently found on the surfaces of the bedding planes of shales and other rocks. These are not, however, alteration pseudomorphs produced by the decomposition of the mineral, but are due to the removal of the salt in solution. The material of the pseudomorphs is the same as that of the enclosing rocks. The mode in which they were formed must have been somewhat as follows. During a dry period, at the time when the rocks were deposited, the shores or mud flats of a salt-lake became dried up and the salt crystallized. Some of the crystals that were formed on the surface would perhaps become covered over with a layer of dust or fine mud, which on hardening in the sun would form a mould of the crystal. With the return of wet conditions the salt would be re-dissolved and the cavity filled with a new deposit of mud, and this finally covered over with a protecting layer of sediment, now represented by the next stratum of shale.

Occurrence and Origin. — Sodium chloride in a dissolved form is of extremely wide distribution in the waters of the globe. There is scarcely a brook that does not contain at least traces of salt in solution. Although the relative amount of salt present in fresh water is only minute, yet if the streams flow into a land-locked basin, where the solution will be concentrated by evaporation, they give rise to an accumulation of salt and the formation of a salt-lake. Springs of salt-water also issue at the earth's surface at many places: the saline taste is perceptible when the amount of salt exceeds one per cent., but many springs contain much larger quantities. When we consider the vast amount of salt present in the ocean (with the ratio of land to water as 1 : 2·54), we see that, next to water, salt is the most abundant of mineral substances at the earth's surface.

Although this statement is true for dissolved salt, it does not hold good for the solid mineral, or rock-salt. The latter, owing to its ready solubility in water, is only exceptionally met with at the earth's surface. A hill of pure and compact rock-salt near Cardona in Spain has been quarried since the time of the Romans: and similar occurrences at the surface are known near the Ilek river in the Russian government of Orenburg, and at a few places in Transylvania. On the other hand, beds of rock-salt of enormous extent occur buried in the rocks of the earth's crust in several regions. In some of these beds extensive mines are worked, whilst evidence of the presence of others is given by salt-springs and the brine pumped up through bore-holes.

Rock-salt occurs mostly as thick beds and masses in sedimentary rocks, in association with deposits of gypsum and anhydrite, and protected from inflowing water by a covering of anhydrite, gypsum, or clay. Such beds of rock-salt are not confined to any one geological period, but occur distributed throughout the whole range of the sedimentary strata, as indicated in the following table*): —

Geological formation.	Locality.
Recent	Deserts and Steppes: Kirghiz Steppes; Arabia; South America. Salt-lakes: Dead Sea; Great Salt Lake, Utah; Caspian Sea.
Tertiary	Bedded deposits: Cardona in Spain; Wieliczka, Bochnia, and Kalusz in Galicia, Austria; Transylvania; Asia Minor and Armenia; Rimini in Italy; Louisiana.
Cretaceous	Salt-springs at Unna, Westphalia. South of Medea in Algeria.
Jurassic	Salt-springs at Rodenburg, Hesse-Nassau. Bex in Switzerland.
Keuper	Salzderhelden and Celle in Hanover; Lorraine; Hall in Tyrol; Berchtesgaden in Bavaria; Ischl and Hallstatt in Upper Austria; Aussee in Styria; Cheshire and Worcestershire.
Muschelkalk	On the upper Neckar and Kocher in Württemberg; Ernsthall, Erfurt, and Stotternheim in Thuringia.
Bunter Sandstone	Schöningen near Brunswick; Arnshall near Arnstadt in Thuringia.
Permian (Zechstein)	Gera, Artern (Thuringia), Stassfurt, Egeln, Vienenburg, Halle, Sperenberg; Segeberg (Holstein); Inowrazlaw (Posen); Ilek river (Orenburg).

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*) From H. Credner, "Elemente der Geologie", 9th edit., 1902, p. 197.

Geological formation.	Locality.
Carboniferous	Kanawha river in West Virginia; Durham and Bristol coalfields in England.
Devonian	Saginaw valley in Michigan; Baltic Provinces; China.
Silurian	West Virginia; near Salina and Syracuse in New York State; St. Clair valley in Michigan; Ontario; Salt Range in India.

Although rock-salt is found in the formations of all periods of geological history, yet in particular districts the beds are limited to certain formations. This limitation suggests that during each period the geological and climatic conditions favourable for the accumulation and preservation of beds of salt obtained only in certain districts. Thus, as shown by the above table, these conditions prevailed in northern and central Germany during Permian times; in southern Germany at the time of the deposition of the Muschelkalk; in England and the Salzkammergut in the Keuper period; and in Galicia, Roumania, and Spain during the Tertiary.

In the rock-salt deposits the lowest stratum consists always of gypsum, above which are alternate layers of rock-salt and gypsum with thin seams of anhydrite, whilst the capping of the deposit consists of anhydrite, gypsum, or clay. At Sperenberg, near Berlin, the total thickness of these beds amounts to 1200 metres, whilst at Wieliczka in Galicia they attain a thickness of over 1400 metres (about 4600 feet).

Anhydrite and gypsum both consist, as we shall see farther on, of calcium sulphate, the former without and the latter with water. By the absorption of water, anhydrite becomes changed into gypsum, and the change is accompanied by a considerable increase in volume. This change has taken place more especially when the protecting covering of the deposit consists of gypsum rather than of anhydrite, and it has a particular significance in connexion with the preservation of the rock-salt deposits. When the protecting cover of anhydrite becomes cracked by earth movements, the fissures become filled up again by the swelling which accompanies the change from anhydrite to gypsum, and the percolating surface waters are thus excluded from the underlying rock-salt.

In a few districts, for example, between the Harz and the Thuringian Forest, the rock-salt is overlain by other salts — the so-called abraum-salts, to be described later — which are still more readily soluble in water. And only when these are present is a salt deposit a complete whole. Often, however, the formation of the deposit has not proceeded sufficiently far for these later salts to be laid down; or in certain cases if originally present they may at some later period have been re-dissolved and almost completely removed.

The mode of occurrence of beds of rock-salt leaves no doubt that they have been deposited from sea-water. A precipation of salt is, however, not possible in the open ocean, since the amount of salt present is relatively small. The water of the open ocean contains in 100 parts 3·433 parts of dissolved salts; and 100 parts of the solid salts contain 75·81 parts of sodium chloride, 3·62 of potassium chloride, 9·07 of magnesium chloride, 5·58 of magnesium sulphate, 4·73 of calcium sulphate, and 1·19 parts of sodium bromide. Sea-water is, however, so dilute a solution that these salts are not present as such, but are dissociated into their ions. Only when the solution becomes more concentrated are these combined, and when supersaturation occurs they separate as the solid salts.

Sea-water can only become supersaturated by extensive evaporation, and this can only take place in a closed basin or a land-barred gulf, such as the Dead Sea or the Kara-boghaz (in the Caspian Sea) of the present time. In former geological periods the constant variations in the outlines of the land and sea must have frequently given rise to the separation of such basins and gulfs from the main sea; and in these the water would be evaporated and the salt solutions concentrated. The dissolved salts separate from the solution in an order governed by their degree of solubility and by the relative amounts in which they are present. First the more difficultly soluble calcium sulphate separates as gypsum, forming the base of the deposit; and then follows the predominating sodium chloride as rock-salt. At later stages calcium sulphate is deposited in the anhydrous form as anhydrite. The reason for this being that in the more concentrated solution the dissolved potassium and magnesium salts exert a sort of attraction for the water, and constrain the calcium sulphate to crystallize in an anhydrous state. The frequent presence of seams of anhydrite alternating with beds of rock-salt may be explained by variations in the degree of concentration of the solution, brought about no doubt by the partial breaking down of the land barrier and the admission of a further supply of sea-water; or due perhaps to climatic variations. To the salt miners these seams of anhydrite are known as year-rings, and they believe that each one of them marks a year's growth of the salt-deposit. But it is to be noted that these anhydrite seams are not present in all salt-deposits.

It remains to be mentioned that rock-salt is also found as a volcanic product. It at times forms a white crust on the lava or a loose powder in the crater, and only rarely are distinctly-formed crystals met with. It owes its origin to the action of the hydrochloric acid, present in the volcanic gases, on the lava. The crust of chlorides so produced is not pure sodium chloride, but is intermixed with greater or less amounts of calcium and iron chlorides. As compared with the rock-salt of marine origin, that of volcanic origin is of no importance.

Winning of Salt. — In places where the rock-salt outcrops at the surface it is quarried just like any other kind of stone. When buried beneath the surface it is obtained by ordinary mining operations, or it is pumped up as brine.

Salt mines display a grandeur such as is not seen in other mines, and those of Stassfurt in Prussian Saxony and of Wieliczka in Poland have long been famous for their sights. An opportunity of visiting a salt mine should not be missed, and the underground trip is easily and comfortably made. The visitor descends the vertical shaft for a distance of 400 to 700 yards with perhaps somewhat unpleasant swiftness. From the bottom of the shaft a short dry level leads us into an enormous vaulted chamber, the glistening white walls, roof, and floor of which consist of crystalline rock-salt — literally a crystal palace. Between the several chambers, formed by the excavation of the salt, huge pillars are left for the support of the roof. To and from the main shaft there is a constant stream of laden and empty wagons; the hauling being done by horses which live for years down the mines, or by electricity which is also employed for lighting. At the end of our wanderings we find a table with a snow-white covering of powdered salt and lighted with candles set in clear blocks of rock-salt. Here we are offered bread and salt, the ancient symbol of trust and friendship; and although enraptured by the beautiful surroundings we are glad to find that it is not salt-water that is provided to quench our thirst in this salt-laden atmosphere. After filling our pockets with fine pieces of clear rock-salt, we return up the shaft to the dazzling daylight.

In the Salzkammergut and the neighbouring districts in Austria, the salt is won by a method of leaching. Galleries are driven into the salt beds, and into these "sink-works" (German, Sinkwerke) or reservoirs, fresh-water is admitted and allowed to remain for several weeks until saturated with salt. The well-known mines at Berchtesgaden in Bavaria, which are fitted up for the convenience of visitors, contain a huge cavern formed in this way, at the bottom of which a salt-lake is to be seen. From the water so left standing for long periods there are often deposited beautiful groups of gypsum crystals with the characteristic form of swallow-tail twins. The brine from these underground reservoirs is pumped up to the surface and is evaporated on the spot, or it may be conveyed in pipes to the salt-works. For example, some of the brine from Berchtesgaden is conveyed to Reichenhall and there, after being mixed with the brine from springs, treated in the salt-works. Here salt has been won in this manner for hundreds of years, whilst at Hallstadt in Upper Austria the graves of the salt workers date back to the first century before Christ. This method of winning salt forms a connecting link between the ordinary methods of mining and those of collecting brine from salt-springs and bore-holes.

At many places salt-springs issue at the earth's surface, and in other districts, for example, in Cheshire, the brine is pumped up through artificial bore-holes. The larger part of the salt of commerce does not consist of powdered rock-salt, but has been obtained from these natural and artificial brine-springs. As given by the solubility of salt in water a saturated brine should contain 27 per cent. of salt, but this maximum amount is never reached. One of the strongest brines is that of the natural spring at Reichenhall in Bavaria, which carries $25^1/_2$ per cent. of salt. As a rule, however, the brines from artifical bore-holes are the richest, whilst those of natural springs are often so dilute that they require considerable evaporation before the salt can be separated.

In the process of evaporating the brine, a saving of fuel is effected by first concentrating the more dilute solutions by exposure to the air. This is done in the "graduation houses", so called because the degree of concentration of the brine is measured by the graduations on the stem of a hydrometer. The method consists simply in allowing the brine to trickle over a stack of brush-wood and thorns, whereby a large surface is exposed to the air and evaporation accelerated. This is repeated several times, until the brine contains 18 to 26 per cent. of salt. During this process the less soluble calcium salts fall out of solution and form a thick, stony crust on the thorns. This material, known to the salt workers as thorn-stone, consists mainly of gypsum; when crushed, it is used as a manure.

The concentrated brine now passes to the boiling house, where it is further evaporated in large iron pans heated by fires or by steam. If the brine is allowed to stand undisturbed in these pans, the salt crystallizes out on the surface as large hopper-shaped crystals (text-fig. 241). These are built up of numerous minute cubes grown together in parallel position. They are square in outline with a deep funnel-shaped depression, and are weighted beneath by a solid cube of salt. They increase in size by the addition of material to the sides and base; and when the latter becomes too large, the floating crystals sink to the bottom of the pan. The specimen represented in the figure is from the salt-works at Friedrichshall in Württemberg. Crystals of this size are, however, unsuitable for use as cooking and table salt, and it is necessary to hinder their growth by stirring the evaporating brine. The minute crystals as they separate then fall to the bottom of the pan, and the salt is obtained as a fine, white powder. This when dried is ready for use, and is the brine-salt, boiled salt, or white salt of commerce. Being purer than the salt obtained directly from rock-salt, it is better and at the same time much more expensive. Rock-salt is worth on an average 4s. 6d. per ton, whilst for boiled salt the price reaches 27s. per ton.

Fig. 241.

Hopper-shaped crystal of boiled white salt. (The crystal is tilted forward, showing the interior of the square hopper-like depression: beneath is a solid cube of salt.)

In the drying rooms a concentrated solution of brine drips from the shelves and frames on which the salt is supported; and in this way remarkable hollow stalactites of salt are formed. These are very delicate and friable, and are not easily preserved: when taken out of the hot drying room they absorb moisture from the air and melt away. In the old boiling house at Bad Nauheim, in Hesse, there are to be seen many very fine examples of these hollow stalactites. Here, as at some other health resorts, the salt-laden atmosphere of the graduation houses is inhaled by the invalid visitors.

The winning of salt from brine-springs and by leaching in underground reservoirs has been carried on for many centuries; and this ancient industry has left its mark in the names of places. "Hall" means in German "salt-works", and this word enters into the names of many places in Germany and Austria: for example, Hall, Halle, Hallein, Hallstatt, Reichenhall, Herzogenhall, and Friedrichshall, are all towns where the salt industry has been carried on or where the product has been marketed; Saale and Salzach are rivers along which the salt was carried; the Hallforst belonged to the salt-works for the supply of fuel; the Hallgraf possesses the mineral rights, and Hallburg is his castle. The workmen at the salt-works are called *Halloren*; and the *Heller* is a small coin formerly used in the salt towns. In the same way, "wich" as a termination in place-names is of frequent occurrence in the English salt districts; for example, Northwich, Middlewich, Droitwich, Dirtwich, Foulwich, Nantwich, and Shirleywich; and the buildings in which the salt is manufactured are known as wych-houses.

The largest and indeed inexhaustible supply of salt is that in the sea, the water of which contains on an average $3^1/_2$ per cent. of salts. Other salts besides sodium chloride are, however, present, and the unpleasant, bitter taste is due to the magnesium salts. Salt is won from sea-water on many coasts. At high tide the water is led into the ponds or salt-pans of the so-called salt-gardens or salterns, and there allowed to evaporate under the sun's rays. The product is the well-known sea-salt or bay-salt. The ancients inhabiting the coasts of the Mediterranean knew of no other kind of salt, and in the Homeric and early Roman periods the inland inhabitants were without even this form of salt. The salt-works established by the king Ancus Marcius (640—616 B. C.) were on the sea-coast at Ostia, and the produce was carried on the Via Salaria into the Sabine country. Also in later classical times the sea was the only source of salt, and even to the present day the industry flourishes in the Tyrrhenian and Adriatic Seas. Much salt is also now collected during the warm summer months on the Atlantic coasts of France and Portugal (see below, for the production of sea-salt in France).

Although a considerable amount of salt is collected from the sea, still larger quantities are obtained from salt-lakes, such as those lying to the east and north of the Caspian Sea, of which the best known is the Elton salt-lake, and from the salt-saturated steppes of the same region.

Production of salt.— The United States takes the first place amongst the salt-producing countries of the world: the quantity obtained from rock-salt, brine-wells, and by the evaporation of sea-water during the year 1908 amounted to 28,822,062 barrels of 280 pounds (= 3,660,608 metric tons), valued at over $1^1/_2$ million pounds sterling. Next come Germany, Russia, and the United Kingdom, each with an annual output of very nearly two million tons, the exact amount varying from year to year, so that sometimes one country and sometimes another takes the first place. In the United Kingdom the bulk of the salt is obtained from brine-wells in Cheshire, Staffordshire, Durham, Lancashire, Worcestershire, Yorkshire, Co. Antrim, and the Isle of Man. In Russia there are extensive deposits of rock-salt in the Bachmut district in government Ekaterinoslav; and lake-salt is obtained in large quantities in the governments of Bessarabia, Kherson, Taurida, and Astrakhan. France produces rather over a million tons per annum; and here the greater part is sea-salt obtained from the Mediterranean along the coasts of the departments Bouches-du-Rhône and Gard. The total production of sea-salt in France during

1908 amounted to 391,072 metric tons, valued at £ 251,316, whilst for the year preceding the production exceeded half a million tons. The production of salt in India also exceeds a million tons per annum; and Japan, Spain, Italy, and Austria also contribute considerable amounts. The total production of the whole world amounts to 13 or 14 million tons per annum.

Uses of Salt.— Of first importance is the use of salt in the preparation and flavouring of food. Water and salt are not only the most abundant of mineral substances, but they are also essential for the nourishment of man and animals. Water without salt is unpalatable, and indeed when absolutely pure it acts as a poison. The water of the poison-spring at Gastein in Salzburg has, owing to its purity, a deleterious effect on the digestion. Salt is essential for the formation of the gastric juice that promotes digestion. It has been estimated that an adult man requires 7·8 kilograms (17·2 pounds) of salt annually. Another important use of cooking salt depends on its property of preserving animal and vegetable matter from decay, and large quantities are for this reason used for salting fish and meat.

Being an essential commodity, salt has since ancient times been subjected to a tax, and it has in many countries proved a fruitful source of revenue. In Germany at the present day the tax on culinary salt amounts to £6 per ton, whilst the value of the salt itself is only 27s. With an annual consumption of 420,000 tons, this gives to the state a revenue of $2^1/_2$ million pounds sterling. In order to prevent the use of cattle salt for household purposes the untaxed salt is rendered unpalatable by the addition of train-oil, iron oxide, and wormwood; and that intended for industrial purposes is treated with train-oil and lamp-black, or with sulphuric acid and ammonia.

Besides being given to cattle, salt is used in agriculture as a fertilizing agent. Sodium chloride is not necessary for the growth of plants, but it acts beneficially in the soil by converting the combined calcium and potassium salts into a more soluble form. The use of salt for this purpose is, however, not extensive.

In various industries and technical processes salt finds numerous applications. In the pottery works it is used for producing the glaze; in the leather industry it enters into the composition of the tanning liquor; in the manufacture of colours pure salt is used for precipitating the colouring matters from their solutions. But more especially it forms the material from which all other sodium preparations are derived; and it is also the most important raw material for the preparation of chlorine and hydrochloric acid. The latter, known popularly as spirits of salt, has many applications.

At the present day chlorine is obtained principally by the electrolysis of sodium chloride: it is liquified under pressure in steel cylinders and in this form is extensively employed for many purposes. It is used for bleaching vegetable fibres in fabrics and paper, for disinfecting and sterilizing, and mostly for the manufacture of bleaching powder used for the same purposes. Another product of the electrolysis of sodium chloride is sodium, but in the aqueous solution this at once gives rise to the formation of sodium hydroxide or caustic soda. The latter is employed as a reagent in the chemical laboratory, and in large quantities for the manufacture of soap and in the colour industry. Caustic soda is also produced in the soda works, and some works now manufacture it in place of soda. By the electrolysis of fused caustic soda in iron pots provided with a porous partition metallic sodium is obtained. This is a silver-white, soft and easily fusible metal, which is so readily oxidized in the air and so readily attacked by water, that it must be kept in petroleum or other indifferent liquid. It is much used in organic chemistry as an energetic reducing agent.

The most important product obtained from rock-salt is *soda* or sodium carbonate. This is used as a reagent in the chemical laboratory, for washing purposes, in the manufacture of glass (p. 273), and very largely in the colour industry. Soda occurs in nature, but not in sufficient quantities to supply all the demands, and hence the larger part used commercially has to be manufactured from salt. The mineral *trona*, of which the formula is $Na_2CO_3 \,.\, NaHCO_3 \,.\, 2\,H_2O$, is found in the soda-lakes of Lower Egypt and Central Africa, and it separates from the salt-lakes of Merida in Venezuela, in the state of Nevada, and in south-eastern California — all of these districts supplying soda in commercial quantities.

Soda was formerly manufactured by the Leblanc salt-cake process, but now the Solvay ammonia-soda process has very largely taken its place. In the latter process a solution of sodium chloride — which in practice is the natural brine from the salt-wells or springs — is saturated with ammonia, and into the mixture carbon dioxide gas is passed. Sodium bicarbonate separates, and by heating this, soda is obtained. The carbon dioxide is generated by burning limestone, and the quicklime thereby formed is employed for converting the ammonium chloride or salammoniac that is formed in the solution back again into ammonia for further use in the process. Here the only raw materials used are salt and limestone, and there are no by-products; the process is a continuous one, and being simpler and cheaper than the older Leblanc process it is gradually replacing the latter. In the Leblanc process the salt is first converted into sodium sulphate by the action of sulphuric acid, with the formation of hydrochloric acid as a by-product. This change is expressed by the equation

$$2\,NaCl + H_2SO_4 = Na_2SO_4 + 2\,HCl.$$

The sulphuric acid (oil of vitriol) used in large quantities for this operation is manufactured from iron-pyrites, and this part of the process forms a branch of the soda works. The sodium sulphate is mixed with coal and limestone, and roasted. The coal reduces the sulphate to sulphide —

$$Na_2SO_4 + 4\,C = Na_2S + 4\,CO,$$

and the sodium sulphide reacts with the limestone, forming sodium carbonate —

$$Na_2S + CaCO_3 = Na_2CO_3 + CaS.$$

When the coal is present in excess this process results in the production of caustic soda instead of soda. For many years vast waste heaps of this calcium sulphide accumulated, but methods were later introduced by which the sulphur could be recovered and used again in the cycle of operations.

Calcined soda, from which the water of crystallization has been expelled by heat, is the form in which soda is employed in the chemical industries. *Crystal-soda*, such as is employed for household purposes, is sodium carbonate with ten molecules of water of crystallization ($Na_2CO_3 \,.\, 10\,H_2O$). Since this contains 63 per cent. by weight of water it is not so conveniently transported. The total annual production of soda, caustic soda, and sodium bicarbonate amounts to about $1^1/_4$ million tons, or about 0·8 kilogram ($1^3/_4$ lb.) per head of the world's population. Of this amount Germany produces about 325,000 tons, France 150,000 tons, the United States 120,000 tons, Russia 82,000 tons, whilst the largest quantity is manufactured in England.

Still another important product manufactured from salt is *glauber-salt*, which is sodium sulphate with much water of crystallization, the formula being $Na_2SO_4 \,.\, 10\,H_2O$. This salt occurs in nature in a few minerals; it is present in many mineral waters; and it separates from the waters of some salt-lakes. These sources are, however, insufficient to supply the demand, and, as with soda, the greater portion of the commercial material is obtained artificially from rock-salt. It is formed as a by-product in the manufacture of hydrochloric acid from rock-salt and sulphuric acid; and, as noted above, it is formed as an intermediate product in the Leblanc soda process. It is also obtained by the interaction of sodium chloride and magnesium sulphate at a temperature below 0^0 C. in the solution which remains after extracting potassium chloride from carnallite (p. 363). A low temperature is necessary, since glauber-salt can only be formed below 16° C. The material obtained by the last method is very pure, being especially free from iron; and it is therefore used by preference for making colourless glass. Sodium sulphate is now largely used in the manufacture of common glass (p. 173), since it is cheaper than soda. It is also used in the preparation of ultramarine, in the cellulose industry, etc.

The exports from the German customs district during the year 1898 of artificial products derived mainly from rock-salt were of the following values: soda $3^1/_2$ million marks (about £ 175,000), caustic soda 939,000 marks, bleaching powder $1^3/_4$ million marks, and hydrochloric acid 600,000 marks. Far greater quantities were, however, consumed in the home industries, especially in the colour industry.

From the above brief account of the chemical industries we see how far-reaching and varied are the applications and uses of the mineral rock-salt.

Sylvite and the Abraum-Salts.*)

At Stassfurt, in the Prussian province of Saxony, now the centre of the salt industry, salt-works were long ago established, and during the eighteenth century they were of considerable importance. In the year 1839, however, operations ceased, since the weak brine could no longer be worked at a profit in competition with the richer brines and salt-deposits discovered in other parts of Germany. The Prussian government thereupon decided to put down a bore-hole at Stassfurt. This was commenced in 1839, and in four years the salt-bearing strata were reached at a depth of 256 metres; the bore-hole was continued for a further depth of 315 metres without reaching the base of the salt-deposit. The results obtained were, however, unexpected; for instead of brine saturated with sodium chloride, the bore-hole yielded a solution containing much magnesium chloride and potassium chloride. In spite of this, the government decided to sink two shafts for the purpose of opening up these salt-deposits, expecting that beneath the more soluble salts pure rock-salt would be found — and in this they were not deceived. These two shafts, known as the "Manteuffel" and the "von der Heydt" were started at Stassfurt in 1852, and in five years reached the rock-salt at a depth of 330 metres (1080 feet), after penetrating 42 metres of the potassium and magnesium salts. These more readily soluble salts were considered worthless, and their presence added to the difficulty of sinking; they were consequently known as abraum-salts, *Abraum* meaning in German, rubbish or waste material to be removed. Their great value was, however, very soon recognized, and now they are sometimes referred to as "Edelsalze" or noble salts. Not long before, the celebrated German chemist, Justus Liebig, had shown that potash is necessary for the nourishment of plants, and that it is extracted by them from the soil; and consequently if the soil is to remain fruitful its supply of potash must be replenished. When, therefore, the agriculturists began to inquire for potash, the abraum-salts very opportunely supplied their needs. The salts were treated by the chemical industries, and very soon the potash-salts became one of the most sought for products in mining operations. Other shafts were sunk; first at Leopoldshall in the duchy of Anhalt (1857), and afterwards at Westeregeln (1871),

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*) F. Bischof, "Die Steinsalzwerke bei Stassfurt." 2nd edit., 1875. H. Precht, "Die Salzindustrie von Stassfurt und Umgebung." 4th edit., 1889. C. Ochsenius, "Die Bildung der Steinsalzlager und ihre Mutterlaugensalze." 1877.

Neu-Stassfurt near Löderburg (1877), Aschersleben (1882), Vienenburg near Goslar (1884), Bernburg on the Saale (1885), Thiede in Brunswick (1885), and others. It was also proved by borings that the deposits of potash-salts are of wide distribution in Thuringia, Brunswick, and Mecklenburg. In order to avoid an over-production of the material, the state works and those controlled by private individuals formed a syndicate for the sale of the salts, placing a limit on the production and fixing a uniform price. This arrangement has led to good results, especially as the industry connected with the potash-salts is practically confined to Germany. Outside that country they are met with only at Kalusz in Galicia and in the Salzkammergut in Upper Austria, but here in such small quantity that the occurrence is of little more than scientific interest.

The more important of the abraum-salts are the following: —

Sylvite, potassium chloride (KCl).

Carnallite, a hydrated double chloride of potassium and magnesium ($KCl \;\; MgCl_2 . 6\,H_2O$).

Kieserite, magnesium sulphate with one molecule of water of crystallization ($MgSO_4 . H_2O$).

Kainite, a hydrated double salt of potassium chloride and magnesium sulphate ($KCl . MgSO_4 . 3\,H_2O$).

Picromerite, a hydrated double sulphate of potassium and magnesium ($K_2SO_4 . MgSO_4 . 6\,H_2O$).

Polyhalite, a hydrated triple sulphate of potassium, magnesium, and calcium ($K_2SO_4 . MgSO_4 . 2\,CaSO_4 . 2\,H_2O$).

In addition to the above, there are also present in the abraum-salts other salts containing no potassium. These, although of little or no economic value, possess a scientific interest and add to our knowledge of the salt-deposits as a whole. They include: —

Tachhydrite, a hydrated double chloride of calcium and magnesium ($CaCl_2 . 2\,MgCl_2 . 12\,H_2O$).

Bischofite, hydrated magnesium chloride ($MgCl_2 . 6\,H_2O$).

Bloedite, a hydrated double sulphate of magnesium and sodium ($MgSO_4 . Na_2SO_4 . 4\,H_2O$).

Boracite, borate and chloride of magnesium ($2\,Mg_3B_8O_{15} . MgCl_2$).

In the salt-deposits these salts are, as a general rule, ranged in the order of their solubilities. They are, however, always more or less intermixed with rock-salt and anhydrite, more especially in the lower layers, whilst in the upper layers the salts of greater solubility predominate. At many places the abraum-salts are themselves overlain by gypsum and anhydrite and a bed of younger rock-salt, the latter being in turn covered by gypsum and salt-clay. Disregarding these intermixtures and repetitions, the several beds of salts possess quite distinctive characters, and they can be subdivided into the following "regions" (passing from the top of the deposit downwards): —

1. *Carnallite Region*, 15—40 metres in thickness; with carnallite, sylvite, kainite, kieserite, bischofite, tachhydrite, bloedite, picromerite, and boracite.
2. *Kieserite Region*, about 60 metres in thickness; consisting of kieserite, together with carnallite, bischofite, rock-salt, and anhydrite.
3. *Polyhalite Region*, also about 60 metres in thickness; with polyhalite, rock-salt, and anhydrite.
4. *Anhydrite Region*, some hundreds of metres in thickness; consisting of the older rock-salt and anhydrite in frequently alternating layers, and forming the base of the deposit.

In the majority of salt-deposits only the last of these regions is represented; the others not having been deposited, or if originally deposited they were at some later period removed by solution. Complete and typical salt-deposits, such as those of the Stassfurt district, are not known outside Germany.

Most of the salts found in these deposits have been formed, like the rock-salt, gypsum, and anhydrite, by the evaporation of sea-water, but under especially favourable topographical and climatic conditions. Their constituents are all present in sea-water; and when the degree of concentration, relative proportions of the several components of the solution, and the temperature reach certain points, one or other of the complex salts may be formed and separate from the solution. The exact conditions necessary for the formation of these salts have been studied in detail by the celebrated Dutch chemist, J. H. van't Hoff, working with his pupils in Berlin. The important results of this work were published in a series of fifty-two memoirs;*) they are too complex and detailed to be given in this place. The salts as found in the deposits have not all been formed directly from the concentrated sea-water, but are the result of later changes. Water percolating through the beds along cracks and crevices has brought about many changes and interactions in these readily soluble salts, and in addition to those originally deposited there are others of secondary origin.

In this place we will give a brief description of the more important of the abraum-salts. Most of them, possessing neither distinctive form nor colour, are not recognizable by the eye alone; and, indeed, only the first and the last mentioned in the list above, namely sylvite and boracite, are suited for illustration on the coloured plates.

Sylvite or Sylvine. This is the potassium compound analogous to rock-salt, being potassium chloride (KCl) instead of sodium chloride. Formerly it was known only as a white, powdery encrustation on the lavas of Vesuvius; and fine, large crystals were first found in the abraum-salts of Stassfurt and Leopoldshall in Germany. As shown by the crystal represented in fig. 7, plate 70, the form is that of the cubo-octahedron, consisting of the cube and the octahedron each developed to the same extent (text-fig. 242). This combination is just as characteristic for sylvite as the simple cube is for rock-salt. The crystals thus belong to the cubic system, and to all appearance they possess the same degree of symmetry as do crystals of rock-salt.

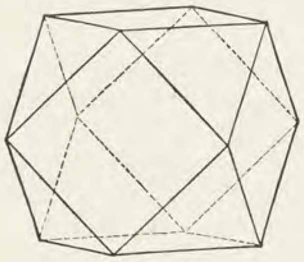
Fig. 242.
Crystal (cubo-octahedron) of Sylvite.

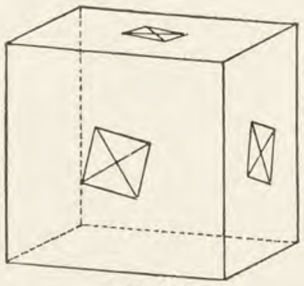
Fig. 243.
Etched figures on cleavage cube of Sylvite.

As proved by the orientation of the etched figures on the faces, the crystals of sylvite do not, however, belong to the holohedral division of the cubic system in which the full number of the possible elements of symmetry are present. The etched figures on the cleavage surfaces of sylvite are represented in text-fig. 243, and a comparison with text-fig. 240 (p. 349) will show that they have exactly the same form as those developed by solution on rock-salt; they consist of shallow pits with a square outline and formed by

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J. H. van't Hoff, "Untersuchungen über die Bildungsverhältnisse der ozeanischen Salzablagerungen, insbesondere des Stassfurter Salzlagers." Sitzungsber. der Preuss. Akad. der Wissensch. zu Berlin, 1897—1908. A collected account has been published under the title "Zur Bildung der ozeanischen Salzablagerungen." (Braunschweig, 1905 and 1909.)

four isosceles triangles slightly sunk beneath the surface. We notice, however, that these etched figures are differently orientated in the two minerals with respect to the cube. In rock-salt the edges of the pits are parallel to the edges of the cube, whereas in sylvite there is no such parallelism; neither are the edges of the pits parallel to the diagonals of a cube face. From this obliquity of arrangement of the etched figures we can conclude that in crystals of sylvite there are no planes of symmetry perpendicular to the cube faces, and consequently an absence of all the planes of symmetry. On the other hand, the four-fold symmetrical arrangement is preserved on the cube faces, so that the three tetrad axes are still effective; similarly, the three triad axes and the six dyad axes are also present. This class of the cubic system, with the full number of axes but no planes or centre of symmetry, is known as the plagihedral-hemihedral or gyrohedral class. Crystals possessing this type of symmetry are exceptional, and only in a few instances (on cuprite) has any hemihedral development of the faces been observed.

In its other characters sylvite presents a striking resemblance to rock-salt. It possesses the same perfect cleavages parallel to the cube faces, and also the same degree of hardness (H. = $2^1/_2$). Its specific gravity (1·9 -- 2·0) and refractive index (1·490 for sodium-light) are, however, both slightly lower than for rock-salt. It is transparent and colourless, or sometimes reddish or of a fine blue colour as in rock-salt (p. 349); often however, the material is cloudy and white. The mineral is readily soluble in water; but its degree of solubility is more dependent on the temperature than in the case of rock-salt. One hundred parts of water at 0° C. dissolve 28 parts of potassium chloride, whilst at 100° C., 57 parts are dissolved. A hot, saturated solution of sodium chloride and potassium chloride deposits on cooling mostly potassium chloride; and by this means it is possible to separate the two salts when they occur mixed together. There is a marked difference in taste between sylvite and rock-salt, that of the former being much sharper. The two minerals may be readily distinguished by the colour they impart to the colourless flame of the Bunsen-burner: sylvite produces a violet coloration, whilst rock-salt gives an intense yellow. When the salts are mixed, the yellow colour completely masks the violet; but the latter can be detected by viewing the flame through a sheet of dark blue glass or a flask filled with a solution of indigo.

Crystals and large cleavage masses of sylvite are on the whole of rare occurrence. More usually the mineral occurs as granular masses forming nests or beds which may exceed a metre in thickness. Such granular material may consist of an intimate intermixture of sylvite and rock-salt, being then known as "sylvinite". A similar mixture containing also kieserite is known as "Hartsalz", but these terms are of loose application. "Hartsalz" occurs as dark brownish-red masses, frequently mixed with anhydrite, in which the sylvite is usually red or brown, the rock-salt colourless or grey, and the kieserite is white.

In the salt-deposits sylvite always occurs in association with carnallite, from which it has been derived. When carnallite is exposed to a moist atmosphere it absorbs water (owing to the deliquescence of its contained magnesium chloride) and it is thereby decomposed. The more readily soluble magnesium choride is removed in solution, to crystallize again as bischofite in deeper and drier parts of the deposit. The potassium chloride remains behind as a coarsely crystalline powder; and larger crystals are formed if the crystallization is slow and continued for a long period of time. In this way sylvite is now being formed in the mine galleries penetrating beds containing carnallite; and is found, sometimes as stalactitic or botryoidal masses, but more usually as a crystalline powder.

Besides being found at Leopoldshall and Stassfurt and elsewhere in the deposits of abraum-salts in Germany, sylvite is also known at Kalusz in Galicia, where it forms lenticular masses and thin beds in the salt-deposits. In quite small amounts it has also been found at Berchtesgaden in Bavaria and Hallein in Salzburg. Its occurrence at these places suggests that abraum-salts were here also originally present, but that they have been subsequently dissolved and removed, leaving only traces of their former existence.

Application of Sylvite and other Potash-salts.— Potassium chloride, the richest of the potash-salts, contains theoretically 52·4 per cent. of potassium, and it is employed in enormous quantities in the chemical industries and in agriculture. Only a very small part of this is, however, supplied by the mineral sylvite, the bulk being obtained from the other abraum-salts, more especially carnallite. By a process of leaching and crystallization the latter yields a crude product containing about 80 per cent. of potassium chloride. This, together with "sylvinite", kainite, potassium sulphate, and potassium-magnesium sulphate, constitutes the potash-salts of artificial manures, now so indispensable in agriculture. These materials are exported from Germany to all parts of the world. Owing to cost of transport, it is mostly the more concentrated form of crude chloride that is exported, whilst the other salts, less rich in potassium, are used in the country of their origin. For agricultural purposes it is unnecessary that the salts should be specially purified; but they are sent out with a guaranteed minimum percentage of potash, and for the sulphates the amount of chlorine present is also stated.

About 75 per cent. of the production of potash-salts is consumed for agricultural purposes, the remaining 25 per cent. being used in the chemical industries. Potassium chloride is converted by the Leblanc process (p. 357) into potashes (potassium carbonate), formerly obtained by lixiviating wood ashes; this is employed in glass-making for producing a difficultly fusible glass, and for making a soft soap (potash soap). By the electrolysis of potassium chloride either caustic potash or metallic potassium and chlorine are yielded; and an electrolytic method is also employed in the manufacture of potassium chlorate. From potassium carbonate and coal the extremely poisonous potassium cyanide is prepared; this is used at the present day in large quantities in the extraction of gold from its ores by the cyanide process (p. 74). By the interaction of sodium nitrate (Chile saltpetre) and potassium chloride, potassium nitrate (saltpetre) is obtained, which possesses an advantage over the sodium salt in not attracting moisture from the air. With the disuse of black smoky gunpowder, much less saltpetre is now manufactured by this method than was formerly the case. Potassium sulphate is largely used for the preparation of alum; this finds many applications in dyeing, tawing, paper-making, medicine, etc. Still another artificially prepared potassium salt with important technical applications is potassium bichromate.

Production of Potash-salts.— The sales syndicate of the Stassfurt potash-works during the year 1898 disposed of 44 million hundredweights of potash-salts of the value of about $1^1/_2$ million pounds sterling. This amount included 1,056,226 tons of kainite and "sylvinite", 177,938 tons of crude 80 per cent. potassium chloride, 68,000 tons of carnallite with kieserite, 17,700 tons of potassium sulphate, and 10,500 tons of potassium-magnesium sulphate (48 per cent.). Further, 1900 tons of potassium cyanide of the value of nearly £200,000 were exported, and large quantities were also consumed in Germany. The potash-salt deposits of northern Germany are unique; no others of anything like the same extent and availability for working being known in any part of the world. For this reason Germany possesses a monopoly of the industry in potash-salts.

Carnallite. When pure, this mineral salt is colourless and water-clear, but often it is coloured by intermixed impurities, which remain as a fine, muddy deposit when the salt is dissolved in water. Particularly striking is the red carnallite with its intense colour and metallic sheen, such material presenting quite the appearance of the artificial avanturine glass (p. 273). If a fragment of this variety of the mineral is dissolved in water and the residue examined under the microscope we see vast numbers of minute, yellow to brownish-red, transparent scales with beautifully sharp six-sided or triangular outlines. These scales have been found to consist of the mineral haematite (p. 151). Sometimes we see, instead of scales, only a red, earthy mud; but in this case the red carnallite exhibits no metallic sheen. A suggestion that presents itself is that the carnallite has been so greedy for water that it has constrained the iron oxide to separate out in the anhydrous form. Still more remarkable is the presence in the insoluble residues of carnallite of minute crystals of quartz and tiny tetrahedra of boracite. To judge from the intensity of the colour of red carnallite one would imagine that it is very rich in iron; but as a matter of fact the mineral contains no more than 0·075 per cent. of haematite.

Pure carnallite has a specific gravity of 1·62, and contains potassium chloride 26·8, magnesium chloride 34·2, and water 39·0 per cent. The rarely-occurring crystals belong to the rhombic system, but they present the appearance of hexagonal forms. For their preservation it is necessary that they should be immediately placed in sealed, air-tight vessels. Pseudomorphs of rock-salt after carnallite have been found in the salt-clays of Westeregeln near Magdeburg.

Carnallite greedily absorbs water from a moist atmosphere, forming a solution of magnesium chloride whilst potassium chloride is deposited as minute cubes. On this difference in solubility of the two component salts of carnallite is based the commercial process for extracting the potassium chloride, of which carnallite is the most important source. The salt is dissolved in water, and as the hot, concentrated solution cools the potassium chloride is deposited. The remaining mother-liquor contains the magnesium chloride, together with traces of bromine and rubidium. Although the proportion of bromine present is relatively only minute, yet from the enormous quantities of carnallite that are worked for potash-salts bromine forms an important by-product. This is, indeed, the principal source of bromine, which finds many important applications; for example, in the preparation of eosine and other colouring matters, of potassium bromide used in medicine, and of silver bromide which is extensively employed in photography. The value of bromine and bromine preparations exported from Germany during 1898 amounted to £30,000, and still greater was the value of these materials used for home consumption. About 500 tons of bromine are produced annually in Germany, and from the American salt-springs about 400 tons per annum. This large production has caused a fall in price from about 50 s. per pound in 1865 to 3—4 s. at the present time. The enormous quantities of magnesium chloride liquor have so far not been utilized to any advantage; only to quite a small extent has this waste material been employed for the preparation of hydrochloric acid, chlorine, and magnesia.

Carnallite occurs in the uppermost layers of the beds of abraum-salts, it having been the latest product of deposition from the saturated solutions. The conditions necessary for its formation are that the solution should contain a large excess of magnesium chloride and that the temperature should not be much lower than 25° C. Long before carnallite had been found in the abraum-salts, its chance formation in the mother-liquors of the Bad Salzhausen had been described in 1826 by Justus Liebig (1803—1873). Little could the young German chemist have guessed that this new compound, to which be devoted some of his earliest work, would one day come to be of such importance in agriculture, and, indeed, largely help to put into practice his later teachings in agricultural chemistry.

Besides occurring in the salt-deposits of northern Germany, carnallite has been found in small amounts at Kalusz in Galicia, Maman in Persia, and in Colorado.

Kainite. This salt was first met with in the Anhalt shaft several years after the work there had been commenced, and being a new and unfamiliar material it was accordingly named from the Greek καινός, new. In a pure condition it forms white, pale yellow, reddish, or grey, translucent masses with a granular structure and somewhat resembling loaf-sugar in appearance. The pure salt has a specific gravity of 2·13, and contains potassium chloride 30·0, magnesium sulphate 48·2, and water 21·8 per cent. It is, however, in the larger masses always intermixed with kieserite, carnallite, rock-salt, and anhydrite. It occurs in the uppermost layers of the carnallite region, and at one time it was regarded as being always a secondary product produced by the interaction of the carnallite and kieserite with which it is found associated. The recent investigations of van't Hoff have proved, however, that kainite, like carnallite, can be directly deposited from evaporated sea-water. A portion of the kainite, and especially that which occurs in the kieserite region, has no doubt been formed by direct precipitation from sea-water; but the bulk of the material occurs in the salt-deposits in such a manner as to strongly suggest that it has been formed from the carnallite and kieserite. The latter appear to have been partly dissolved by percolating water and so converted into kainite. Here the kainite forms a covering over the carnallite, in a manner analogous to the "iron hat" of metalliferous veins (p. 72).

Raw kainite and also the potassium-magnesium sulphate prepared from this are the forms in which the potash-salts are principally used as artificial manures in Germany. The mineral is also employed for the preparation of potassium chloride and of potassium sulphate.

Kieserite. Magnesium sulphate separates from a pure aqueous solution with seven molecules of water of crystallization, forming the well-known epsom-salts or epsomite, $MgSO_4 . 7 H_2O$. In the abraum-salts, however, magnesium sulphate occurs for the most part crystallized with only one molecule of water, $MgSO_4 . H_2O$, and combined as this hydrate it is the mineral kieserite. The reason for this is that magnesium chloride and other readily soluble salts, when also present in the solution, exert a sort of attraction for the water, constraining the magnesium sulphate to crystallize with less water than it would take up from a pure solution. As we have already seen (p. 353), the crystallization of calcium sulphate as gypsum or as anhydrite is governed in a similar manner by the presence of other salts in the solution. Under these conditions kieserite can be deposited at a temperature of 25° C. or less, but from a pure solution of magnesium sulphate it is not deposited at a lower temperature than 67° C.

Kieserite occurs as finely granular to compact aggregates of a greyish-white colour. In the pure condition it has a specific gravity of 2·52, and contains magnesium sulphate 87·1 with water 12·9 per cent. When exposed to the air it gradually becomes cloudy and finally falls to a white powder. This is due to the absorption of water from the air, and the conversion of the kieserite into epsomite. The latter is of rare occurrence in the abraum-salts, and it has no doubt always been formed as a secondary product by the alteration of kieserite. A massive variety of epsomite found at Leopoldshall has been called reichardtite.

In the abraum-salts the kieserite is always accompanied by carnallite, in which it forms strings and large nests. It often also forms a part of the "*Hartsalz*", which sometimes consists of a mixture of equal parts of kieserite and rock-salt (each 30—40 per cent.) with about 25 per cent. of sylvite and 1 per cent. of anhydrite. It is possible that "Hartsalz" represents still another compound salt with the formula $KCl . MgSO_4 . H_2O$, formed by the union of sylvite and kieserite, and containing mechanically intermixed rock-salt.

Of less importance than the "Hartsalz" is *picromerite* (also known as schoenite), which is a hydrated double sulphate of potassium and magnesium with the formula $K_2SO_4 . MgSO_4 . 6 H_2O$. It has been proved experimentally that this compound salt can be formed only at a temperature below 26° C. It occurs together with kainite, and has probably been derived from this. In the salt-deposits at Westeregeln picromerite forms a capping, 10 metres in thickness, on the kainite; and at Wilhelmshall it forms the base of a bed of sylvite.

In addition to its occurrence in the German abraum-salts, picromerite is also known from Kalusz in Galicia and Hallstatt in Upper Austria, sometimes as monoclinic crystals.

Owing to its high content of potash, "Hartsalz" is one of the most important of the salts for use as artificial manures. Like kieserite, it is also used for the conserving of stable manure: the magnesia it contains combines with the ammonia generated by the manure more readily than does gypsum, which is often used for the same purpose. Another application of kieserite is in the preparation of epsom-salts, which is largely employed in the dressing of fine cotton materials. The production of epsom-salts from this source amounts to 20,000 or 30,000 tons per annum. Considerable quantities of kieserite are obtained as a by-product in the extraction of potassium chloride from carnallite, remaining after the removal of the dissolved salts as a fine slime. With the evaporation of the water it hardens; and it is moulded into blocks and sold as block-kieserite, as distinct from the rock-kieserite (Ger. Bergkieserit) obtained directly from the salt-deposits.

Polyhalite. As indicated by its name, many salts (i. e. more than in the case of the ordinary double salt) enter into the composition of this mineral; these are potassium sulphate, magnesium sulphate, and calcium sulphate, together with water of crystallization, the formula being $K_2SO_4 . MgSO_4 . 2 CaSO_4 . 2 H_2O$. In the pure condition it contains 28·9 per cent. of potassium sulphate, and has a specific gravity of 2·72. The polyhalite found in the north German abraum-salts is pale grey and finely granular, whilst that from Ischl, Hallein, and Berchtesgaden is often brick-red and with a columnar structure.

Polyhalite occurs in the lowest region — the polyhalite region — of the abraum-salts. The bulk (about 90 per cent.) of this deposit consists of rock-salt, and in this the polyhalite forms seams with a thickness of 1—4 cm., similar to the seams of anhydrite. This salt differs from the other abraum-salts in its lower degree of solubility; and as compared with these its economic value is small. Another mineral salt closely allied to polyhalite is krugite: this differs in containing four, in place of two, molecules of calcium sulphate. It occurs as white or grey, finely granular masses.

Bischofite. This extremely deliquescent salt, $MgCl_2 . 6 H_2O$, forms white or yellowish masses with a granular or columnar structure. It occurs in part as an original deposit, and was formed, together with carnallite and kieserite, by the evaporation of the last of the mother-liquors. It also occurs, as previously mentioned (p. 361), as a secondary formation derived from carnallite. Another very deliquescent salt is one consisting of a combination of magnesium chloride with calcium chloride, namely *tachhydrite*, $2 MgCl_2 . CaCl_2 . 12 H_2O$. This is the most easily soluble of the Stassfurt abraum-salts, and it therefore occurs only in the uppermost portion of the carnallite region. In most of the deposits it is, however, completely absent. It has been proved experimentally that this salt can only be formed at temperatures above 22° C., and we can consequently conclude that this must have been the minimum temperature at the time of the deposition of the abraum-salts which contain the tachhydrite. By such means modern chemical investigation is able to throw some light on the climatic conditions which prevailed in past geological epochs. Such conclusions can, however, only be arrived at when we are certain that the tachhydrite is an original deposit from the sea-water: in the case of the secondary deposits, where the tachhydrite has been re-crystallized at some depth in the earth's crust, the temperature may very well have exceeded 22° C.

Bischofite is employed, like the waste magnesium chloride from carnallite, for the preparation of bromine and magnesia, and formerly also of chlorine and hydrochloric acid.

Sodium Salts. As compared with the potassium-bearing double salts, the sodium-bearing double salts which occur amongst the abraum-salts are of little importance; the most valuable of the sodium salts occurring throughout the whole of the deposit is always the rock-salt. A few of these sodium salts and double salts remain to be briefly mentioned in this place.

Bloedite (or astrakanite) is a double sulphate of sodium and magnesium with the formula $Na_2SO_4 . MgSO_4 . 4\ H_2O$, and is one of the few of the abraum-salts that occur in good, clear crystals. These are monoclinic, but they are of rare occurrence. More often the mineral forms granular aggregates which are colourless, yellowish, reddish or salmon-pink in colour. It shows a conchoidal or somewhat splintery fracture; but, like so many of the other salts, it presents no very striking characters to the unaided eye. Bloedite occurs as irregular masses, reaching a metre across, embedded in the kainite, "Hartsalz", or sylvite. It has probably been formed, at a period subsequent to the deposition of the salts, by the action of dissolved magnesium sulphate on the rock-salt. This mineral is met with in the abraum-salts of Stassfurt, Leopoldshall, and Westeregeln; in the salt-deposits of Ischl and Hallstatt in Austria, and as remarkably fine crystals in the Salt Range in India. It is also found in the salt-lakes of Astrakhan.

Loeweite is another double salt containing the same constituents as bloedite, but with less water of crystallization, the formula being $Na_2SO_4 . MgSO_4 . 2^1/_2H_2O$. This is of rare occurrence and of no technical value, and it is only mentioned in this place because it presents a point of scientific interest. A temperature of over 43° C. is necessary for its formation; so that its presence in the salt-deposits marks, like a minimum thermometer, the lowest temperature at which the deposition took place.

Mirabilite (or Glauber-salt) is the simple sulphate of sodium with ten molecules of water of crystallization, $Na_2SO_4 . 10\,H_2O$. This can separate from a solution rich in salt only at temperatures below 16° C. The occurrence of this salt therefore marks a point on the maximum thermometer, just as loeweite marks a point on the minimum thermometer. Mirabilite is deposited at the present time on the floor of the Gulf of Kara-boghaz (also called Aji-darya) on the eastern coast of the Caspian Sea; but it is formed only during the cold winter months, whilst during the summer the deposit consists mainly of sodium chloride. For the same reason also, the manufacture of glauber-salt is only undertaken during the winter. In the German abraum-salts mirabilite occurs only in small amount and is of no practical importance: it has no doubt been here formed as a result of secondary changes. It occurs in large quantities at Logroño in Spain, Bompensieri in Sicily, and at few other places. The bulk of the glauber-salt used for industrial purposes is, however, a manufactured product (p. 357).

Thenardite (Na_2SO_4) is the form in which sodium sulphate crystallizes from a salty solution at temperatures above 16° C. Its crystals have the form of simple rhombic pyramids as shown in plate 78, fig. 12. These are at first water-clear, but on exposure to the air they absorb moisture and become cloudy. Thenardite is a mineral of rare occurrence in the deposits of abraum-salts. It is more frequently found as a deposit from the borax- and soda-lakes of Nevada, California, and Arizona; and especially in the sodium nitrate deposits of Chile, from whence came the crystal shown in the picture.

Glauberite is the anhydrous double sulphate of sodium and calcium, $Na_2SO_4 . CaSO_4$. This has been found in the German abraum-salts only in the massive form; but fine large, monoclinic crystals are met with in the salt-deposits at Villarrubia in Spain, and in the Borax Lake in San Bernardino Co., California. These are colourless, white, or yellow, and have a specific gravity of 2·7—2·8. This mineral is of interest from an optical point of view: the biaxial interference-figure shown in convergent polarized light (plate 4, fig. 4) changes its form with rise in temperature; the hyperbolic brushes gradually approach one another and finally open out in the plane at right angles to their former position.

Vanthoffite, a double sulphate of sodium and magnesium, $3\,Na_2SO_4 . MgSO_4$, is a new mineral recently detected in the abraum-salts at Wilhelmshall near Stassfurt. It was named in honour of the celebrated chemist, J. H. van't Hoff, whose work has thrown so much light on the mode of formation of the salt-deposits.

Boron Minerals.

In the readily soluble abraum-salts, but also in the gypsum and anhydrite of the salt-deposits, there occurs, often in some abundance, a mineral which is practically insoluble in water, but one which must obviously have been deposited from an aqueous solution. This is the mineral boracite. In respect to its insolubility it should scarcely find a place amongst the salts, but, since it occurs in the abraum-salts, it may conveniently be dealt with here; and at the same time we may mention some other minerals which contain the chemical element boron in large amount.

Boracite is of interest from several points of view; and especially by reason of the anomaly it presents in the lack of agreement between its crystalline form and its optical characters. The crystals (plate 70, figs. 9—12) are always small, and those measuring more than a centimetre across are quite rarities. Their form is that a cubic crystal with tetrahedral hemihedrism. Some have the shape of simple and sharply defined, though small, tetrahedra; others are richer in faces, with the tetrahedron, the cube, or the rhombic-dodecahedron predominating, and the other faces smaller in size. Although some of these crystals richer in faces may have the appearance of a holohedral cubic crystal, yet the hemihedrism is indicated by the number and arrangement of the smaller faces on the corners. Thus in text-fig. 244 a crystal of cubic habit is combined with the rhombic-dodecahedron and alternate corners are truncated by the tetrahedron. This corresponds to the natural crystal portrayed in fig. 11, plate 70, in which, however, the faces of the rhombic-dodecahedron are relatively rather wider than in the text-figure. In fig. 10 the same forms are also present with the addition of the second or complementary tetrahedron on the remaining corners. Here we have apparently a combination of the cube, the rhombic-dodecahedron, and the octahedron: but an examination of the actual crystal will show that these triangular faces corresponding to the octahedron are of two kinds, one set of alternate faces being smooth and bright, whilst those of the other set are dull and rough. The smooth, bright faces therefore belong to one tetrahedron, and those which are dull and rough belong to

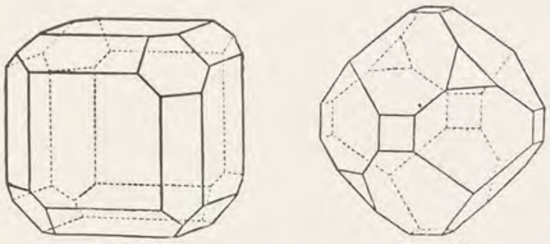
Fig. 244. Fig. 245.

Crystals of Boracite.

the complementary tetrahedron; and the apparent octahedron is thus really a combination of the two tetrahedra. The crystal in text-fig. 245 is bounded by exactly the same forms as that in text-fig. 244, only here the faces of the rhombic-dodecahedron are large and those of the cube are small. This habit corresponds most nearly with the natural crystal represented in fig. 9, plate 70. In fig. 12, the crystals embedded in the matrix are bounded by only the rhombic-dodecahedron.

The typical forms of the cubic system being so beautifully and sharply developed on boracite, we should naturally expect the mineral to be singly refracting and optically isotropic. On the contrary, it is strongly birefringent, and a thin section when examined in polarized light displays brilliant polarization-colours. This discrepancy, first noticed by Sir David Brewster in 1821, long remained a puzzle to mineralogists. But in 1882 a French savant, E. Mallard, made the interesting discovery that when boracite is heated to a temperature of 265° C. the double refraction suddenly disappears, and the crystals are then truly cubic. On cooling again, the "optical anomalies" reappear. We can therefore draw the conclusion that the boracite substance is dimorphous, existing as a cubic modification above 265° C., and as a rhombic modification below this temperature. The crystals at the ordinary temperature, although still preserving their external cubic form, really each consist of a twinned aggregate of twelve rhombic pyramids with their bases forming the twelve faces of the rhombic-dodecahedron and their apices at the centre of the group.

The change from one modification to the other takes place at a perfectly definite and fixed point on the thermometer (265° C.), just as the change from water to ice, or vice versa, takes place at 0° C. Further, the change is a reversible one: on cooling, when the point 265° C. is passed, there is a conversion of the cubic modification into the rhombic; and with rising temperature, a transformation from the rhombic to the cubic modification takes place at the same point. Only one modification is thus stable at any particular temperature, and the two forms cannot exist side by side, as in the case of many other dimorphous substances, for example, diamond and graphite. Substances that exhibit this special kind of dimorphism are said to be enantiotropic. The mineral leucite (p. 299) and a few artificial salts (e.g. ammonium nitrate and silver iodide) behave in the same manner. These changes of state in a substance are particularly beautiful when watched under the polarizing microscope. They can be readily observed when a fragment of ammonium nitrate or of silver iodide is fused between a glass slip and a thin cover glass and allowed to cool on the stage of the microscope. The reverse change with rising temperature can only be studied with a specially constructed microscope provided with a heating stage.

In the case of leucite the explanation of the "optical anomalies" is quite simple, for here the mineral crystallized in the cubic form from a molten lava. Boracite, however, presents a difficulty, since its crystals are found embedded in carnallite and gypsum, which were deposited by the evaporation of an aqueous solution at the earth's surface; and, further, it is inconceivable that the salt-deposits could have been subjected to a temperature as high as 265° C. at any period subsequent to their formation. It is thus certain that the boracite substance could not have originally crystallized in the cubic modification, the very existence of which requires a temperature of not less than 265° C. Further, it may be remarked that the rhombic modification of the boracite substance has never yet been observed in simple crystals showing external forms characteristic of the rhombic system. The crystals are always complex twins of many individuals so united as to produce the external form of a cubic crystal. It thus seems probable that when the rhombic modification crystallizes (at temperatures lower than 265° C.) it is always constrained by twinning to produce an external form identical with that proper to the cubic modification. The production of pseudo-cubic forms by complex twinning has been observed in several minerals; an excellent example, given by phillipsite, is illustrated by text-figs. 225—228 on pp. 305—306.*)

Another interesting feature presented by crystals of boracite is their pyro-electrical character, which was noticed by the Abbé Haüy so long ago as 1791. Like the pyro-electric crystals of hemimorphite (p. 131) and tourmaline (p. 245), crystals of boracite also exhibit a different development of faces at the two ends of certain axes (here the triad axes of the cubic crystal); and in consequence of this, together with the fact that the material is a non-conductor of electricity, the crystals develop positive and negative electrical charges at opposite ends of these axes when subjected to changes of temperature. A cube of boracite when warmed becomes positively electrified on four of its alternate corners, and negatively electrified on the remaining four corners; and when the crystal cools these charges are reversed. If a crystal so changing in temperature is dusted over with a mixture of red-lead and flowers of sulphur from a fine sieve, the distribution of the electrical charges will be marked out in red and yellow colours.

Crystals of boracite may be transparent with a bright and glassy surface, or they may be cloudy and dull. Their colour is white, grey, yellowish, or sometimes greenish. The specific gravity is 2·9—3·0; and the hardness is remarkably high, being equal to that of quartz. In addition to the crystals, bounded on all sides by faces, which occur embedded in carnallite and gypsum, boracite is also found in a massive form. This variety, known as stassfurtite, occurs as nodules, sometimes as large as a man's head, in the uppermost layers of the Stassfurt salt-deposits; it is white and earthy with much the appearance of chalk.

Chemically, boracite is a borate and chloride of magnesium with the formula $2Mg_3B_8O_{15} . MgCl_2$, and contains 62·5 per cent. of boric acid. It is soluble in hydrochloric acid, but practically insoluble in water. The conditions under which it was formed are not known.

The largest boracite crystals are those found embedded in gypsum on the Kalkberg at Lüneburg in Hanover, from which locality come the crystals figured on plate 70. Smaller crystals are found in gypsum at Segeberg in Holstein. Clear, sharply-developed tetrahedra, or tetrahedra with their edges narrowly truncated by cube faces, are obtained from the carnallite at Stassfurt; these vary in size down to microscopical dimensions. At the same place are also found pale greenish tetrahedra containing some iron, and known as iron-boracite. The earthy boracite, or stassfurtite, is collected to the extent of about 100 tons per annum, and is used for the preparation of borax and boric acid.

Some other borates are also present in the abraum-salts, but they are of rare occurrence. Others again, though not met with in the abraum-salts, are found in the salt-lakes of some other countries; and these being of some importance will be now mentioned as an appendix to boracite.

Borax, or tincal. This well-known salt is a hydrated borate of sodium with the formula $Na_2B_4O_7 . 10H_2O$. It forms monoclinic crystals which present a striking resemblance in their shape and angles to crystals of augite (p. 315). Here also the vertical prism of 87° is truncated by the ortho-pinacoid and the clino-pinacoid, and terminated by an obliquely-placed basal plane and pyramid faces. When fresh, the crystals are colourless

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*) The peculiar case of boracite has given rise to much discussion, and various explanations have been offered; and it must be remarked here that the explanation given above differs somewhat from that given in the original German edition of this work. There it is suggested that the modification stable at the higher temperature may actually have crystallized out as such at the lower temperature; and in support of this is cited the case of the crystallization side by side of the two dimorphous modifications of potassium nitrate (described below, p. 373).

and transparent, but on exposure to the air they lose water and become cloudy and dull, finally falling to powder. Borax fuses easily in the flame, with an energetic bubbling, and gives a colourless glass. In this fused glass metallic oxides are readily dissolved, and in many cases they impart to it a characteristic coloration. On this property depends the use of the borax bead, formed in a small loop of platinum wire, in the blowpipe analysis of minerals. The use of borax in soldering also depends on its property of dissolving metallic oxides, thus preparing a clean surface for the adhesion of the solder.

A plate cut from a crystal of borax, in a direction parallel to the plane of symmetry, shows in convergent polarized light a biaxial interference-figure (plate 4, figs. 3 and 4), which is remarkable in the arrangement of the colours when viewed in white light. The figure is symmetrical only with respect to the central point; and borax affords the best example of this phenomena of crossed dispersion of the optic axes.

Borax is comparatively easily soluble in water, and it occurs in considerable amounts dissolved in the waters of certain lakes —the so-called borax-lakes. Borax crystals separate in the dried mud on the shores of such lakes in Tibet, California, and Nevada; and under these conditions it is found in association with thenardite (p. 366), gaylussite ($CaCO_3 . Na_2CO_3 . 5\,H_2O$), and other sulphates and carbonates.

Ulexite, or boronatrocalcite, occurs as white, ball-like nodules consisting of an aggregate of small pearly scales and fibres. It is found in the covering sands of the saltpetre deposits in Chile, where, from its resemblance to chalk, it is known as "tiza"; in the borate deposits of California it goes by the name of "cotton-ball". This material has the composition $NaCaB_5O_9 . 8H_2O$, and contains 43 per cent. of boric acid. The latter is separated commercially by blowing steam through a sulphuric acid solution of the mineral; or by boiling with soda solution, borax is prepared.

Sassolite is native boric acid (boracic acid), H_3BO_3, occurring in the free state. It forms loose, friable masses of small, pearly white scales, which are very soft and greasy to the touch. The masses are frequently tinged with pale yellow, owing to the admixture of native sulphur. Sassolite is only slightly soluble in cold water, but it dissolves easily in hot water, so that the crude mineral can be readily purified by re-crystallization. It readily volatilizes in steam, and this property plays an important part in the origin and in the winning of the mineral. At Sasso in Tuscany, and throughout the district extending between Volterra and Massa Marittima in the Italian provinces of Pisa and Grosseto, jets of steam highly charged with boric acid issue at the earth's surface, and are known in Italy as *soffioni*. For the purpose of collecting the boric acid, the steam is led into water, and the solution so obtained is evaporated. A perfectly pure product is prepared by converting the boric acid into borax and decomposing this with hydrochloric acid, when the boric acid separates as a fine scaly powder. Sassolite is also found in some volcanoes, particularly that of Vulcano in the Lipari Islands.

Boric acid also occurs as a constituent of some silicate minerals already discussed, namely tourmaline, axinite, and datolite. Of interest also, as being found as beautiful, colourless crystals is the mineral *colemanite*, a calcium borate $Ca_2B_6O_{11} . 5\,H_2O$, which is mined in California as a source of boron compounds. A closely allied mineral, but occurring in a massive form in large nodules, is the *pandermite* of Asia Minor' which is shipped from the port of Panderma on the Sea of Marmora.

An easily applied test for boric acid is afforded by the characteristic green coloration it imparts to the Bunsen-flame. Alcohol mixed with boric acid burns with a green-edged flame.

Applications of Boron Minerals.— The most important product obtained from these various minerals is borax, whilst sassolite is also employed in the preparation of pure boric acid. Borax is extensively used for the production of starch glazes; in glass-making it is added to certain kinds of glass; in the pottery industry it is used for producing the glaze and as an addition to the colouring material. Boric acid is employed in medicine, as an antiseptic, and for preserving meat and fish; in the preparation of flint glass and the strass for imitations of precious stones; in the manufacture of candles, and in many other industries. The world's annual production of borax and boric acid amounts to about 14,000 tons, of which about 3000 tons are yielded by the Tuscan soffioni.

Nitrates.

The nitrates are salts readily soluble in water, and they are not often met with as minerals. The only ones of any importance are the sodium ($NaNO_3$) and the potassium (KNO_3) compounds. They are sometimes known collectively as saltpetre, a term more properly applied, however, to the potassium nitrate or nitre, the sodium salt being distinguished as Chile saltpetre or soda-nitre. The calcium salt (lime-nitre or wall-saltpetre) is sometimes seen as an efflorescence on the walls of stables. Barium nitrate, employed for producing the green fire of pyrotechnic displays, is known only as an artificial product. This salt crystallizes from an aqueous solution as beautiful, colourless, cubic crystals, which are optically isotropic and exactly similar to the crystals of the artificially-produced lead nitrate. Mixed crystals containing both barium and lead nitrates, however, possess the curious feature of exhibiting "optical anomalies".

Nitratine, Soda-nitre, or Chile saltpetre. This is an unattractive mineral forming granular masses intermixed with rock-salt, sand, and clay; such crude salt being known in Chile as *caliche*. Owing to the presence of the various impurities it may be white, grey, brown, yellow, or violet in colour. The purest white caliche contains 75 per cent. of nitratine with 20 per cent. of rock-salt; and in the brown material there is about 50 per cent. of nitratine and 40 per cent. of rock-salt, together with various other salts, sand, clay, and often some guano. Amongst the associated salts there are several which we have already noticed in the abraum-salts, for example, sylvite, thenardite, mirabilite, glauberite, epsomite, bischofite, anhydrite, and gypsum; whilst borates are here represented by ulexite.

In addition to these salts, two minerals containing iodine have been described from the nitrate deposits, namely lautarite (CaI_2O_6), and dietzeite ($7CaI_2O_6 . 8CaCrO_4$); but these are only very rarely met with and in extremely small amounts. Traces of iodine, probably in combination with calcium and with sodium, are, however, present throughout the caliche; and although the amount is only small, yet, from the large quantities of salt that are worked, this iodine forms a very important by-product. The Chilean nitrate deposits are indeed the principal source of iodine, which finds many important applications, not only in the form of the element, but also in the compounds potassium iodide, iodoform, and methylene iodide (p. 55). A ton of iodine costs about £1200, and in the year 1901 Chile produced 2460 tons.

The degree of solubility of sodium nitrate in water varies widely with the temperature. At 0° C. 100 grams of water dissolve 73 grams of the salt, but at 100° C. 180 grams are dissolved, and 110° C. as much as 200 grams. When a hot, concentrated solution cools it therefore deposits an abundant crop of crystals. On this property depends the method adopted for the purification of the crude salt; and by such re-crystallization a perfectly pure product is obtained. Pure sodium nitrate contains 63·53 per cent. of nitrogen pentoxide (N_2O_5) or 16·47 per cent. of nitrogen. It fuses at 320° C. and colours the flame yellow.

When heated with powdered charcoal it deflagrates and is completely dissipated. It absorbs water from a moist atmosphere; and it possesses a cooling saline taste.

The crystals grown artificially from a solution of sodium nitrate are rhombohedral in form, and they are in all respects strikingly similar to the rhombohedral crystals of calcite. They possess perfect cleavages parallel to the faces of the rhombohedron, the angles between which are 106° 30′ (corresponding to the angle 105° 5′ in calcite). Their double refraction is unusually strong, the refractive indices for sodium-light being for the ordinary ray 1·587 and for the extraordinary ray 1·336. On this account crystals of sodium nitrate would be suitable for the construction of polarizing prisms, but unfortunately it is not possible to obtain crystals, otherwise clear and colourless, free from enclosures of the mother-liquid. All attempts so far made to obtain large, clear, and perfectly homogeneous crystals of sodium nitrate, to take the place of the increasingly rare and expensive Iceland-spar, have been without success. Of further interest is the fact that when a drop of sodium nitrate solution is allowed to evaporate on a clean cleavage of calcite it deposits numerous tiny rhombohedra all arranged in parallel position on the calcite.

Occurrence. — The extensive deposits of soda-nitre in Chile were discovered about the year 1825, and since then the material has been worked in ever increasing amounts. It is found in the rainless districts of northern Chile, especially in the provinces of Tarapaca and Antofagasta. The saltpetre fields are situated in valleys and troughs at an elevation of 600—1500 metres above sea-level, and extend from Tarapaca in the north to Taltal in the south for a distance of nearly 400 miles. The surface of the deposits is usually covered with a snow-white efflorescent crust of impure glauber-salt, which serves as an indication of the presence of the nitrates. The upper layers consist of an ash-grey sand cemented by rock-salt, and beneath this is the caliche forming a bed never exceeding 1·5 metre in thickness. The base of the deposit consists of a bed of loose pebbles of quite recent geological age.

Extensive deposits of soda-nitre have also been reported to occur in California and Nevada. Those in California extend over a region from the Mohave Desert in San Bernardino County to Death Valley in Inyo County, and are said to crop out in beds 3 to 10 feet in thickness and to contain 15 to 40 per cent. of soda-nitre. These deposits have, however, not been exploited.

Beds of clay containing soda-nitre are met with in Egypt, and this material has been used, probably since early times, as a fertilizing agent. The so-called "tafle" found in the neighbourhood of Maalla and Esneh, on the Nile in Upper Egypt, is a clay containing 13—18 per cent. of soda-nitre and the same amount of common salt.

Origin. — Very little is known as to the mode of origin of the nitrate deposits in Chile. The associated minerals prove that the salts have been originally deposited from sea-water, and that at one time they formed part of a salt-deposit; but it is probable that they do not now lie in their original situation. The presence of nitrates and of iodates indicates that extremely energetic oxidation must have taken place; and W. Ostwald has suggested that, at the time of the formation of the deposits, some conditions favourable for the production of ozone in large amounts may have been effective.

Production. — The export of nitrates from Chile in the year 1830 amounted to only 800 tons, but in 1900 it reached 1,430,000 tons. Of this, the largest part, 1,129,000 came to Europe, and about 185,000 tons was used in America. In 1908 the output was very nearly two million tons, valued at about £9 per ton. The nitrates are subject to a heavy export duty, and bring to the state a revenue of 16—17 million dollars.

Application. — Soda-nitre is used extensively in agriculture as an artificial manure, and for corn and root crops it is the best and cheapest form in which nitrogen can be supplied.

Ammonium salts, obtained as a by-product in the manufacture of coke and coal-gas, hold their nitrogen in a form less readily assimilated by plants, and for this reason they are less useful as artificial manures. In Germany alone the annual comsumption of Chile saltpetre in artificial manures amounts to about 350,000 tons; and for the same purpose there are used 90,000 tons of ammonium sulphate, 600,000 tons of potash-salts, and in addition the phosphates to be considered later. In no other country are salts used in agriculture to such an extent.

Considerable amounts of Chile saltpetre are treated with potassium chloride at the Stassfurt salt-works (p. 362), with the production of potassium nitrate, and the nitrate is re-exported in this form to all parts of the world. By decomposition with barium chloride, barium nitrate is prepared (see under barytes). Another large proportion of the raw material is used for the manufacture of nitric acid (aqua fortis), which is obtained by decomposing the nitrate with sulphuric acid. By fusing sodium nitrate with metallic lead, sodium nitrite is prepared, a salt which finds extensive applications in the colour industry; and red-lead is prepared from the lead so oxidized.

It has been estimated that the Chilean nitrate deposits will become exhausted in about half a century, and fears have been expressed as to the shortage of supply of nitrates for use in agriculture. Recently, however, the fixation of atmospheric nitrogen, in the form of calcium nitrate, has been successfully accomplished and worked on a commercial scale; and the supply from this source is inexhaustible.

Nitre, or Saltpetre. Until the discovery of the deposits of soda-nitre in Chile, potassium nitrate was the only source of saltpetre. This nowhere occurs in such extensive and thick deposits as those in Chile; but, on the other hand, it is of far wider distribution, being rarely absent from the neighbourhood of human habitations. When potassium salts and decaying nitrogenous organic matter are present together in the soil the conditions are favourable for the formation of saltpetre. The potassium is supplied by silicates such as felspar or by wood-ashes, and the nitrogen is present in the form of ammonium compounds in dung and urine. By the action of nitrifying bacteria (*nitrosomonas*) in the soil the ammonium compounds are converted into nitric acid, and this combining with the potash gives potassium nitrate. In the dry weather this salt forms a snow-like efflorescence on the surface of the ground especially in the neighbourhood of villages. This is swept up and collected as crude saltpetre; but only in certain districts, where the material occurs abundantly, can the industry now compete with the Chile saltpetre.

Crude nitre is grey in colour, fibrous or earthy in texture, and much intermixed with impurities of various kinds. It is purified by re-crystallization from water. We have already seen that crystals of soda-nitre possess a great similarity to those of calcite; and now we find that crystals of potassium nitrate are remarkably similar to those of aragonite, which is the other crystalline modification of calcium carbonate. The text-figure of a simple rhombic crystal of aragonite given on a later page would do equally well for a crystal of saltpetre; and this salt shows the same forms as the simple (fig. 1) and twinned (figs. 5—8) crystals of aragonite shown on plate 74.

If we place a drop of a warm and slightly supersaturated solution of potassium nitrate on a slip of glass, the crystallization of the salt can be watched, and in polarized light some very interesting phenomena observed. At the edge of the drop there first separate small tables with a rhombic outline, these being rhombohedra resting on one of their faces. Next there appear long, spear-shaped crystals, which grow rapidly and soon reach the rhombohedral crystals. As soon as this happens the latter undergo a remarkable change: their outlines, previously straight and sharp, become crinkled, and on all sides spear-shaped crystals shoot out from their surface. The spear-shaped crystal are the more stable rhombic modification of potassium nitrate, whilst the rhombohedral crystals represent an unstable modification of the same salt. We here see a transformation from the unstable into the stable form. At a temperature of 129° C. the rhombic modification is unstable, and passes over into the rhombohedral form. This experiment proves that of the two modifications of a substance the unstable form may first separate and later become transformed into the stable form; and this has perhaps a bearing on the peculiar case of boracite (p. 368).

Saltpetre occurs most abundantly in British India, and the quantity exported still amounts to about 20,000 tons per annum. It is also found in Hungary, Algeria, and many other countries, and also together with soda-nitre in the Chilean deposits. The artificial production of saltpetre, was formerly practised in saltpetre plantations or nitriaries. At the end of the eighteenth century, during the French revolution, large quantities of saltpetre were required for the manufacture of gunpowder; and an appeal made by the vigilance committee to science led to the suggestion by Gaspard Monge (1746—1818) that the material could be collected from stables, cellars, and closets. The results were surprising: in nine months twelve million pounds of saltpetre were collected, sufficient, and from a source at home, to supply the demand. The saying was: "Give us saltpetre earth and in three days we will load the cannons."

At the present day saltpetre is mostly produced from soda-nitre and potassium chloride (p. 362), and it is used largely for the manufacture of gunpowder and fireworks. Soda-nitre is not suited for this purpose, since it attracts moisture from the air.

Fluor-spar.

The minerals that we have just considered present little to attract the eye, and they are not suitable for pictorial representation; their forms and physical characters are of little moment; and their importance depends rather on their chemical composition and abundant occurrence. In fluor-spar, on the other hand, we have one of the most beautiful of minerals, one which in the clearness and colouring of its fine large crystals finds few rivals. But in addition to this, fluor-spar is also of importance from the economic side. Whilst rock-salt and the abraum-salts yield chlorine and bromine, and Chile saltpetre gives iodine as a by-product, fluor-spar is the main source of fluorine. These four chemical elements are known as the halogens, and their salts are called haloids.

From a glance at plate 71 it is clear that crystals of fluor-spar belong to the cubic system. The most frequent form is the cube (figs. 6—8, 11—13). The octahedron is also not rare, occurring either alone (plate 1, fig. 5; plate 71, figs. 2 and 3) or in combination with the cube (plate 1, fig. 3; plate 71, fig. 5). The faces of the cube are always smooth, whilst those of the octahedron are usually dull. Another combination very characteristic of fluor-spar is that of the cube and a hexakis-octahedron with the symbol $4O2$ (plate 71, fig. 9), which is shown more clearly in text-fig. 246, *a* being the faces of the cube and *t*

Fig. 246.
Crystal of Fluor-spar.

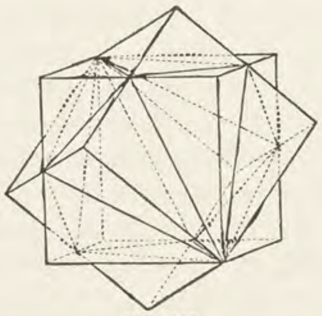

Fig. 247.
Interpenetrating twin-crystal of Fluor-spar.

PLATE 71.

Fluor-spar.

Fig.

1. **Fluor-spar** (or Fluorite), green cleavage octahedron.
   Nerchinsk, Siberia.
2. **Fluor-spar**, violet octahedra on felspar.
   Striegau, Prussian Silesia.
3. **Fluor-spar**, pink octahedra.
   Göschenen, St. Gotthard, Switzerland.
4. **Fluor-spar**, dark purple cubes on quartz.
   Zinnwald, Erzgebirge, Bohemia.
5. **Fluor-spar**, cube with rough octahedron faces.
   St. Gallen on the Enns, Styria.
6. **Fluor-spar**, **cubes**.
   Rappoltsweiler, Elsass.
7. **Fluor-spar**, yellow cubes.
   Annaberg, Saxony.
8. **Fluor-spar**, group of twinned cubes.
   Allenheads, Northumberland.
9. **Fluor-spar**, cube with hexakis-octahedron.
   Teufelsgrund, Münsterthal, Schwarzwald, Baden.
10. **Fluor-spar**, interpenetration twin of two cubes.
    Weardale, Co. Durham.
11. **Fluor-spar**, cube, interior yellow, exterior blue.
    Todtnau, Baden,
12. **Fluor-spar**, cube, yellow with violet border.
    Annaberg, Saxony.
13. **Fluor-spar**, interpenetration twin of two cubes.
    Alston, Cumberland.
14. **Fluor-spar**, massive, fibrous, with differently coloured bands.
    Castleton, Derbyshire.


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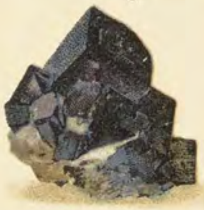
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those of the hexakis-octahedron. Combinations of the cube with narrow faces of the rhombic-dodecahedron or a tetrakis-hexahedron (text-figs. 27 and 28, p. 24) also occur.

Twinned crystals are common, especially in the fluor-spar from the north of England. Two cubes grow together in such a manner that the corners of one project from the faces of the other, whilst they both possess an octahedral face (the twin-plane) in common (plate 71, figs. 8, 10, and 13; text-fig. 247). At the points where the corners break through the cube faces the latter are often raised into a low square pyramid bearing striations parallel to the edges of the cube (plate 71, fig. 13).

An important character of fluor-spar is the possession of four directions of perfect cleavage parallel to the faces of the octahedron. Perfectly regular octahedral cleavage forms (plate 1, fig. 6 and plate 71, fig. 1) can be readily obtained by splitting off the corners of a cube. These cleavage surfaces are smooth and bright, whilst the natural octahedral faces are usually rough and dull.

Fluor-spar displays, perhaps more than any other mineral, a remarkably wide range in its colours, as is well represented by the several figures on plate 71. There may also be wide differences in the depth of colour; for example, from the palest yellow to deep wine-yellow, from a light violet to an intense purple, from a delicate shade of green to a rich bluish-green. Frequently also, one and the same crystal may exhibit different colours or shades of colour in different portions. The crystals represented in plate 71 fig. 11 are yellow in their interior and blue in their outer portions; those in fig. 12 are violet along the edges; and those in fig. 2 blue on the corners. The small piece of massive, fibrous fluor-spar in fig. 14 shows alternating bands of green, violet, and white.

As if not satisfied with even this liberal provision of colours, certain crystals of fluor-spar possess the peculiar property of displaying a difference in colour according to whether they are viewed in light that has passed through the crystal or in light that has been reflected from their surface. This colour phenomenon, being well shown by fluor-spar, is known as *fluorescence*. The crystal represented in plate 71, fig. 10, when held between the window and the eye shows a pale green colour; but if it is viewed with the source of light behind the observer (i.e. in reflected light) the colour seen is a rich velvety purple. Such a feature cannot of course be represented in a picture, more than as a mere suggestion.

The richness of colouring in fluor-spar being often combined with perfect transparency we are reminded of the precious stones; and, indeed, there are many points in common between the colouring of fluor-spar and tourmaline (p. 246). Fluor-spar is, however, not at all suited for use as a gem-stone, since its hardness (No. 4 on the scale) is much too low, the mineral being softer than glass. Its refractive power ($n = 1{\cdot}4338$ for sodium-light) and colour dispersion are also low.

In addition to crystals, fluor-spar also occurs as fibrous, granular, or compact masses; these are generally of a light colour, but granular fluor-spar from Wölsendorf in Bavaria is bluish-black with a tinge of red. The mineral from this locality is further of interest in emitting a peculiar smell, resembling that of chlorine, when it is powdered in a mortar. This was formerly considered to be due to the presence of ozone; but recently it has been suggested that the smell is due to fluorine, an element not know to occur elsewhere in the free state.

The nature of the pigment to which fluor-spar owes its varied colours is unknown. It is present only in minute amounts, and is diffused throughout the colourless fluor-spar substance in an extremely fine state of division, in much the same way that a dye is held in solution. The fact that the colour is often destroyed when the mineral is heated to a temperature of 200° to 300° C., had led to the suggestion that the colours are due to hydrocarbons; but there are various objections to this view. A perfectly colourless and water-clear crystal of fluor-spar is represented in plate 1, fig. 6.

Certain specimens of fluor-spar become luminous when heated to a temperature far below a red-heat, giving out a soft greenish or bluish light. This phenomenon, known as *phosphorescence*, is also exhibited by some other minerals, for example calcite, but we know little as to its cause. The green fluor-spar from Nerchinsk in Siberia (plate 71, fig. 1) displays a particularly strong phosphorescence when heated. Fluor-spar is only slightly transparent for the Röntgen rays.

In its chemical composition fluor-spar is quite simple, being fluoride of calcium with the formula CaF_2. When pure, it contains fluorine 48·72 and calcium 51·28 per cent. The presence of fluorine is readily demonstrated by adding sulphuric acid to the powdered mineral: hydrofluoric acid and calcium sulphate are thereby formed, and the former is recognizable by its penetrating odour and its property of etching glass. Other reagents have little or no action on fluor-spar; and yet we often find etched and deeply corroded crystals of the mineral which must have been acted upon by solutions in nature. The specific gravity of fluor-spar is relatively high, lying between 3·1 and 3·2.

Fluor-spar is a mineral of wide distribution, and in certain districts it is found in considerable abundance. It occurs most frequently in veins traversing granitic rocks and the rocks surrounding these igneous masses. In these cases the mineral has been deposited from the hot solutions which accompanied the eruption of the igneous rocks. Often, however, it occurs in sedimentary rocks, particularly limestones, quite independently of any igneous intrusions; and it has even been found in the interior of fossils. Here the mineral has no doubt been formed by the action of solutions containing soluble fluorides on the limestone rocks. The usual associates of fluor-spar are quartz (often present as a sparkling crust on the fluor-spar crystals), calcite, barytes, and metallic ores of various kinds.

The finest crystals of fluor-spar are those found in the veins of lead-ore in the north of England, particularly in a limited district on the borders of the counties of Cumberland, Durham, and Northumberland; namely in Weardale in Durham (plate 1, fig. 4; plate 71, fig. 10), at Allenheads in Northumberland (plate 71, fig. 8), and near Alston in Cumberland (plate 71, fig. 13). Fine specimens were also formerly found at many places in Cornwall (Menheniot, Redruth, St. Agnes, etc.), and at Beeralston in Devonshire. Fluor-spar is also of abundant occurrence in Derbyshire, but here usually as granular masses and as small, colourless crystals. The noted "blue-john", much employed for small ornamental objects, is found at Tray Cliff near Castleton in Derbyshire. This is a fibrous form of a rich purple colour with white and sometimes green bands; one variety is represented in plate 71, fig. 14.

Excellent specimens of crystallized fluor-spar are also found at many places in Germany. Beautiful, rich-yellow cubes and pale-yellow cubes with violet edges come from Annaberg in the Saxon Erzgebirge (plate 71, figs. 7 and 12). Good crystals are also found at Stolberg, near Wernigerode in the Harz Mountains (plate 1, fig. 3), and in the Black Forest in Baden (plate 71, figs. 9 and 11). An interesting occurrence is that in granite at Striegau in Prussian Silesia.

Cubes of a dark purple colour, and sometimes overgrown with colourless fluor-spar, are found together with tin-ore at Zinnwald in Bohemia (plate 71, fig. 4). Colourless fluor-spar is found in the neighbourhood of Meiringen in Switzerland; and the highly-prized pink octahedra are from the Göschenen valley in the St. Gotthard district (plate 71, fig. 3). Crystals of a delicate green colour come from Baveno in Italy (plate 1, fig. 5), and others of a peculiar reddish-violet from St. Gallen on the Enns in Styria (plate 71, fig. 5). Large green crystals have been found in considerable quantity at Macomb in St. Lawrence Co., New York.

Application. — At the present time colourless fluor-spar is much in request for optical purposes. Owing to its low refractive power and very low colour dispersion, it is especially suitable as a material for correcting the spherical and chromatic aberration of lens-systems. The so-called apochromatic microscope-objectives contain a lens of fluor-spar placed between lenses of glass. The specially clear and colourless fluor-spar from the neighbourhood of Meiringen has been worked by Professor Abbe for this purpose. The coloured varieties of the mineral, particularly the "blue-john" of Derbyshire, have been much employed as a material for small ornamental objects, such as vases, bowls, paper-weights, etc.; and it is supposed to have been the material of the famous murrhine vases of the Romans. Clear, richly coloured fluor-spar is no doubt sometimes passed off as a gem-stone, but owing to its low degree of hardness it is little suited for use in jewellery.

Fluor-spar is further the most important source of hydrofluoric acid and other fluorine compounds. When the powdered mineral is mixed with concentrated sulphuric acid there is an abundant evolution of hydrofluoric acid, and this is employed directly as an agent for etching glass. As a flux in smelting and in other metallurgical operations, fluor-spar has been used since early times; and indeed, its name, from the Latin (*fluo*, to flow), has reference to the property of the mineral of producing a fluid slag. In England, the annual production of fluor-spar amounts to about 40,000 tons, valued at 10s. to 20s. per ton; whilst in the United States some 50,000 tons are mined per annum.

Cryolite.

Cryolite carries a still larger amount of fluorine than fluor-spar, the pure mineral containing 54·4 per cent. of this element. This is combined with the metallic elements sodium (32·8 per cent.) and aluminium (12·8 per cent.). The chemical formula may be expressed as a double salt of sodium fluoride and aluminium fluoride, $3\,NaF \,.\, AlF_3$; but it is more probable that cryolite is the sodium salt of alumino-hydrofluoric acid, with the formula Na_3AlF_6. We thus see that, as with spinel, there are alternative ways of writing the formula of this mineral.

Cryolite is usually met with as coarsely granular or sparry masses, which are white and translucent, or rarely of a black colour. A peculiar moist-looking vitreous lustre renders the mineral easy of recognition. Other important characters are the three perfect cleavages approximately at right angles to one another, the low degree of hardness (H. = $2\,^1/_2$—3), the high specific gravity (2·97), and the easy fusibility. A thick piece of cryolite melts readily in the flame of the Bunsen-burner, to which it imparts an intense yellow coloration, proving the presence of sodium. The mineral is decomposed by sulphuric acid with the evolution of hydrofluoric acid, and the latter is readily recognized by its power of etching glass.

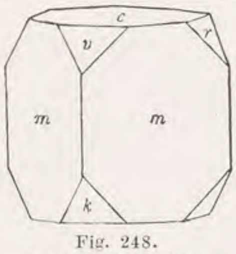

Fig. 248.
Crystal of Cryolite.

The characters just enumerated are sufficient for the identification of the mineral even in the absence of any crystalline form. Crystals are, indeed, not often seen; they always occur closely crowded together on the surface of the massive cryolite (plate 70, fig. 8). These crystals present quite the appearance of cubes, sometimes with truncated corners (text-fig. 248); but by accurate measurement they have been proved to be monoclinic. The faces *m* of the vertical prism enclose an angle of $91^0\,58'$, and they are each inclined to the basal plane *c* at $90^0\,8'$. The solid bounded by the four faces of the prism and the two faces of the basal pinacoid thus approximates to a cube. The cleavage, being parallel to *m* and *c*, is also apparently cubic; but that parallel to *c* is rather better developed than those parallel to the two *m* faces. The small triangular faces truncating the corners belong to two ortho-domes (*ν* and *k*) and to a brachy-dome (*r*).

A large deposit of cryolite occurs in granite or gneiss at Ivigtut in west Greenland. The mineral has probably been deposited by the vapours and hot solutions that emanated from the erupted mass of granitic rock. Large blocks of the material are rarely pure, but contain 10—30 per cent. of admixed impurities, mainly chalybite, but also zinc-blende, galena, copper-pyrites, cassiterite, and other minerals. This deposit, measuring 500 feet in length by 100 feet in width, is quarried, and the cryolite exported to Europe and the United States. The production in the year 1897 amounted to 13,361 tons, and in 1908 to 5,740 tons.

All the constituents of cryolite are utilized in one way or another. The mineral is employed for the manufacture of soda and of metallic aluminium (p. 222). It is also used for the preparation of pure hydrofluoric acid, and in the manufacture of opaline glass and of enamels on iron.

Minerals of the Calcite and Aragonite Groups.

The minerals of these groups are carbonates, that is, combinations of carbon dioxide, or carbonic acid, with a metal; and the latter is here either calcium or some other related element. The members of the two groups differ from one another in their crystalline form, those of one group being rhombohedral and those of the other rhombic. The types of each group consist of calcium carbonate, which is therefore dimorphous, crystallizing in the rhombohedral system as calcite, and in the rhombic system as aragonite. The members within each of these groups are closely related to one another in crystalline form and are analogous in chemical composition, in other words, they are isomorphous.

Calcite possesses perfect cleavages parallel to the faces of the primary rhombohedron, and any piece of calcite when struck with a hammer separates into rhombohedral fragments. The same kind of cleavage is possessed by all the other members of this group, and the cleavage fragments differ only slightly, in the several instances, in the angles between their surfaces. The members of the aragonite group, on the other hand, possess no cleavage; but here we find throughout the group a characteristic mode of twinning. By the repeated twinning of these rhombic crystals there are built up hexagonal forms which simulate the rhombohedral forms of the calcite group.

The several members of these two groups are tabulated below, giving the name of the mineral and its chemical composition; and also, for the calcite group, the angle of the cleavage rhombohedron *R*, and, in the aragonite group, the angle of the vertical prism ∞P. We see that in the calcite group the place of calcium may be taken by the related elements magnesium, iron, manganese, or zinc; whilst in the aragonite group calcium may be replaced by barium, strontium, or lead.

Calcite Group.
(Rhombohedral).

Mineral.	Formula.	*R*.
Calcite	$CaCO_3$	105° 5′
Magnesite	$MgCO_3$.	107° 20′
Chalybite	$FeCO_3$	107° 0′
Rhodochrosite	$MnCO_3$	107° 0′
Calamine	$ZnCO_3$	107° 40′
Dolomite	$CaCO_3 . MgCO_3$.	106° 20′
Ankerite	$CaCO_3 . FeCO_3$.	106° 10′

Aragonite Group.
(Rhombic).

Mineral.	Formula.	∞P.
Aragonite	$CaCO_3$	116° 10′
Witherite	$BaCO_3$	117° 48′
Strontianite	$SrCO_3$	117° 18′
Cerussite	$PbCO_3$ . . .	117° 14′
Alstonite	$(Ca,Ba)CO_3$	

PLATE 72.

Calcite I.

Fig.

1. **Calcite** (or Calc-spar), coloured black with manganese oxide; the obtuse, negative rhombohedron $-{}^{1}/_{2}\,R$.
   Bieber, Giessen, Hesse.
2. **Calcite,** isolated crystal viewed from above; the edges of the primary rhombohedron $+R$. are truncated by narrow faces of the obtuse, negative rhombohedron $-{}^{1}/_{2}\,R$.
   Andreasberg, Harz Mountains, Germany.
3. **Calcite,** the obtuse rhombohedron $-{}^{1}/_{2}\,R$ with the prism of the first order ∞R. The faces of the rhombohedron are dull and those of the prism bright.
   Freiberg, Saxony.
4. **Calcite,** acute, negative rhombohedra $-2\,R$.
   Andreasberg, Harz Mountains, Germany.
5. **Calcite,** primary rhombohedra $+R$.
   Poretta, Bologna, Italy.
6. **Calcite,** rhombohedron $-{}^{1}/_{2}\,R$ with prism ∞R.
   Oberscheld, Dillenburg, Hesse-Nassau.
7. **Calcite,** very acute rhombohedron with dull white base.
   Andreasberg, Harz Mountains, Germany.
8. **Calcite,** acute, negative rhombohedron $-2\,R$ enclosing sand-grains; "Fontainebleau Limestone".
   Fontainebleau, Paris, France.


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Some of these minerals have been already considered, namely, chalybite (p. 158), rhodochrosite (p. 170), calamine (p. 130), and cerussite (p. 120). The remaining important members to be now dealt with are calcite, magnesite, and dolomite of the calcite group, and aragonite, witherite, and strontianite of the aragonite group.

Minerals of the Calcite Group.

Calcite is a mineral of extremely wide distribution, and in its crystalline form and physical characters it presents many points of interest; further, by reason of its chemical composition, it has many economic applications of the first importance.

In its *crystalline form* calcite affords the best example of the rhombohedral system. In no other mineral do we meet with such an extensive variety of forms and combinations. The shapes of the crystals are indeed so varied, and frequently so complex, that were it not for the perfect rhombohedral cleavage to act as a guide it would not always be easy to interpret their forms correctly. The cleavage rhombohedron is taken as the primary rhombohedron with the Naumannian symbol $+R$, and the angles between its faces (arbitrarily lettered p in text-fig. 249) are $105^\circ 5'$ and $74^\circ 55'$. A rough classification of the numberless shapes of calcite crystals may be made according to the predominance of certain forms. Thus we may have crystals of rhombohedral, scalenohedral, prismatic, or tabular habit.

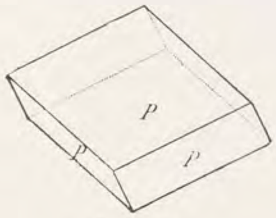

Fig. 249.
Crystal of Calcite: primary rhombohedron.

Fig. 250.
Crystal of Calcite: obtuse negative rhombohedron.

Amongst crystals showing a *rhombohedral habit* we have first those consisting simply of the primary rhombohedron (plate 72, fig. 5), in which the form is identical with the cleavage rhombohedron (plate 73, fig. 8). This rhombohedron is described as a positive rhombohedron, and all other rhombohedra which have their faces sloping in the same direction are also regarded as positive; other rhombohedra in which the slope is in another intermediate direction are called negative. The most commonly occurring form on calcite is the obtuse negative rhombohedron $-{}^1/_2\,R$ (text-fig. 250), with an angle of 135° between its faces. This is derived from the primary rhombohedron by truncating the three pairs of upper and lower edges of the latter form: its faces slope in the same direction as the edges of the primary rhombohedron, as may be seen from a comparison of text-figs. 249 and 250. This form is shown alone in plate 72, fig. 1, and in combination with the hexagonal prism of the first order in figs. 3 and 6; in fig. 3 the prism is short, while in fig. 6 (and text-fig. 251) it is much longer. The Naumannian symbol for this combination is $-{}^1/_2\,R,\ \infty R$.

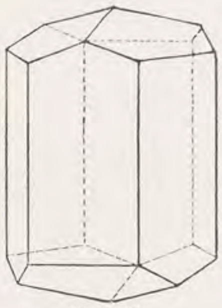

Fig. 251.
Crystal of Calcite: combination of obtuse negative rhombohedron and hexagonal prism.

Another rhombohedron of frequent occurrence is the acute negative rhombohedron with the symbol $-2\,R$, and an angle of $78^\circ 50'$ between its faces (plate 72, figs. 4 and 8; and text-fig. 252). The edges of this form are truncated by the faces of the primary rhombohedron (compare text-figs. 249 and 252). Many more rhombohedra, in all about seventy-five, have been observed on the mineral calcite. A combination of two rhombohedra is represented in plate 72, fig. 2; here the narrow faces of the form $-{}^1/_2\,R$ truncate the edges of the form $+R$.

Crystals of *scalenohedral habit* are of frequent occurrence. The commonest scalenohedron is that with the symbol R 3, represented as a simple crystal in plate 73, fig. 3, and text-fig. 253: here there are two sets of angles over the edges which meet at the top and the bottom of the crystal, three being more acute (104° 38′) and the alternate three more obtuse (144° 24′). The same form is shown in combination with the hexagonal prism ∞ R in fig. 2; and with this prism and the obtuse rhombohedron — $^1/_2$ R in fig. 1. The large crystal in fig. 4 is a combination of the scalenohedron R 3 and the obtuse rhombohedron — $^1/_2$ R, and below it is bounded by large cleavage surfaces. In all about 187 different scalenohedra have been observed on calcite.

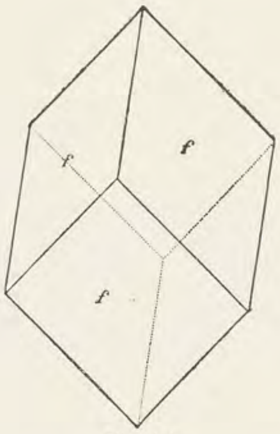

Fig. 252.
Crystal of Calcite: acute negative rhombohedron.

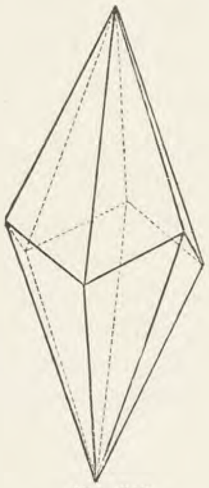

Fig. 253.
Crystal of Calcite: scalenohedron.

On crystals of a *prismatic habit* the hexagonal prism is generally that of the first order. Such a form cannot of course exist alone, unless the ends of the crystal are broken. It is shown in combination in plate 72, fig. 6, and plate 73, fig. 2, and with the basal plane in plate 2, fig. 6. Calcite crystals of the form last mentioned are sometimes called "cannon-spar".

In crystals of *tabular habit* we have a preponderating development of the basal plane 0 *P*. Plate 72, fig. 7, shows this form in combination with a short hexagonal prism ∞ P. Sometimes such crystals are extremely thin, like wafers, when the popular name "paper-spar" is applied.

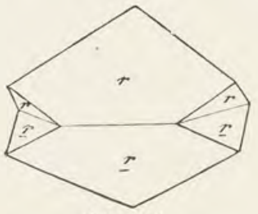

Fig. 254.
Twinned crystal of Calcite: rhombohedron twinned on the base.

Twinned crystals of calcite are also of frequent occurrence, and there are several types of twinning. The primary rhombohedron twinned on the basal plane is shown in text-fig. 254, and the cleavage form of such a twin in plate 73, fig. 9; when the re-entrant angles are not developed (as in fig. 9) such a form is a double triangular pyramid. When the scalenohedron is twinned on the base, the zig-zag edges at the side of the crystal are replaced by horizontal edges, and on three of the corners there are re-entrant angles each formed by a group of four small faces (plate 73, fig. 6, and text-fig. 255).

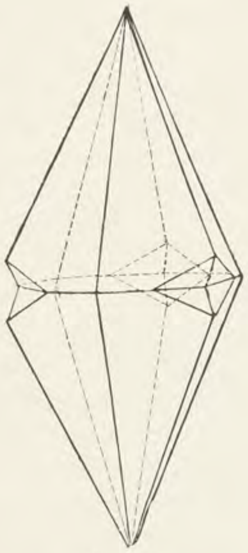

Fig. 255.
Twinned crystal of Calcite: scalenohedron twinned on the base.

Crystals twinned on the primary rhombohedron + R are represented in text-fig. 256 and in plate 73, fig. 5. In the former, showing a cleavage fragment, we see distinctly the twin junction running through the middle and parallel to the cleavages at the top and bottom. Such a twin combination may be exactly imitated by placing two cleavage rhombohedra of calcite one over the other in reversed positions. In fig. 5 is shown one of the beautiful "heart-shaped" twins from the Cumberland iron mines; and similar crystals, but more compressed in form, the so-called "butterfly-twins", are common from Derbyshire. In this figure the twin-plane is set vertically, and there are to be seen indications of the cleavage parallel to this direction: the vertical axes of the two individuals are inclined on either side, and make with one another an angle of approximately 90° (actually 90° 46′).

Twinning on the obtuse negative rhombohedron — $^1/_2$ R is shown by the cleavage fragment in plate 73, fig. 7. Here the lower shaded portion is in twinned position with respect to the upper portion, and a re-entrant angle is shown to the right: the twin-plane and face of union of the two portions runs parallel to the face of — $^1/_2$ R that would truncate the uppermost edge of the figure. This is the commonest of the twin-laws of calcite, but only exceptionally is it represented by completely developed twinned crystals with two distinct individuals. Most frequently the twinning is often repeated, giving rise to a lamellar structure or twin-lamination in the crystal. This produces the striations often to be seen on cleavage surfaces of calcite, these striations being parallel to the longer diagonal of the rhomb-shaped faces of the cleavage form. In plate 73, fig. 8, we see colourless lamellae running in this direction through a yellow rhombohedron.

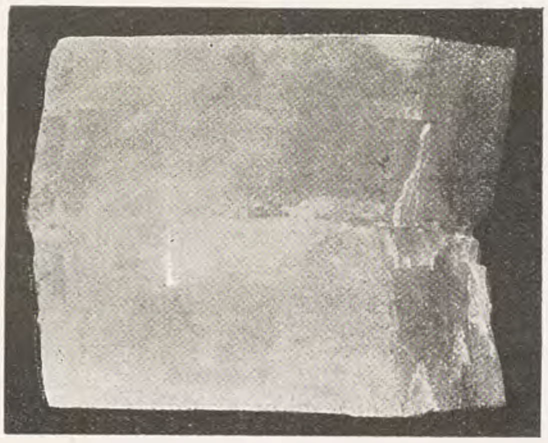

Fig. 256.
Twinned cleavage of Calcite : twin-plane + *R*.

Still another type of twinning is that in which the twin-plane is the acute negative rhombohedron — 2 R, but this is of rare occurrence.

The common type of twinning on the obtuse negative rhombohedron — $^1/_2$ R is related to the existence in calcite of a *glide-plane* parallel to this direction. We have already seen that cleavage cubes of rock-salt may be separated by pressure along a plane of gliding (p. 348), but in calcite translation along the glide-plane gives rise to secondary twinning. If a knife be gently pressed into a polar edge (i.e. one of the three edges meeting in the apex of fig. 249) of a cleavage fragment of Iceland-spar, it will be found that the material gives almost like cheese, slipping away towards the apex in the direction of the arrow (text-fig. 257). The displaced portion now shows an acute solid angle where formerly there was an obtuse solid angle, and a re-entrant angle has been developed on the face at the side. As shown in the text-figure this displaced portion is in twinned position with respect to the main fragment. The glide-plane, which at the same time is the twin-plane, is seen from the figure to be parallel to a plane which truncates the edge of the primary rhombohedron, being in fact a face of the obtuse negative rhombohedron — $^1/_2$ R.

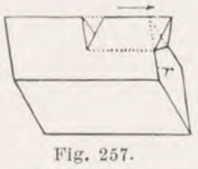

Fig. 257.
Calcite showing twinning artificially produced along the glide-plane — $^1/_2$ *R*.

Such secondary twinning is also produced naturally in calcite as a result of movements in the earth's crust; and the twin shown in plate 73, fig. 7, has no doubt been formed in this way. Calcite showing lamellar twinning (plate 73, fig. 8) is frequently met with in mountainous districts where earth pressures have operated. Twin-lamellae of the same kind may be induced in a thin cleavage flake of calcite by the following method: the flake is placed on an elastic cushion and pressed gently with the blunt edge of a chisel applied in the direction of the longer diagonal of the rhomb face. Along each line that the pressure is so applied a twin-lamella is developed without the plate being broken.

Of the *physical characters* of calcite the most striking and remarkable is the very strong double refraction, of which mention has already been made (p. 58; plate 3a). The index of refraction of the ordinary ray is 1·6585 and of the extraordinary ray 1·4863 (for sodium-light). By reason of this very strong double refraction the perfectly clear and colourless calcite from Iceland (Iceland-spar) is more suited than any other material for the construction of polarizing prisms (nicol prisms and dichroscopes) and for other optical purposes. Unfortunately, however, the production cannot keep pace with the demand, and consequently the price of such material is continually rising. In the year 1900 material of the best quality sold for £12 per kilogram, and the total production of the quarry in Iceland amounted to only £280.

A plate of calcite cut perpendicularly to the vertical crystallographic axis gives in convergent polarized light a uniaxial interference-figure (plate 4, fig. 1). When viewed in white light the rings are brilliantly coloured, providing the plate is not too thick: a thickness of a quarter of a millimetre gives the best result.

In the degree of transparency of crystals of calcite there may be a wide range. The material is itself without colour, and in fact most crystals are colourless. The yellow colour of the crystals in plate 72, fig. 6, is due to a thin surface film of iron hydroxide, and that of plate 73, figs. 4 and 6, is perhaps also due to the same foreign colouring material. The blackish colour of the crystals in plate 72, fig. 1, is due to an intermixture of earthy manganese oxide; and red crystals (plate 3, fig. 11) are coloured by iron oxide. The enclosure of foreign materials in crystals of calcite is well illustrated by the well-known specimens from Fontainebleau near Paris (plate 72, fig. 8), which sometimes contain as much as 60 per cent. of quartz sand. This has been erroneously called crystallized sandstone; but it is only the calcite that is crystallized and the sand accidentally caught up in this as a mechanical intermixture.

In the mineralogist's scale of hardness calcite is chosen as No. 3. This choice, although convenient, is not a good one, since there is an appreciable difference in the degree of hardness according to the direction in which the test is made. On a cleavage face in the direction of the shorter diagonal (plate 73, fig. 8) the hardness is greater when we scratch downwards from the top of the crystal than when we scratch in the reverse direction along the same line. A piece of calcite will produce a scratch in the upward direction, but not in the downward direction. The specific gravity of calcite is 2·72, and this affords one means of distinguishing calcite from the heavier aragonite.

As we have already seen, calcite consists chemically of calcium carbonate, containing when pure 56 per cent. of lime (CaO) and 44 per cent. of carbon dioxide (CO_2). Sometimes, however, a small proportion of the lime may be replaced by magnesia, ferrous oxide, or manganous oxide. When calcite is strongly heated its carbon dioxide is expelled and lime remains. This is the well-known quicklime which greedily absorbs water with the development of a considerable amount of heat; and the slacked lime absorbs carbon dioxide from the air with the formation again of calcium carbonate, passing gradually into a hard stony mass. Calcite dissolves readily in cold dilute acetic acid or hydrochloric acid, with a brisk effervescence owing to the escaping carbon dioxide. The solution imparts a yellowish-red colour to the Bunsen-flame. Calcite is appreciably attacked by water containing carbon dioxide in solution.

Origin. — The solubility of calcium carbonate in water charged with carbon dioxide is a factor of considerable importance in nature. Rain water absorbs carbon dioxide from the atmosphere and from the soil, and penetrating into the rocks at the earth's surface it is thus capable of taking up calcium carbonate in solution. When the carbon dioxide escapes from the solution the calcium carbonate is deposited and then frequently acquires a crystallized form. In this manner beautiful crystals of calcite have been formed in the cavities of limestone rocks (text-fig. 2, p. 6).

In the same way, also, are formed the wonderful stalactitic growths of calcite in limestone caverns. Carbonated waters percolating through the crevices in the limestone rocks take up calcium carbonate in solution, and by so dissolving the rock the crevices are at the same time enlarged with the formation of underground water-courses and caverns. When the water so charged drips from the roof of such a cavern it loses some of its dissolved carbon dioxide, and the calcium carbonate consequently falls out of solution. This process continued for a long period of time gives rise to a rod of calcite — known as a *stalactite* — suspended from the roof of the cavern. While falling, the drops of water lose still more carbon dioxide, and there is thus formed on the floor of the cavern an upward-growing *stalagmite*. With the slow but continued growth of the stalactite downwards and of the stalagmite upwards the two at last meet forming a column extending from the floor to the roof of the cavern. All manner of fantastic forms, with resemblances to organ-pipes, heavy curtains, etc., are formed by this constant dripping of water in limestone caverns. Text-fig. 258 gives a view of the Alhambra grotto in the Dechen Cave (so named after a German geologist) at Letmathe in Westphalia. The limestone caves of certain districts are far-famed, for example, those at Rübeland in the Harz Mountains, in the limestone districts of Derbyshire and Yorkshire, the Adelsberg Cave in Carinthia, the Jenolan Caves in New South Wales, and the Mammoth Cave of Kentucky; the last named, probably the largest of all, extending for a distance of 240 kilometres (144 miles).

Fig. 258.
Stalactites and Stalagmites in the Dechen Cave at Letmathe, Westphalia.

Under other conditions the carbon dioxide may be extracted from the charged waters by living plants; the calcium carbonate is then deposited around the plants and takes their form, giving rise to porous masses of calcareous *tufa* or calcareous sinter. The *travertine* of Tivoli, which formed the principal building stone of ancient Rome, is of this nature.

The waters of all rivers contain calcium carbonate in solution, and enormous quantities are thus carried to the ocean. Here the solution is so dilute that there can be no direct precipitation of calcium carbonate. Nevertheless, practically the whole of the limestone rocks which form part of the solid crust of the earth have been deposited in the sea. Calcium carbonate is extracted from sea-water by various organisms for the formation of their hard parts, such as shells and coral skeletons. Accumulations of these give rise to the formation of beds of *limestone*, for example, shell-limestone, coral-limestone, crinoidal limestone, nummulitic limestone, etc. The common *chalk* is also of the same nature, being formed largely of the minute shells of foraminifera. Of the many other varieties of limestone rocks, mention may also be made of the very fine-grained and compact *lithographic stone* quarried at Solenhofen in Bavaria, which is extensively used in printing: all the coloured plates in this volume have, for instance, been printed from lithographic stones. Another form of limestone is that known as *oolite* or roe-stone, which consists of a close aggregate of tiny spheres like the roe of a fish.

All these various forms of limestone are more or less compact and close grained in texture. They are of wide distribution, and it is not necessary in this place to enter into any further description, nor to mention occurrences at particular localities. In some the texture is sufficiently compact to allow the material to take a fine polish, and we then have a rock which is popularly known as a *marble*. Here with the various enclosed fossils and the intermixed colouring materials we have an endless variety. The mineralogist and petrologist, however, limit the term marble to a crystalline limestone. Here the material of the compact forms of limestone has been re-crystallized by metamorphic agencies acting within the earth's crust. Such a change may be brought about by pressure, or by a baking action and the action of hot solutions in contact with an intruded mass of igneous rock. Crystalline limestones formed by contact-metamorphism are often of a peculiar and light shade of blue (plate 47, fig. 8), and they are characterized by the presence in them of certain minerals, such as garnet, idocrase, wollastonite, etc. When more pure, containing only occasional quartz crystals (plate 54, fig. 11), such crystalline limestones are of importance as statuary marbles.

Crystals of calcite are of common occurrence in the cavities and crevices of limestone rocks. Here the limestone has supplied the material for the growth of the crystals. There are, however, many other ways in which calcite crystals have been formed in nature. By the weathering of lime-bearing silicates, particularly the felspars, calcium carbonate may result and be deposited as brilliant crystals in the cavities of volcanic rocks. In metalliferous veins calcite is rarely absent, and here indeed we find the largest and the finest crystals. A peculiar formation is that of crystals in loose sand, the sand being cemented by the crystallized calcite (plate 72, fig. 8).

The *artificial production* of calcite crystals from calcium carbonate is not a difficult matter. A wet precipitate of calcium carbonate, obtained by adding ammonium carbonate to a solution of a calcium salt, is allowed to stand for some time exposed to the air. Carbon dioxide is absorbed, causing the calcium carbonate to go into solution, when it is re-deposited in a crystalline form In this way microscopic rhombohedra slowly grow in the amorphous mass until the whole becomes crystalline. It is well known to chemists that freshly precipitated calcium carbonate partly passes through a filter-paper giving a turbid filtrate; but if the precipitate be allowed to stand for a day, a clear filtrate can be then obtained. The explanation of this is that the finely-divided amorphous particles are transformed into larger crystalline grains. We have here an example of the fact that when crystals are growing together under certain conditions, the larger ones grow at the expense of the smaller — in the mineral kingdom, just as in the animal kingdom, the larger devour the smaller.

Another method of growing crystals of calcite is to pass a current of carbon dioxide gas through water containing freshly precipitated calcium carbonate: after a little time the liquid is filtered, and the clear solution allowed to stand in contact with the air. With the gradual evaporation of the solution and loss of carbon dioxide, crystals of calcite are deposited. These crystals are, however, as also in the last experiment, only of microscopic dimensions. This method has been employed in order to determine the conditions under which calcium carbonate crystallizes as calcite or as aragonite. It has been found that form a pure and cold solution the product is mainly calcite; whilst from a hot solution, and especially in the presence of lead or strontium salts, aragonite is deposited.

Still another method is that devised long ago by Sir James Hall (1761—1832), who was the first investigator to attack the problems of geology by the experimental method. He enclosed chalk in a closed gun-barrel, and heated it to a high temperature in a furnace. Owing to the evolution of carbon dioxide from the chalk, the pressure inside the barrel must have been very considerable. After slowly cooling it was found that the amorphous calcium carbonate had become crystalline throughout and converted into marble.

Crystalline limestones must have been formed in nature by some such process as this, for when beds of compact limestone are deeply buried in the earth's crust they would be subjected to heat and pressure. The presence of water and carbon dioxide also no doubt aided the crystallization of the material.

The simple *weathering* of limestone does not take place by reason of any chemical alteration or destruction of the material, but rather by reason of its solubility in water charged with carbon dioxide. The rocks are simply dissolved, and their surfaces present a corroded aspect.

The case is different, however, when waters containing metallic salts in solution come into contact with limestone or calcite. Here we have extensive chemical replacements, as amply testified by the many kinds of pseudomorphs after calcite which we find in nature. The pseudomorph after calcite shown in plate 3, fig. 12, has already been discussed in some detail on p. 50. Pseudomorphs of pyrolusite, dolomite, and calamine after calcite are also of common occurrence.

By a similar metasomatic replacement of beds of limestone there may be formed extensive deposits of iron, manganese, and zinc ores, as already explained in the case of zinc (p. 130). To give another example, we may mention that of the alteration of limestone in the Schmalkalden mining district in Prussia. Here springs of chalybeate waters rising through crevices in the limestone rocks have transformed the latter into chalybite and limonite. In all these cases we have a replacement of a more readily soluble mineral by one that is less soluble.

The *localities* at which fine crystals of calcite are found are very numerous, and here only a few of the more important can be mentioned. In crevices in *limestone*, crystals are found at Bieber in Hesse (plate 72, fig. 1), Iserlohn in Westphalia (plate 3, fig. 10), etc. Cavities in contact-marble at Auerbach in Hesse contain large twinned crystals (plate 73, figs. 7—9, and text-fig. 256). In *volcanic rocks*, the agate-lined cavities of the Nahe district in Germany contain crystals of calcite, and fine crystals are found in the copper mines of Lake Superior in North America. The noted Iceland-spar occurs filling a large cavity in basalt close to the farm Helgustadir, near Eskifjördur on the Reydar Fjördur, east coast of Iceland. Occurrences in *metalliferous veins* are especially abundant; for example, at Andreasberg in the Harz (plate 2, fig. 6; plate 72, figs. 2, 4, and 7), Freiberg in Saxony (plate 72, figs. 3), Cornwall, Devonshire, and Derbyshire (plate 73, fig. 6), Joplin in Missouri (plate 73, fig. 4), Guanajuato in Mexico (plate 73, fig. 3), etc. Deposits of *iron ores* frequently yield good crystals; the haematite mines in the neighbourhood of Egremont in west Cumberland produce magnificent crystals and groups in almost superfluous quantities (plate 73, figs. 1 and 3). A similar occurrence in red-iron-ore is also met with at Oberscheld near Dillenburg in Nassau (plate 72, fig. 6). Good calcites are also found in the *crystal-lined crevices* traversing the gneissic rocks of the Alps; and a similar occurrence is that at Poretta near Bologna in the Apennines (plate 72, fig. 5). Crystals are found in loose *sand* at Fontainebleau near Paris (plate 72, fig. 8), at Dürkheim in Rhenish Bavaria, Sievring near Vienna, and in the Bad Lands of Washington Co., South Dakota.

Applications of calcite, limestone, and marble.—The use of clear crystallized calcite for the construction of polarizing prisms has already been mentioned above more than once. The varied applications of limestones depend, on the one hand, on their texture, and, on the other, on their chemical composition. The extremely fine grained and homogeneous limestone of Solenhofen in Bavaria is used as a lithographic stone. Other limestones are used extensively for building purposes, for example, the Roman travertine, the English Portland and Bath stones, and many others of importance. When compact enough to take a polish limestones are much used as ornamental stones for inside decoration. The softer chalk is used as a writing material, for polishing, and many other purposes.

Enormous quantities of limestone are quarried to be burnt in kilns for lime and for the manufacture of cement. A pure limestone yields when burnt a "fat" or white lime which is readily slacked; whilst the "poor" lime given by an impure limestone slakes only with difficulty. Cements manufactured from limestone include hydraulic cement, in which the lime is combined with free silica, and the important Portland cement. The latter is made from a clayey limestone or from limestone and clay intimately intermixed in the proper proportions by artificial means; this is burnt in kilns of a special type until the mass sinters; the clinkers are then ground to a fine powder, and this when mixed with water sets to a hard mass. Portland cement contains: lime (CaO) 55—66, silica (SiO_2) 19—26, alumina (Al_2O_3) 4—10, iron oxide (Fe_2O_3) 2—4 per cent., together with small amounts of magnesia, alkalis, sulphuric acid, carbonic acid, and water. In the year 1901 the production of Portland cement in 85 works in Germany amounted to $3^1/_3$ million tons; but since that date far larger quantities are produced, in that and other countries, owing to the extensive employment of concrete for building purposes.

In the smelting of iron ores the addition of limestone is necessary for the formation of the slag, the lime combining with the silica and phosphorus of the ore (p. 160). Lime is used for the manufacture of glass (p. 273); when mixed in water for white-washing; mixed with various metallic oxides, it is used in the manufacture of colours (p. 114). In the chemical industries, limestone is used in the manufacture of soda (p. 357) and bleaching powder. The latter is a calcium salt consisting of a mixture or combination of chloride and hypochlorite, $CaCl_2 + Ca(OCl)_2$, which is readily decomposed by the weakest acids with the evolution of chlorine; and being easily transported and handled it contains the chlorine in a readily available form for bleaching and disinfecting purposes. Another important product, namely calcium carbide (CaC_2), is manufactured by heating a mixture of limestone and coal in the electric furnace; this when decomposed by contact with water gives a supply of acetylene gas, which is now much used for illuminating. These examples serve to indicate the extremely important rôle that limestone plays in the industries and in technical processes.

PLATE 73.

Calcite II.

Fig.

1. **Calcite** (or Calc-spar), group of crystals on iron-ore; prism ∞R with scalenohedron $R\,3$ and obtuse rhombohedron $-{}^1/_2\,R$.
   Egremont, Cumberland.
2. **Calcite,** prism ∞R with scalenohedron $R\,3$.
   Niederrabenstein, Chemnitz, Saxony.
3. **Calcite,** scalenohedron $R\,3$.
   Bolanitos mine, Guanajuato, Mexico.
4. **Calcite,** large scalenohedron $R\,3$, with obtuse rhombohedron at the top and cleavage surfaces below.
   Joplin, Jasper Co., Missouri, U. S. A.
5. **Calcite,** heart-shaped twin-crystal.
   Egremont, Cumberland.
6. **Calcite,** scalenohedron $R\,3$ twinned on the base; on fluor-spar.
   Matlock, Derbyshire.
7. **Calcite,** cleavage rhombohedron twinned on the obtuse rhombohedron $-{}^1/_2\,R$.
   Auerbach an der Bergstrasse, Hesse.
8. **Calcite,** cleavage rhombohedron with twin lamellae parallel to $-{}^1/_2\,R$.
   Auerbach an der Bergstrasse, Hesse.
9. **Calcite,** cleavage rhombohedron twinned on the base, forming a double triangular pyramid.
   Auerbach an der Bergstrasse, Hesse.


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The *occurrence of marble*, presenting many points of interest, may be briefly dealt with in this place. The most important deposits are those in Greece and Italy, and it was these that supplied the material for the famous sculptures of the ancients.

The largest deposit is that in the neighbourhood of Carrara in Tuscany; it reaches a thickness of 1000 metres, and extends over a wide area in the Apennines. Here, as a result of the pressures accompanying mountain building, the limestones of Triassic age have become crystalline and converted into marble. At the present day Carrara is the most important marble-producing district in the world; together with the neighbouring districts of Massa and Seravezza, the annual yield is about 70,000 cubic metres, of the value of £ 800,000 to a million pounds. The best quality, the "statuario" or statuary marble, is snow-white with a fine saccharoidal texture, and a slight shimmer and translucency on the surface. Such material amounts to only about 5 per cent. of the whole production; the remainder is sawn into slabs for use as table-tops, window-sills, etc. (and, curiously, is used under the trade-name of "Sicilian" marble).

The famous Greek statuary marbles came mainly from the adjoining mountains of Pentelicus and Hymettus in Attica, and from the islands of Paros and Naxos. According to R. Lepsius*) there are twenty-five ancient marble quarries to be seen on Mt. Pentelicus, from which at a moderate estimate 400,000 cubic metres of marble have been taken. This large quantity of material was used, not only for the famous buildings (Parthenon, Erechtheum, Propylaea, Theseum, Olympieum) of Athens, but also in other parts of ancient Greece and in Rome. Almost every museum in modern Europe contains examples of statuary executed in this antique Pentelic marble. Several large buildings in London have recently been constructed of this material. It is snow-white with a tinge of yellow, and a fine-grained crystalline texture rather like that of beet-sugar. This stone possesses the peculiarity that the small grains of calcite are set in a very fine-grained to compact groundmass which is milk-white and translucent.

Such a compact groundmass is not seen in the marbles of Paros and Naxos, in which the grain is much coarser. In the Parian marble the grains seldom exceed 3 mm. across, whilst in that from Naxos they reach 10 mm. The most important quarries in ancient times on the island of Naxos were worked underground, and, as lamps were used, the stone was known as *lychnites lithos* or lamp-stone. This is snow-white and very pure, and owing to the coarseness of the grain the light is able to penetrate beneath the surface as in no other marble. The beautiful statue of Hermes of Praxiteles in Olympia is carved in the best Parian marble, and the soft shimmer seen on the surface is due to this transparency of the grains of calcite of which the stone is composed.

Marbles are also of wide distribution in the Alps. The best is the Laas statuary marble from the Vintschgau in Tyrol; this is white and compact with a slightly larger grain than the "statuario" of Carrara. In Germany, marble occurs at Wunsiedel in the Fichtelgebirge, Gross-Kunzendorf in Silesia, and Auerbach in Hesse; but none of these are of statuary quality. Variegated marbles, often rich in fossils, are quarried on the Lower Lahn. Marbles of a similar character are also worked in Devonshire and Derbyshire. The so-called "petit granit" of Belgium is black marble marked with numerous fossils: about 12,000 cubic metres are quarried per annum, of the value of 2—3 million francs. A white marble has recently been worked in Norway. Lastly, there are numerous marble occurrences in the United States; but Carrara marble is imported for the best work.

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*) R. Lepsius, 'Griechische Marmorstudien' (Abhandlungen der Akademie der Wissenschaften, Berlin, 1890).

The so-called *onyx-marble* (Algerian onyx, Mexican onyx, and "oriental alabaster") also consists of calcite in a finely granular or fibrous form. It is distinguished by its high degree of translucency; and with its bands and cloudy patches of different colours it has a pretty effect. Material of this nature has not been formed by the re-crystallization of a limestone rock, but it has been deposited directly from solution in much the same way as stalagmitic calcite. Onyx-marble is frequently cut and polished for small ornamental objects or as larger decorative slabs.

Magnesite. Calcite we have dealt with above at some length, but the other members of this group will occupy much less of our time, for they show less variety of form and their applications are limited. Whilst in calcite the primary rhombohedron is comparatively rare as a simple form, in the other members of the group this form is of common occurrence, and in magnesite it is practically the only one met with. Crystals of magnesite are never of large size and they are only found embedded in the matrix; plate 75, fig. 8, shows a dark-coloured rhombohedron embedded in chlorite-schist (the piece of rock being trimmed square). The crystals are sometimes colourless, but mostly yellow or brown, owing to a partial replacement of magnesium carbonate by iron or manganese carbonate. The hardness (H. $= 4—4^1/_2$) and specific gravity (2·9—3·1) are higher than for calcite.

Crystals of magnesite are found embedded in chlorite-schist and talc-schist in the Swiss and Tyrolese Alps (for example, in the Pfitsch and Ziller valleys); and in serpentine at Snarum in Norway. Black, compact masses are found in gypsum at Hall in Tyrol. More usually, the mineral is met with as fissured nodules of snow-white colour and compact texture. Such material is often impregnated with silica, and it occurs in connexion with serpentine as a product of the weathering of olivine-rocks. Localities are: Frankenstein in Prussian Silesia, Kaiserstuhl in Baden, Kraubat in Styria, and Hrubschitz in Moravia. In the eastern Alps it occurs in considerable quantities and is won by mining. Formerly it was used for the preparation of pure carbon dioxide and of epsom-salts, but now these products are obtained respectively from springs and the Stassfurt salts. At the present day magnesite is largely used for the manufacture of refractory bricks and furnace linings, artificial stone, tiles, etc.

Dolomite. The two compounds which we have considered under calcite and magnesite enter into combination to form the double salt $CaCO_3 . MgCO_3$, which expresses the composition of dolomite. Since the two components belong to the same isomorphous group, the question may very naturally be asked, why is this a double salt and not an isomorphous mixture? It is found that pure crystals of dolomite always contain very nearly 54 per cent. of calcium carbonate and 46 per cent. of magnesium carbonate; that is, the two carbonates are present in equal molecular proportions. With isomorphous mixtures, on the other hand, the two components are present in indefinite and variable proportions. In some varieties of dolomite, to which the name brown-spar is loosely applied, a portion of the magnesium is replaced by iron and manganese; and in these instances the double salt relation is expressed in the ratio of $(MgO + FeO + MnO) : CaO = 1 : 1$.

Chemically, therefore, dolomite is clearly a double salt, but this double salt possesses the unusual feature of exhibiting a crystalline form very like those of its component salts. The rhombohedral angle of dolomite (106° 20′) lies, in fact, between the corresponding angles of calcite (105° 5′) and magnesite (107° 20′). But it has been shown by closer examination that the degree symmetry possessed by crystals of dolomite is not the same as in calcite and magnesite. Etched figures and the occasional presence of certain rare faces prove that the symmetry of dolomite is rhombohedral-tetartohedral (p. 36).

The crystals are, as a rule, bounded by only the faces of the primary rhombohedron; and they are sometimes quite large and sharply developed (plate 75, fig. 7). In this figure we have a twin intergrowth of two (or rather three)*) rhombohedra: being viewed from above, we see the three polar edges which meet in the apex of the crystal. The two crystals are orientated in reverse positions with respect to one another; and if we imagine one crystal to be rotated through 180° about the vertical axis (approximately perpendicular to the paper as represented in the picture), we shall find that it comes into the position of the other crystal. The basal plane (perpendicular to the vertical axis) would therefore, if present, be common to the two individuals of the twin; and this is consequently regarded as the twin-plane.

Large and sharply-developed crystals like those just described are, however, of exceptional occurrence. More usually the mineral is observed as small rhombohedral crystals with a saddle-like curvature, and they are closely crowded together on the surface of the matrix (plate 75, fig. 10). This peculiar curvature of the crystals (text-fig. 259) is due to their being built up of a number of smaller individuals arranged next to one another in not quite parallel position, each successive one being removed farther and farther from its true position. A sub-parallel grouping of a similar nature we have already observed in the twisted crystals of smoky-quartz, and the sheaf-like crystals of stilbite. The small, black crystal represented in plate 75, fig. 9, consists of a combination of an acute rhombohedron 4 *R* with the basal plane 0 *R*, the edges between these two forms being truncated by narrow faces of the primary rhombohedron *R*.

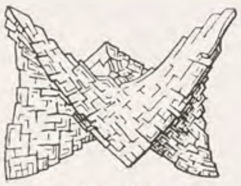
Fig. 259.
Saddle-shaped crystal of Dolomite.

Dolomite shows practically no effervescence with cold hydrochloric acid, but it dissolves readily and completely when warmed. This difference in behaviour from calcite affords an easy means of distinguishing the two minerals. Also in carbonated water dolomite is much more difficultly soluble than calcite, and this difference has an important bearing on the formation of the mineral. 10,000 parts of water saturated with carbon dioxide at a temperature of 18° C. dissolves 10—12 parts of calcite, but only 3 parts of dolomite. In its higher hardness of $3^1/_2$—4 and specific gravity of 2·85 — 2·95, dolomite also shows a difference from calcite. The double refraction is here also very strong; but the crystals being usually small and not clear this is not an obvious character. Twin-lamellae, which are so common in calcite, are never seen in dolomite, and there is no glide-plane or plane of secondary twinning.

Colourless, water-clear crystals of dolomite are found in the drusy cavities of the snow-white, saccharoidal dolomite-rock of the Binnenthal in Wallis, Switzerland. Large, yellowish or greyish-yellow crystals (plate 75, fig. 7) occur together with crystals of quartz, iron-pyrites, and mesitite ($2MgCO_3 . FeCO_3$) in the deposits of magnetic iron-ore at Traversella in Piedmont. Small black crystals, coloured by carbonaceous matter, are embedded in gypsum at Hall in Tyrol and Teruel in Spain (plate 75, fig. 8). Yellowish crystals occur together with magnesite embedded in the talc- and chlorite-schists of the Alps: and the two minerals are then so similar in appearance that they are readily mistaken the one for the other. Small, white, grey, or yellowish crystals with curved faces are of frequent occurrence in mineral-veins; for example, at Freiberg in Saxony, Schemnitz in Hungary, Cornwall and Devonshire, Cumberland and Co. Durham, Laxey in the Isle of Man, etc.

In addition to crystals, dolomite occurs abundantly as large masses, forming a rock to which the name dolomite is also applied. Here again the parallel with calcite is complete. Corresponding with marble we have the crystalline saccharoidal dolomite of

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*) The third, smaller individual, on the right in the lower part of the picture, is in twinned position with respect to the central individual, and therefore parallel to that on the left.

the Alps. This occurs, for example, in the Binnenthal in Wallis, and is shown in plate 20, fig. 3, as the matrix of crystals of zinc-blende: it also carries a number of rare minerals for which this locality is famous. A very similar rock is met with at Campo longo in Canton Tessin, here forming the matrix of splendid crystals of green tourmaline, and also of red and blue corundum. Corresponding with common limestone we have a compact dolomite rock, which frequently displays a characteristic spongy or cavernous texture. In such rocks, however, there is often less magnesium carbonate than is required by the formula $CaCO_3 . MgCO_3$, and they are then more correctly described as magnesian limestones. They are of wide distribution, and are often employed as building stones; the Houses of Parliament in London, for example, being built of magnesian limestone from Bolsover Moor in Derbyshire. In the north of England this rock is of Permian age: that of the Dolomite mountains in southern Tyrol is of Triassic age; and the dolomite of Swabia belongs to the Jurassic formation.

Much has been written on the origin of dolomite rocks. In some instances they have doubtlessly been formed by the weathering of limestones containing a small proportion of magnesium carbonate: by the removal of the more soluble calcium carbonate there has been an enrichment of magnesium carbonate in the cavernous rock which remains behind. Again, solutions carrying magnesium salts when brought into contact with limestone would carry away calcium carbonate and deposit magnesium carbonate, in the same manner that zinc ores are deposited (p. 130). It has been proved by borings in coral islands that the coral-limestone is slowly acted on by the magnesium salts contained in sea-water.

Minerals of the Aragonite Group.

Aragonite is the other and rarer modification of calcium carbonate, but still it is a mineral of importance. A small proportion of the calcium is sometimes isomorphously replaced by strontium or lead; and formerly it was believed that this admixture of strontium constrained the calcium carbonate to crystallize as aragonite rather than as calcite. Now, however, we know that many substances crystallize as different modifications, and calcium carbonate is one of such dimorphous substances. The difference between aragonite and calcite lies mainly in their crystalline form and physical characters, and less markedly in the chemical properties: in their ultimate chemical composition they are identical.

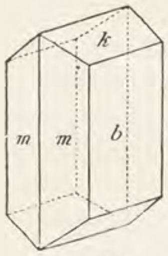

Fig. 260.
Untwinned crystal of Aragonite.

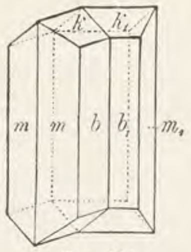

Fig. 261.
Twinned crystal of Aragonite.

Crystals of aragonite when untwinned exhibit a very simple and typical rhombic form: as shown in plate 74, fig. 1, and text-fig. 260, they are bounded by a vertical prism $m = \infty P$, the brachy-pinacoid $b = \infty P \breve{\infty}$, and a brachy-dome $k = P \breve{\infty}$. The angle between the faces of the vertical prism is 116° 10′, and that of the brachy-dome is 108° 26′. Spear-shaped crystals, with faces more steeply inclined, also occur; these usually form columnar aggregates (fig. 12) or small tufts.

Usually, however, the crystals are twinned, the twin-plane being a face of the vertical prism; but owing to differences in the form of the single crystals and the manner in which they are united, the twin-crystals may present very different appearances. In text-fig. 261 we have a simple twin of two individuals of equal size: here in the actual crystals (plate 75, fig. 4) the re-entrant angle formed by the brachy-pinacoid faces b b_1 is usually grown over by the extension of the adjoining prism-faces; so that the twinned crystal

PLATE 74.

Aragonite.

Fig.

1. **Aragonite,** simple (i. e. untwinned) rhombic crystal; prism, brachy-pinacoid, and brachy-dome.
   Horschenz, Bilin, Bohemia.
2. **Aragonite,** twinned once on a prism face; showing re-entrant angle at the top.
   Horschenz, Bilin, Bohemia.

3, 4. **Aragonite,** twinned several times on the same prism face.
   Horschenz, Bilin, Bohemia.

5. **Aragonite,** trilling; three crystals twinned together on two prism faces of one crystal; forming an apparently hexagonal crystal. (Viewed on the basal plane.)
   Sicily.
6. **Aragonite,** trilling.
   Bastennes, Dax, dept. Landes, France.
7. **Aragonite,** trilling.
   Molina, Aragon, Spain.
8. **Aragonite,** trilling.
   Herrengrund, Hungary.
9. **Aragonite,** twinned crystals, altered to calcite.
   Blaue Kuppe, Eschwege, Hesse.
10. **Aragonite,** trilling, altered to native copper.
    Corocoro, La Paz, Bolivia.
11. **Aragonite,** radially fibrous on basalt-tuff.
    Leidenhofen, Giessen, Hesse.
12. **Aragonite,** a radial aggregate of spear-shaped crystals.
    Frizington, Cumberland.


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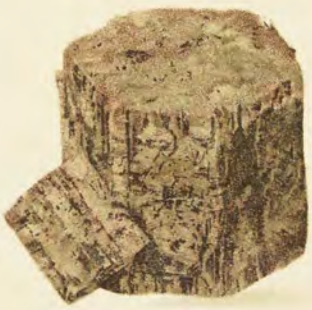
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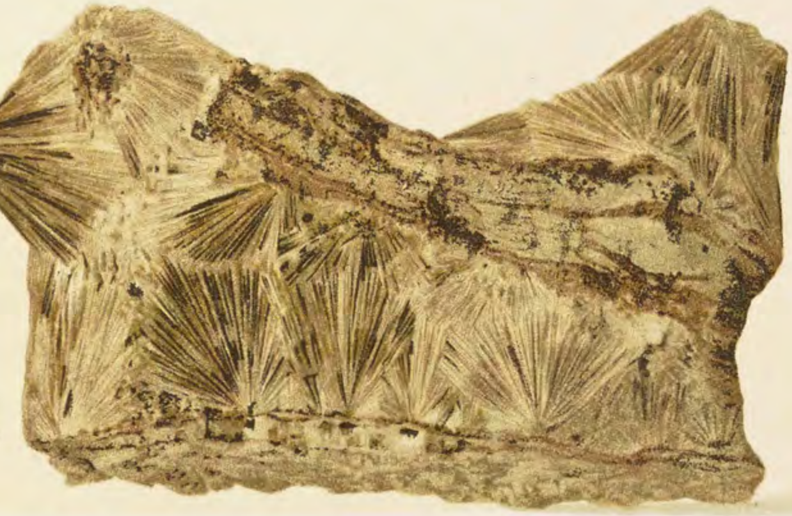
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shows a re-entrant angle only at its end between the dome-faces $k\ k_1$. This twinning on one of the prism-faces may be repeated several times (text-fig. 262), the adjacent portions being in twinned position with respect to one another, but alternate layers (first, third, fifth) are in parallel position. In this case the first and last portions are usually larger in size, the intermediate portions being quite thin, as represented in plate 74, figs. 3 and 4. If the first and last portions are in parallel position the crystal may then present the appearance of a simple crystal, and the presence of lamellar twinning is betrayed only by the striations on the surfaces.

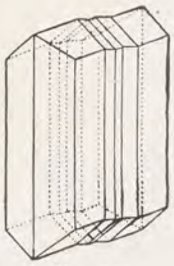

Fig. 262.
Crystal of Aragonite repeatedly twinned on the same prism-face.

In other crystals the twinning takes place on both faces of the rhombic prism; but, curiously, this happens only in crystals that are terminated by the basal plane. When, in these twinned groups, the obtuse angles of the prisms lie towards the centre only three crystals are necessary to almost close the ring, for the prism angle 116° 20′ approximates to a third of the circumference of a circle. The remaining space is sometimes left open, but more usually it is grown over by the material of the adjoining crystals. If, however, the acute angles of the prisms fall in the centre of the group, then six individuals may enter into the ring. There may thus be considerable variation in the manner of grouping, but the result is always an apparent hexagonal prism terminated by the basal plane, as shown in plate 74, figs. 5—8. The twinned crystal in fig. 5 appears to be built up of four individuals, two with their acute prism angles at the centre, and two with their obtuse angles in this position; here the ring is completely closed, for twice 63° 50′ and twice 116° 10′ give 360°.

The exact manner in which the several individuals are joined together cannot always be made out from an inspection of the striations and the areas of different lustre. But this is readily seen when the crystals are examined in parallel polarized light. For this purpose it is necessary to cut a thin plate parallel to the basal plane. The area of extent of each individual is then marked out distinctly, and on rotating the stage of the polariscope one is dark while the others are light. Such a plate when examined in convergent polarized light shows a biaxial interference-figure (plate 4, figs. 3 and 4). Placing the plate in the diagonal position (fig. 4), there is no change in the figure so long as the area of a single individual remains in the field of view, but if the section be shifted so that we pass over a twin-junction the figure suddenly jumps into another position. The double refraction of aragonite is very high, the three principal indices of refraction being, for sodium-light,

$$\alpha = 1{\cdot}5301,\ \beta = 1{\cdot}6816,\ \gamma = 1{\cdot}6859.$$

As represented in plate 74, crystals of aragonite may be white, pale yellowish, wine-yellow, brownish, or reddish to violet. They are sometimes clear and transparent, but more frequently cloudy, and in thicker crystals opaque.

We thus see that there are important differences between calcite and aragonite in their crystalline form and optical characters, in spite of the fact that the latter by its twinning in pseudo-hexagonal forms mimics the former. With distinctly developed crystals the two minerals may be readily distinguished, but with small grains and finely fibrous aggregates this is less easy. Here we must rely on the other physical characters. In aragonite there is an absence of cleavage, its fracture being irregular to sub-conchoidal. Of first importance is the higher specific gravity of 2·93, as against 2·72 of calcite. In pure bromoform aragonite therefore sinks, whilst calcite floats, and this difference in behaviour can be observed with quite tiny grains. Aragonite can be readily distinguished from the other rhombic carbonates by its flame reaction: when moistened with hydrochloric acid it imparts a yellowish-red colour to the Bunsen-flame.

As in the case of other dimorphous substances, a change of state is brought about by the application of heat, but here the change takes place in one direction only. When heated to a temperature of about 300° C. aragonite passes into calcite, but on cooling the reverse change does not take place. Such dimorphous substances are known as *monotropic*, and of this aragonite affords the best example amongst minerals. When this change takes place the particles of calcite that are developed within the aragonite crystal are orientated in a perfectly definite manner: their vertical axes are all parallel to the vertical axis of the aragonite. The change in state being accompanied by an appreciable increase in volume (corresponding to the difference in specific gravity), the altered crystal is incoherent and readily falls to powder.

This alteration of aragonite to calcite, as well as the conditions necessary for the formation of the two minerals (p. 385), indicate that aragonite is the more unstable form of calcium carbonate; a fact which is also borne out by the weathering of the mineral. Like calcite, aragonite is also readily attacked and dissolved by weathering agents. At the same time it becomes in part altered into calcite; this being possible by reason of the easier solubility of aragonite. A solution of calcium carbonate, which is saturated for aragonite, is capable of depositing calcite, since for this substance such a solution is supersaturated. Aragonite when in contact with carbonated water will thus be slowly converted into the more stable calcite. That such changes have taken place in nature is shown by the occurrence of pseudomorphs of calcite after aragonite (plate 74, fig. 9). Here the external form is the same as in figs. 5—8, but the crystals are hollow, owing to the partial removal of calcium carbonate in solution; and their surfaces are rough and drusy, owing to the secondary growth of calcite. Another pseudomorphous crystal of the same twinned form is shown in fig. 10; here the replacing substance is native copper.

Aragonite also frequently forms fibrous aggregates with a divergent or radial arrangement: a tendency in this direction is shown by the specimen in fig. 12, and more distinctly by that in fig. 11, plate 74. Usually, however, the fibres are extremely fine, and their aggregation gives rise to a variety of external forms. The *pisolite* or pea-stone (fig. 1, plate 75) deposited by the hot springs at Carlsbad in Bohemia consists of a number of small spherical masses, which possess a concentric shelly structure; each shelly layer being built up of fibres of aragonite arranged perpendicularly to the surface. In the curious variety known as *flos-ferri* (plate 74, fig. 2) the fibres radiate from a central axis, producing branching forms of a snow-white colour and somewhat resembling coral in appearance. It receives this name ("flower of iron") because of its occurrence as an efflorescence in certain iron mines, being produced by the weathering of calcareous spathic iron-ore (chalybite).

As to the modes of occurrence of aragonite: it is found embedded in beds of gypsum; in metalliferous veins and in beds of pyrites; in the cavities of volcanic rocks; as a deposit from hot springs; but only rarely together with calcite in the crevices of limestones. It also frequently occurs as a constituent of the univalve and bivalve shells of molluscs, forming the nacreous layer and constituting also the material of pearls.

The fine, wine-yellow crystals shown in plate 74, figs. 1—4, are found in basalt-tuffs at Horschenz, near Bilin in Bohemia. The crystals altered to calcite in fig. 9 are from the basalt-tuff of the Blaue Kuppe, near Eschwege in Hesse. More usually, however, the aragonite found in basalts and basalt-tuffs has the form of delicate spear-like crystals or of radially-fibrous aggregates, as in the specimen in fig. 11 from the Leidenhöfer Kopf near Giessen in Hesse. Crystals embedded in gypsum are found at Bastennes, near Dax in dep. Landes, France (fig. 6), and at Molina in Aragon (fig. 7). Other localities for crystals

PLATE 75.

Aragonite, Witherite, Strontianite, Dolomite, Magnesite.

Fig.

1. **Aragonite,** variety "Pisolite" or "Pea-stone".
   Carlsbad, Bohemia.
2. **Aragonite,** variety "Flos-ferri".
   Eisenerz, Styria.
3. **Witherite,** twinned crystal with the appearance of a hexagonal pyramid.
   Fallowfield mine, Hexham, Northumberland.
4. **Witherite,** large crystal with basal plane.
   Fallowfield mine, Hexham, Northumberland.
5. **Witherite,** group of twinned crystals.
   Fallowfield mine, Hexham, Northumberland.
6. **Strontianite,** columnar aggregate of crystals with terminal faces.
   Drensteinfurt, Westphalia.
7. **Dolomite,** large rhombohedra interpenetrating in twin position.
   Traversella, Piedmont, Italy.
8. **Magnesite,** rhombohedron in chlorite-schist.
   Pfitschthal, Tyrol.
9. **Dolomite,** the upper face to the right is the basal plane, and the other faces belong to an acute and to an obtuse rhombohedron.
   Teruel, Aragon, Spain.
10. **Dolomite,** group of saddle-shaped rhombohedra.
    Raibl, Carinthia.

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of this habit are Herrengrund in Hungary (fig. 8), the sulphur mines near Girgenti in Sicily (fig. 5), Leogang in Salzburg, and in Keuper marl at Klein-Sachsenheim in Württemberg, the last as large crystals partly altered to calcite. Divergent groups of spear-like crystals are found in iron mines at Frizington in Cumberland (fig. 12) and Iberg in the Harz. The flos-ferri variety comes from the iron mines of Eisenerz in Styria (plate 75, fig. 2), and Hüttenberg in Carinthia. Pisolite and banded masses of finely-fibrous "Sprudelstein" are from Carlsbad in Bohemia: here this material is fashioned into small ornamental objects.

Witherite. Crystals of witherite, although belonging to the rhombic system, are always pseudo-hexagonal in form. The complex twinning which we found to be frequently present in aragonite is here never absent. Simple, untwinned crystals are unknown: their form can only be deduced from a study of the twinned crystals. Such an idealized simple crystal is represented in text-fig. 263; where $p = \infty P$ is the unit vertical prism with an angle of $117^3/_4{}^0$, $o = P$ the unit pyramid, $b = \infty P \breve{\infty}$ the brachy-pinacoid, and $q' = 2 P \breve{\infty}$ a brachy-dome. When sections taken parallel to the basal plane are examined in parallel and convergent polarized light, we find a division into six sectors in each of which the plane of the optic axes is parallel to the corresponding side of the hexagon. The pseudo-hexagonal crystals are therefore here bounded by the brachy-pinacoids (or brachy-domes); thus differing from aragonite, in which the exterior of the twinned groups is formed by the faces of the unit prism. The pseudo-hexagonal witherite twins may be regarded either as composed of six individuals meeting in the centre, or of three individuals which overlap and interlock with one another across the centre.

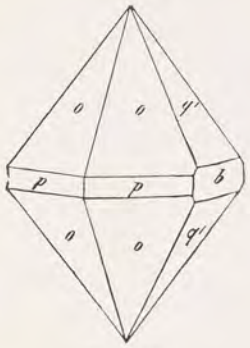

Fig. 263.
Idealized simple crystal of Witherite.

These pseudo-hexagonal crystals vary considerably in their habit. Usually, as shown in plate 75, figs. 3—5, the habit is pyramidal, and the crystals are often terminated at both ends. Or again, the habit may be prismatic with a longer or shorter development of the pseudo-hexagonal prism, which may be combined with either the pyramid or the basal plane or with both. Lastly, when the basal plane is largely developed, the habit may be tabular. The basal plane often shows a flat dome-like curvature, and the crystals of tabular habit may be quite lenticular in shape. The faces of the pseudo-prism and of the pseudo-pyramid are always striated horizontally, just like the prism faces of quartz. There is in fact a striking resemblance in general appearance between the bipyramidal crystals of witherite and certain crystals of quartz, as may be seen from a comparison of the pictures on plates 52 and 75. The great difference in specific gravity, however, at once distinguishes these two minerals.

Witherite also occurs as coarse fibrous aggregates, which frequently show a globular surface, and as granular to compact masses. It is white, grey, pale yellowish or sometimes pale greenish, never exhibiting an intense coloration. The larger crystals are usually cloudy and opaque, but small crystals are occasionally clear and transparent. The hardness is slightly greater than that of calcite, but the specific gravity, 4·3, is far higher. When pure, witherite contains: baryta (BaO) 77·7, and carbon dioxide (CO_2) 22·3 per cent. The mineral is readily soluble with effervescence in dilute hydrochloric acid, and the solution imparts a persistent pale green colour to the Bunsen-flame. This characteristic flame-coloration affords a simple means of recognizing the mineral.

Witherite occurs in some abundance in veins of lead-ore at certain places in the north of England and on the borders of Shropshire and Montgomeryshire. It is sometimes found in association with coal, and near the city of Durham a large vein of barytes and witherite intersects the coal-measures. The best crystals are from the Fallowfield mine near Hexham in Northumberland, which at different periods has been worked for lead, coal, and witherite. The largest quantities (about 10,000 tons per annum) are mined in the Settlingstones mine in the same district. At a few other localities, for example, Leogang in Salzburg, and Przibram in Bohemia, the mineral is found only in quite small amount.

Although of much less abundance than barytes, witherite is next to this the most important mineral containing barium, and it possesses the advantage for technical purposes of being readily soluble in acid. It is therefore the most important raw product for the preparation of barium compounds. Barium chloride is used as a reagent for detecting the presence of sulphuric acid; the nitrate for producing the green light of fireworks; and the hydroxide is employed in the refining of beet-sugar. Witherite is also employed in the manufacture of plate-glass, and for making rat-poison. For the latter purpose the powdered mineral is simply mixed with meal; and being soluble in even very dilute hydrochloric acid (and therefore in the gastric juice) it passes from a tasteless form into the poisonous barium chloride. In certain mining districts in the north of England poultry are not allowed to run on the waste heaps from the mines where perchance they might peck up a grain of witherite.

Strontianite. In the habit and grouping of its crystals this mineral resembles aragonite rather than witherite. These are columnar or spear-like and aggregated in bundles, and only occasionally show terminal faces (plate 75, fig. 6). Isolated, well-formed crystals are of the greatest rarity. Usually, the mineral forms divergent columnar of fibrous masses of a white, yellowish, or pale greenish colour. Such material is readily distinguished from aragonite by the flame test. The mineral dissolves with effervescence in dilute hydrochloric acid, and the solution imparts a rich carmine colour to the Bunsen-flame. The pure mineral contains: strontia (or strontium oxide, SrO) 70·2, and carbon dioxide (CO_2) 29·8 per cent.; frequently, however, a little calcium is present isomorphously replacing strontium. The specific gravity is 3·6 — 3·8, and the hardness $3^1/_2$.

The most abundant and important occurrence of strontianite is that in veins in the chalk formation at Hamm and Drensteinfurt (plate 75, fig. 6) in Westphalia. Other occurrences are in mineral-veins at Strontian in Argyllshire (from which locality this mineral and also the element strontium take their names), Clausthal in the Harz, Bräunsdorf near Freiberg in Saxony, and Leogang in Salzburg; none of these are, however, of any technical importance.

Strontianite is the most suitable raw product for the preparation of strontium compounds, and since it occurs in Westphalia in considerable quantities it is there won by mining. The compound most largely prepared is the oxide; but this cannot be obtained, like lime from calcite, by simply heating the mineral. It must be heated in the presence of steam or of coal, or better still with both of these. Strontium oxide is also prepared by igniting the nitrate. Strontium hydroxide, obtained by adding water to the oxide, is employed in the sugar industry, for the purpose of extracting from the molasses the whole of the sugar. The sugar combines with the strontium hydroxide to form strontium saccharate, which being difficultly soluble separates out. This is then treated with carbon dioxide, when the strontium is deposited as carbonate: the solution of sugar then remains to be evaporated and treated in the refinery. The product, although entirely freed from strontium, is known as strontium-sugar. Another use for strontium salts (here the nitrate) is for the production of the red light of fireworks. The demand for strontium is not met by the output from the Westphalian strontianite deposits; and in addition about 9000 tons of celestite are annually consumed.

PLATE 76.

Barytes I.

Fig.

1. **Barytes** (or Heavy-spar), colourless crystal.
   Dufton, Westmorland.
2. **Barytes,** zoned crystal showing stages of growth; the inner brown crystal is terminated above by a face of the brachy-pinacoid, whilst the external white portion is terminated by the prism planes. The large plane to the front is the base.
   Mowbray mine, Frizington, Cumberland.
3. **Barytes,** greenish crystals tipped with brown.
   Przibram, Bohemia.
4. **Barytes,** same as No. 2.
   Mowbray mine, Frizington, Cumberland.
5. **Barytes,** clear crystals grown on massive, white barytes.
   Ilfeld, Harz Mountains, Germany.
6. **Barytes.**
   La Courtade, Auvergne, France.
7. **Barytes,** tabular crystal bounded by faces on all sides; from the White Jura strata.
   Allmendingen, Würtemberg.
8. **Barytes,** bluish-green crystal.
   Sterling, Weld Co., Colorado, U. S. A.
9. **Barytes,** crystal enclosing cinnabar.
   Almaden, Spain.
10. **Barytes,** large, tabular crystal.
    Frizington, Cumberland.
11. **Barytes,** cock's-comb aggregate.
    Wildemann, Harz Mountains, Germany.
12. **Barytes.** long prismatic crystal.
    Parkside mine, Frizington, Cumberland.


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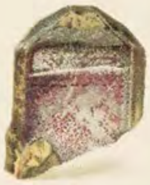
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Minerals of the Barytes Group.

In the aragonite group, which we have just considered, the three metals strontium, barium, and lead are in combination as carbonates; here we find them as sulphates, and forming another rhombic series of isomorphous minerals, namely celestite, barytes, and anglesite. The corresponding calcium salt although also rhombic exhibits wide differences in its form and cleavage, and it does not belong to this isomorphous group.

The three minerals of this group possess two sets of cleavage. The better developed of these is parallel to one of the three planes of symmetry, that is, parallel to one of the three pairs of parallel faces or pinacoids. The other cleavage is prismatic in two directions, which are perpendicular to the single pinacoidal cleavage. By some authors (Naumann and Zirkel, and Tschermak) the direction of single cleavage is chosen as the brachy-pinacoid in setting up the rhombic crystal: here (following Dana and Bauer) we make it the basal pinacoid, the face *a* in text-figs. 264—266. Neither of these methods is, however, well suited for pictorial representation, since there is considerable foreshortening and distortion of the tabular or prismatic form of the crystals. In the coloured plates 76—78 many of the crystals are therefore set up in still another position to show them to the best advantage: here the large basal plane is placed to the front, and the macro-axis (along which the crystals are often prismatically developed) is set vertically. For the correct orientation of the crystals the prismatic cleavages afford a useful guide: these are often to be seen as cracks perpendicular to the basal plane (e.g. plate 76, figs. 1, 2, and 4; plate 78, fig. 5). The basal plane is then placed horizontally, and the line bisecting the acute angle between the prismatic cleavages is set from right to left, that is, in the conventional direction of the macro-axis.

The close relation of these three minerals is at once apparent from their similarity in crystalline form, as shown in plates 76—78. The angles between corresponding faces are also nearly the same; for example, that between the prismatic cleavages is 101° 40′ in barytes, 104° in celestite, and 103° 45′ in anglesite. The last of these minerals has already been described with the lead ores (p. 122, and plate 17).

Barytes, or heavy-spar, is the most abundant of barium minerals. It takes its name, from the Greek βάρυς (heavy), on account of its high specific gravity of 4·5. Few minerals without metallic lustre and containing no heavy metal are so heavy as barytes, and of these barytes is by far the most widely distributed.

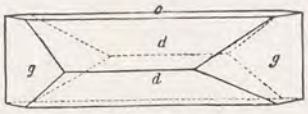

Fig. 264.
Crystal of Barytes.

The two isolated crystals represented in plate 76, figs. 2 and 4, are of the same form as that in text-fig. 264: their apparent difference in appearance being due to the different orientation. The two faces sloping away from the top of the crystals like the roof of a house (figs. 2 and 4) belong to the unit vertical prism parallel to the prismatic cleavages, and correspond to the faces $g = \infty P$ in the text-figure; the large face to the front is the basal plane ($a = 0\,P$); and the long narrow faces at the sides belong to a macro-dome ($d = {}^1/_2\, P \bar{\infty}$). In these two crystals we see also a beautiful zonal structure, marking out the periods of growth of the crystal: a brown kernel is surrounded by a colourless shell, and the two portions present a difference in their crystalline form. In the kernel the acute angle of the prism is truncated by a face of the brachy-pinacoid. At a later stage, when the crystal continued its growth in a purer solution free from iron oxide, this brachy-pinacoid became covered over, and the prism faces grew up to a sharp edge. Beautiful examples of such zonal structures are common in the barytes crystals from the Mowbray iron mine at Frizington in Cumberland.

In fig. 1 we have again the same forms, together with a brachy-dome, shown as a broad face at the top. Here the prism faces (one is visible at the top left-hand corner) are quite small: and in crystals of the same form in fig. 5 they are absent. The latter picture is explained by text-fig. 265, in which the faces are the basal plane ($a = 0\,P$), a macro-dome ($d = {}^1/_2\ P\,\bar{\infty}$), and a brachy-dome ($f = P\,\breve{\infty}$). Exactly the same faces are shown in text-fig. 266, but here the prismatic development is in the direction of the brachy-axis instead of the macro-axis, and the basal plane is smaller. Crystals of this habit are shown in plate 76, figs. 3, 6, and 12.

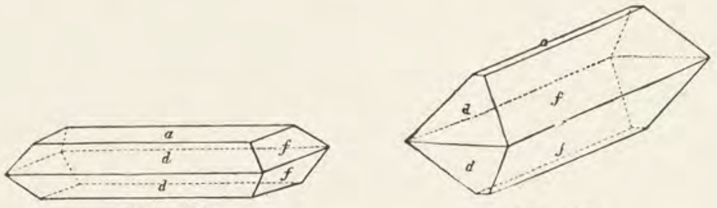

Fig. 265. Fig. 266.

Crystals of Barytes.

The large rhomb-shaped plates in fig. 10 are bounded by the large basal plane with narrow prism faces at the edges. The tabular crystal in fig. 7 shows, in addition to these two forms, the brachy-pinacoid as narrow faces at the sides.

We thus see that barytes crystals may vary considerably in their habit, while at the same time there is little variation in the forms actually present. Faces of rhombic pyramids, though sometimes present, are never of large size. The common faces are sufficiently large and smoothly developed for the angles between them to be easily determined with the contact goniometer; we find:

$$\infty P \text{ to } \infty P\ (g \text{ to } g) = 101^3/_4{}^0;\ 0\,P : {}^1/_2\,P\,\bar{\infty}\ (a\,d) = 141^0;\ 0\,P : P\,\breve{\infty}\ (a\,f) = 127^1/_4{}^0.$$

Fig. 267.

Rose-like aggregates of Barytes crystals ("Barytes-roses") from Rockenberg, Hesse.

The crystals are at times grouped in an irregular manner on the matrix (plate 76, fig. 3); at other times they are grouped in a more regular fashion, giving rise to large parallel groups (plate 76, fig. 5; and plate 77). Or again, crystals of tabular habit may be aggregated in not quite parallel positions, giving rise to cockscomb (plate 76, fig. 11) and rose-like (text-fig. 267) forms. The latter, known as "barytes-roses" and very similar to the well-know "iron-roses" (p. 152), are found in sands of the Tertiary formation at Rockenberg, near Butzbach in Hesse. The figure shows a group of three rosettes, but single ones as well as much larger clusters are found. These crystals enclose a large amount of sand (up to 20 per cent.) in the same manner as the crystals of calcite from Fontainebleau (plate 72, fig. 8), and those of gypsum from Sperenberg (plate 79, fig. 4). Globular masses of barytes with an internal radial-fibrous or platy structure also occur; and sometimes dendritic forms like that of wollastonite shown in plate 2, fig. 5. Most frequently, the mineral forms coarsely grained and sparry

PLATE 77.

Barytes II.

Barytes, large group of crystals grown in parallel position; from a barytes-vein in gneiss. About one-half actual size; the original specimen measures 38 centimetres in height and 32 cm. in breadth.
Ober-Ostern, Odenwald, Baden.

masses showing a lamellar structure and a white or flesh-red colour: from such masses cleavage fragments having the form of rhomb-shaped plates may be readily detached. At times the material is finer grained and more compact.

Distinctly formed twinned crystals of barytes are unknown, but twinning is sometimes represented by the presence of fine twin-lamellae.

The range of colouring shown by barytes is well illustrated in plate 76. The crystals are occasionally colourless and transparent (fig. 1); but usually they are cloudy and of a pale yellow, brown, or reddish colour. Greenish and bluish crystals are less frequent. Attention has already been drawn to the colouring of the zonal crystals in figs. 2 and 4; here the brown colour is due to the enclosure of iron oxide. The crystal in fig. 9 owes its red colour to the presence of enclosed cinnabar. Other crystals enclose stibnite, orpiment, or realgar, which respectively produce a grey, yellow, or red coloration.

In the absence of crystalline form barytes may always be easily distinguished from other minerals by means of its high specific gravity of 4·5, its hardness of $3^1/_2$, and its behaviour when heated. A fragment held in the Bunsen-flame decrepitates violently, and at the same moment a pale green flash characteristic of barium is seen in the flame. When powdered and heated on charcoal with sodium carbonate, barytes gives the hepatic reaction (p. 63), proving the presence of sulphur. Pure barytes contains: baryta (BaO) 65·7, and sulphur trioxide (SO_3) 34·3 per cent. Sometimes the mineral contains a little strontium or calcium replacing the barium.

A variety of barytes known as Bologna-stone, or Bolognian spar, is found as nodular masses in clay at Monte Paterno near Bologna. This is of interest in being the material in which the phenomenon of phosphorescence was first studied in the year 1602 by V. Casciorolus, a shoemaker of Bologna. By heating the mineral with charcoal, barium sulphide is formed, and this, after exposure to the sun's rays, is seen in a dark room to emit light. The material so prepared was made into sticks and under the name of "Bolognian phosphorus" was a source of wonder in the olden days. This property is, however, also possessed by strontium sulphide and by calcium sulphide, and the intensity and colour of the light which is emitted varies with the composition of the material and on the presence of various impurities.

Barytes is one of the most difficultly soluble of minerals; and for this reason a soluble barium salt affords the best reagent for the detection of sulphuric acid, in the presence of which a heavy white precipitate of barium sulphate is immediately thrown down. A litre of pure water at 15° C. takes up only 3 milligrams of barium sulphate; but at a higher temperature and with the presence of other salts in the solution the solubility is appreciably greater. When solutions of barium chloride and sulphuric acid are mixed in the ordinary way, the barium sulphate is deposited as a fine, amorphous precipitate. But if the experiment be so arranged that the extremely dilute solutions shall mix very gradually, the barium sulphate is then deposited as minute crystals; and these more nearly resemble crystals of barytes when the solutions are the more dilute and the experiment the more prolonged. The crystals of barytes in nature must also have been deposited from solution, as is proved by their mode of occurrence. Here there may have been a mixing of two solutions; on the one hand a soluble barium salt (the chloride or the bicarbonate), and on the other a soluble sulphate (gypsum or iron-vitriol). Or the barium sulphate may itself have been held in solution and deposited with a fall in temperature or some other change in the conditions.

Owing to its low degree of solubility, barytes is little affected by weathering agents. Under certain conditions, however, when carbonated waters act on large masses it may be transformed into witherite. More often, quartz is the replacing mineral; in the Odenwald and Taunus, veins of barytes are sometimes replaced by quartz, and at Griedel, near Butzbach in Hesse, large pseudomorphs of quartz after barytes are found.

Barytes occurs in mineral-veins and other deposits in association with ores of lead, silver, cobalt, manganese, and iron; and under these conditions good crystallized specimens are found at many localities. For example, at Przibram in Bohemia (plate 76, fig. 3); Felsöbanya, Schemnitz, and Kapnik in Hungary; Ilfeld (plate 76, fig. 5; and with manganite in plate 34, fig. 5) and Clausthal in the Harz; Dufton in Westmorland. The best crystals are those found in considerable abundance in the iron (haematite) mines in the neighbourhood of Frizington in Cumberland (plate 76, figs. 2, 4, 10, 12).

Veins filled only with barytes, without metallic ores, though often with fluor-spar and quartz, are found in many districts. For example, in the Odenwald (plate 77), Meggen in Westphalia, and New Brancepeth Colliery near Durham. At these and other places the mineral is won by mining.

Barytes is the most abundant raw material for the manufacture of various barium preparations. Barium chloride is made by igniting an intimate mixture of powdered barytes, coal, and calcium chloride, this process being now carried out in the old Leblanc soda works. This salt, being readily soluble in water, finds many applications. When decomposed with Chile saltpetre it gives barium nitrate, which is used for producing the green light of fireworks. When ignited, barium nitrate gives barium peroxide (BaO_2); this when treated with dilute acid yields hydrogen peroxide (H_2O_2), which is extensively used for bleaching. In France alone about 1000 tons of barium peroxide are manufactured per annum. Barium sulphate precipitated from a solution of barium chloride is used under the name of "blanc fixe" for making white paint and for producing the surface of smooth printing papers. The white paint known in the trade as Griffith's white or lithophone is obtained by mixing solutions of zinc sulphate and barium sulphide. Large quantities of the coarser white paints are made by simply mixing finely powdered barytes with oil.

Celestite. The similarity between crystals of celestite and of barytes is remarkably close; and, indeed, it is not always possible to distinguish between the two until the angles between the faces are measured or a chemical test is made. The fine crystals from the sulphur mines in Sicily (plate 76, figs. 1—3) were at one time, before they had been critically examined, regarded as barytes; and the crystals in fig. 7 might easily be mistaken for barytes by even an experienced mineralogist. The crystals from certain well-known occurrences present certain small distinctive features, and having once seen them, we recognize these crystals again as celestite without troubling to test them every time.

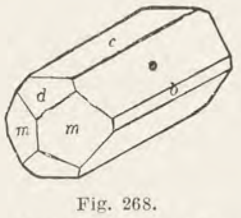

Fig. 268.
Crystal of Celestite.*)

This striking similarity between the shapes of the crystals of the two substances is at once apparent from a comparison of plates 76 and 78. The large celestite crystal in fig. 5 shows the same combination of forms, and these are developed to approximately the same extent as in the barytes crystal in fig. 1. In the same way celestite fig. 7 compares very closely with barytes fig. 4; and text-fig. 264 serves as an illustration of either one or the other. The celestite figs. 1—4 resemble the barytes crystals in figs. 3 and 6, differing slightly in the presence of small faces of the prism. These are illustrated by text-fig. 268; *c* is the basal plane $0\,P$ (which in the pictures is rather narrower than shown in the text-figure), *o* a brachy-dome $P\breve{\infty}$, *d* a macro-dome $^1/_2\ P\bar{\infty}$, *m* the unit

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*) The faces lettered *c o d m* on this crystal correspond respectively to those lettered *a f d g* in the crystals of barytes in text-figs. 264—266.

PLATE 78.

Celestite, Anhydrite, Thenardite.

Fig.

1. **Celestite,** crystals on matrix.
   Girgenti, Sicily.
2. **Celestite,** crystal on matrix.
   Girgenti, Sicily.
3. **Celestite,** with sulphur.
   Girgenti, Sicily.
4. **Celestite.**
   Gloucestershire.
5. **Celestite,** large, tabular crystal.
   Put-in-Bay, Lake Erie, Ohio, U. S. A.
6. **Celestite,** rhombic pyramid 4 *P* with base 0 *P*.
   Brady's, Mineral Co., West Virginia, U. S. A.
7. **Celestite,** group of crystals of the same form as the crystals of barytes represented in Plate 76, fig. 2.
   Gemböck, Westphalia.
8. **Celestite,** crystal on matrix.
   Jebel Mokattem, Cairo, Egypt.
9. **Celestite,** fibrous.
   Dornburg, Jena, Germany.
10. **Celestite,** blue crystals with drusy end faces.
    Leonforte, Sicily.
11. **Anhydrite** ($CaSO_4$), rhombic prism.
    Leopoldshall, Anhalt, Germany.
12. **Thenardite** (Na_2SO_4), rhombic pyramid.
    Pampa central, Antofagasta, Chile.


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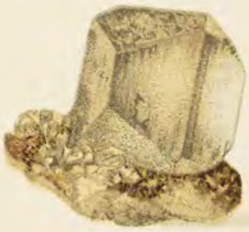
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vertical prism ∞P, and *b* the brachy-pinacoid $\infty P \breve{\infty}$. Here we have a pronounced prismatic habit of the crystals in the direction of the brachy-axis, and such crystals are usually attached to the matrix at one end of this long brachy-dome (fig. 2).

In fig. 6, however, is shown a crystal of celestite which finds no counterpart amongst barytes: here we have a combination of a rhombic pyramid with a small basal plane.

Crystals of celestite are sufficiently large and their faces smooth enough for the angles to be determined with some degree of accuracy with the contact goniometer. The angle of the cleavage prism, ∞P to ∞P, is 104° 10′, and that between the faces of the brachydome *o* has very nearly the same value, namely 104° 0′. The angle $0 P : P \breve{\infty}$ $(c\,o) = 128^\circ\ 0'$, and $0 P : \frac{1}{2} P \bar{\infty}$ $(c\,d) = 140^\circ\ 35'$.

Pure celestite is quite colourless, but in many crystals there is a bluish shade of colour as represented in plate 78. The crystals in fig. 1 are faintly tinted with blue only at their ends, whilst in figs. 5—7, 9, and 10 the colouring is fairly uniform. Usually the blue colour is quite pale, but in figs. 6 and 9 it is more intense. The mineral was first recognized at the end of the eighteenth century in specimens from Frankstown in Pennsylvania, where it occurs in limestone as platy masses with a fibrous structure and a deep sky-blue colour (similar to the specimen in fig. 9); and it was on account of this sky-blue colour that the mineral received the name celestite.

When heated before the blowpipe, celestite decrepitates and colours the flame a deep carmine, thus indicating the presence of strontium. The pure mineral contains: strontia (SrO) 56·4, and sulphur trioxide (SO_3) 43·6 per cent.; a portion of the strontium may be replaced by small amounts of calcium or barium. The specific gravity, though high, 4·0, is appreciably lower than that of barytes: the hardness is $3\frac{1}{2}$.

Beautifully crystallized specimens of celestite are found in some abundance in the sulphur mines in the neighbourhood of Girgenti in Sicily (plate 78, figs. 1—3). Fine crystals lining cavities in the massive material are found in the red marls of Triassic age in Gloucestershire and Somersetshire, particularly in the neighbourhood of Bristol (fig. 4). Here the mineral is mined to the extent of about 20,000 tons per annum. Large crystals, sometimes reaching a foot across and of a delicate blue colour, are found on Strontian Island in Put-in-Bay on the Ohio side of Lake Erie (fig. 5).

Large yellow crystals, beautifully and sharply formed, are found in nummulitic limestone on Jebel Mokattem near Cairo in Egypt (fig. 8). The crystals of pyramidal habit (fig. 6) occur in limestone at Brady's in Mineral Co., West Virginia. In Germany, good crystals are found together with large masses of sparry celestite in Zechstein marl at Gemböck near Corbach in Waldeck (fig. 7), and at Giershagen near Stadtberge in Westphalia. Blue fibrous celestite has long been known from the Muschelkalk at Dornburg near Jena (fig. 9); and material very similar to this occurs in Jurassic clay on the Eichberg near Blumberg in Baden, and also at Frankstown in Pennsylvania. The fibrous structure is now regarded as pseudomorphous after gypsum. Celestite occurs also in mineral-veins, as at Scharfenberg in Saxony, Herrengrund in Hungary, and Leogang in Salzburg.

Being the most abundant of strontium-bearing minerals, celestite is of importance for the manufacture of salts of strontium. It is converted into the readily soluble carbonate by digestion under pressure in a solution of soda; or it is first roasted with coal with the formation of strontium sulphide, which by the action of carbon dioxide is converted into carbonate. The product is applied for the same purposes as strontianite (p. 394).

Gypsum and Anhydrite.

These two minerals are related to one another, but in a different manner to those considered in the last few pages. In their crystalline form they possess no feature in common; but they show resemblances in their chemical composition and their mode of occurrence and origin. Both consist of calcium sulphate, but in gypsum this is combined with two molecules of water, whilst in anhydrite there is no water, as indicated by the name. Such a name might, however, have been equally well applied to many other anhydrous minerals; and its use is more for the purpose of emphasizing the difference between these two forms of calcium sulphate. As to their similarity in mode of occurrence, it may be mentioned that they are frequently found together in salt-deposits, having been formed, like the rock-salt, as a deposit from sea-water. Gypsum has, however, several other modes of occurrence, and for this reason it was not described with the minerals more closely allied to rock-salt.

Gypsum. Being a mineral of wide distribution and frequent occurrence, and with characters that attract the eye, gypsum has been known since very early times, in spite of the fact that it contains no useful heavy metal and that it is much too soft for use as a gem-stone. It is sometimes found as clear, colourless and transparent masses, which are so soft that they can be readily scratched even by the finger-nail. Owing to the possession of a highly perfect cleavage in one plane direction such masses can be readily split into thin plates. Cleavage plates of gypsum have at times been used for windows; and the ancient Romans placed such windows in their bee-hives so that the bees could be seen at work. Small cleavage flakes of gypsum produce a spangled effect and have long been used for decorating statues of the Virgin. On this account gypsum (in common with mica, p. 332) has received the popular name *Maria-glass* (*glacies Mariae*), and, in German, Marienglas and Fraueneis.

In addition to the very perfect cleavage mentioned above, gypsum possesses two other cleavages. The intersections of these on the first cleavage are inclined at an angle of $114^1/_2$°; and the result of the three cleavages is the production of rhomb-shaped platy cleavage fragments, as shown in the left-hand portion of plate 80, fig. 2. Of the two latter cleavages, one is distinguished as the fibrous cleavage, and its presence is very often shown by the fine lines on the surface of the more perfect cleavage. The other is much less perfect, and owing to its somewhat irregular and rounded surfaces it is known as the conchoidal cleavage.

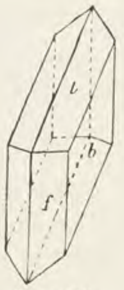

Fig. 269.
Simple (untwinned) crystal of Gypsum.

Crystals of gypsum bounded by plane faces on all sides are of common occurrence, and it is easily seen that these (plate 79, fig. 2) possess only a single plane of symmetry: they therefore belong to the monoclinic system. The pair of faces of the clino-pinacoid $\infty P \grave{\infty}$ (*b* in text-fig. 269) is rarely absent, and this is the direction of the highly perfect cleavage. In addition, we usually find two prismatic forms, each consisting of four faces. One of these is taken as the unit vertical prism ∞P (*f* in text-fig. 269), and the other as a negative hemi-pyramid — P (*l*). The angle between adjoining faces of the vertical prism is $111^1/_2$°, and that between faces of the hemi-pyramid is $143^3/_4$°, as may be easily determined with the contact goniometer. The text-figure corresponds with the crystal in plate 79, fig. 2. Sometimes, in addition to the faces above noted, there is a positive hemi-pyramid $+ P$, as in fig. 1, but being behind it is not visible in the picture.

PLATE 79.

Gypsum I.

Fig.

1. **Gypsum,** large, limpid crystal, bounded by the vertical prism, clino-pinacoid, and pyramids in front and behind.
   Upper Ennsthal, Austria.
2. **Gypsum,** simple crystal with vertical prism, clino-pinacoid, and pyramid; elongated in the direction of the clino-axis.
   Halle, Merseburg, Prussia.
3. **Gypsum,** simple crystal with curved faces.
   Hochheim, Hesse-Nassau.
4. **Gypsum,** group of crystals enclosing sand-grains.
   Sperenberg, Berlin.
5. **Gypsum,** group of crystals.
   Flörsheim, Hesse-Nassau.
6. **Gypsum,** finely fibrous, "Satin-spar".
   Wasenweiler, Kaiserstuhl, Freiburg, Baden.
7. **Gypsum,** alabaster with serpentine markings.
   Eisleben, Province Saxony.

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Crystals of gypsum are, however, not always developed with perfectly plane faces and straight edges as in the two examples just referred to. Frequently they are rounded and curved, as shown in plate 79, fig. 3; and when the vertical prism and the pinacoid are absent such crystals may be quite lenticular in form (plate 80, fig. 4). In these and other puzzling cases, the crystals can, however, always be easily orientated by the help of the three cleavages. The perfect cleavage is parallel to the clino-pinacoid or plane of symmetry, which truncates the side or acute edges of the vertical prism; the conchoidal cleavage is parallel to the ortho-pinacoid $\infty P \bar{\infty}$, which truncates the front or obtuse edge of the vertical prism; and the fibrous cleavage is parallel to the pair of faces of the positive hemi-pyramid $+ P$, which truncates the top of the crystal in plate 79, fig. 2.

Twinning is of frequent occurrence in crystals of gypsum, and several of the characteristic forms so produced are represented in plate 80. Most often the twin-plane is the ortho-pinacoid, the two individuals having the conchoidal cleavage in common. The cleavage fragment in plate 80, fig. 2, shows distinctly the junction of the two individuals along the vertical line (which is the trace of the twin-plane on the perfect cleavage), and the re-entrant angle (132°) formed by the fibrous cleavage of the two portions. The long crystal in fig. 1 of the same plate is also a twin of this kind: at first sight it has the appearance of a simple crystal, but the twinning is betrayed by the re-entrant angle (132°) shown by the fibrous cleavage (represented in the picture by fine lines one-third of the way from the top). In text-fig. 270 we have the same twin, only here the re-entrant angle is formed by the negative hemi-pyramid *l*. Twinned crystals of this kind are of frequent occurrence, and on account of their characteristic shape they are known as "swallow-tail twins". They usually occur attached to the matrix with the re-entrant angle at the free end; and are so found in the drusy cavities of the rock-salt deposits.

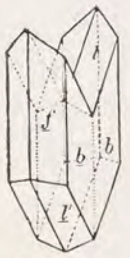


Fig. 270.
Twinned crystal of Gypsum.

Twins of another kind are met with in the crystals with rounded faces which occur embedded in clay, sand, or massive gypsum (plate 80, figs. 4 and 5, and as a cleavage plate in fig. 3). Here the twin-plane is a face of the negative ortho-dome $- P \bar{\infty}$, which truncates the edge of the the hemi-pyramid *l*. The re-entrant angle (at the top of fig. 3) is formed by the faces of the vertical prism *f*; and the fibrous cleavage of one individual falls almost in a line with the conchoidal cleavage of the other individual.

The crystals are sometimes bent in curious zig-zag and twisted forms, just as if they had been sticks of wax subjected to pressure. The best examples of such bent crystals are found in a gypsum cave at Reinhardsbrunn in the Thuringian Forest (plate 80, figs. 6 and 7).

In colour the crystals range from colourless to grey or pale yellowish. Sometimes they enclose considerable quantities of clay or sand (plate 79, fig. 4); and occasionally these enclosures are arranged within the crystal in a regular manner. In text-fig. 271 the areas extending from one set of faces are clouded by enclosed material, whilst the alternate areas are clear. Clear crystallized gypsum is often distinguished by the name *selenite*.

Fig. 271.
Crystal of Gypsum with "pyramids of growth."

When occurring in large masses, the mineral presents a fine-grained texture with a snow-white, grey, yellow, or red colour; and often these colours are distributed in bands, veins, and patches. Material more compact in texture is the well-known *alabaster*, which on account of its softness is easily carved; it takes a good polish and much resembles marble in appearance, but is less serviceable than this. A particular variety of this shows serpentine or contorted banding (plate 79, fig. 7) and is known as "snake-alabaster" or "tripe-stone". Here a grey gypsum loaded with clay is traversed by crumpled veins of pure white gypsum. The material consisted originally of anhydrite, and the crumpling of the veins has been brought about by the increase in volume which accompanied the transformation of anhydrite to gypsum (p. 405). Veins of gypsum frequently exhibit a fibrous structure, the fibres being arranged perpendicularly to the walls of the vein. This fibrous gypsum (plate 79, fig. 6) displays a silky lustre, which is the more pronounced the finer the fibrous structure; this variety is known as *satin-spar*.

Of the physical characters of gypsum, mention has already been made of the low degree of hardness (No. 2 on the scale). The specific gravity is also low, being only 2·3. Being a bad conductor of heat, the mineral does not feel cold to the touch: and this character, together with the difference in hardness, affords a ready means of distinguishing between alabaster and marble. The refractive power is low, the mean index being 1·5228, and the double refraction is moderately strong. Thin cleavage fragments of gypsum display brilliant and clear interference-colours in parallel polarized light; and being readily obtained they afford the best material for the study of this phenomenon. Thin plates of gypsum are cut and skilfully put together to give various patterns or to represent flowers, butterflies, etc., and are supplied by the microscope dealers. These objects show in a very beautiful manner the production of brilliant polarization-colours with the aid of a colourless crystallized material.

Another optical phenomenon well illustrated by gypsum is that of the change in form of the biaxial interference-figure (plate 4, fig. 4) with change in temperature. To show this a plate, cut from a crystal in the correct direction, is warmed on a water-bath (in a covered porcelain dish over boiling water), quickly transferred to the stage of the polariscope, and viewed in convergent polarized light. The dark hyperbolic brushes are at first seen to be in contact and the rings are circular, the figure being then a uniaxial one (as in plate 4, fig. 1); but the brushes quickly separate, moving outwards towards the edge of the field of view. With a more suitable arrangement, by means of which the crystal section can be heated in a current of hot water on the stage of the microscope, the brushes are seen to approach until they meet in the centre, the figure becoming uniaxial at a temperature of 91° for sodium-light; and then with still rising temperature to open out again in a direction at right angles to that which they at first occupied. Here we have not only a change in the value of the angle between the optic axes, but also a change of the optic axial plane itself.

Corresponding with the chemical formula $CaSO_4 . 2\,H_2O$, gypsum contains 20·9 per cent. of water. When heated to 107—130° C. three-fourths of this water is expelled, and the mineral becomes cloudy and white, finally falling to powder; the product is known as calcined or burnt gypsum, or as the half-hydrate. This powder — the well-known plaster of Paris — possesses the property of reabsorbing the amount of water it has lost, with the formation again of gypsum: when mixed with water it soon sets to a hard mass. On this property depends the extensive use of plaster of Paris for making casts and in stucco work. When gypsum is heated to 400° C. the last traces of its water are expelled, and the material (dead burnt gypsum) can then no longer be used for making casts. An intermediate stage is, however, possible; for in hydraulic gypsum or Keene's cement the material, although completely dehydrated, is still capable of combining again with water, hardening after a few days and very gradually returning to the normal composition of gypsum. The researches of van't Hoff have proved that gypsum when heated alone is completely dehydrated at a temperature of 190° C. and the material still possesses the property of re-combining with water; but that this property is lost if the heating be long continued or if the temperature is higher. This is, however, not quite in agreement with the statements in works on technological chemistry, it being said that hydraulic gypsum is manufactured by burning the mineral at a red-heat. This product sets as a hard compact mass very resistant to the weather and therefore very suitable for use as a mortar.

Gypsum is comparatively easily soluble in water, namely, one part in 400. The solubility is appreciably increased in the presence of sodium chloride; a salt solution taking up one part of gypsum in 120 parts of solution. Since gypsum is frequently associated with rock-salt, the extensive solution which beds of gypsum have often suffered is not surprising. Irregular channels and pipes, and even large caverns, are dissolved out in the solid gypsum: and, as the roofs of these fall in, local miniature earthquakes result and funnel-shaped depressions are formed in the surface of the ground. These depressions may become filled with water, forming small lakes. The same things also at times happen in rock-salt and limestone districts.

At the earth's surface gypsum is the most stable form of calcium sulphate, and consequently the most abundant. The bedded deposits of gypsum occurring in association with rock-salt have been, as we have seen (p. 352), deposited directly from sea-water or have resulted by the alteration of beds of anhydrite. The crystals lining cavities in the solid gypsum and in the rocks of the salt formation owe their origin to the re-solution and re-deposition of the calcium sulphate. Owing to the easy solubility of gypsum in water and saline solutions the sides of the underground reservoirs in the salt mines (p. 353) soon become coated with quite large crystals; the pipes for conveying the brine become choked with gypsum crystals; and even the mine timbers become encrusted with beautiful swallow-tail twins.

There are, however, other ways by which gypsum may be formed in nature. Sulphuric acid, produced by the weathering of iron-pyrites and other sulphide minerals, may combine with the calcium of limestones or that present as small amounts in clays and various rocks. In this manner isolated crystals or groups of crystals may grow in beds of clay, sand, or lignite. Again, the sulphur dioxide gas and water vapour emitted by volcanoes and solfataras combine in the air to form sulphuric acid: this decomposes the volcanic rocks and combining with their calcium produces gypsum.

Localities for crystallized gypsum are extremely numerous: those mentioned above under rock-salt may be referred to, and here we need mention only a few of the more important. Fine crystals occur in the salt formation at Reinhardsbrunn in the Thuringian Forest (plate 80, figs. 1, 6, and 7): an enormous group of large, colourless crystals from this locality was presented to the British Museum by the Prince Consort in 1847. Beautiful groups of clear, sharply-developed crystals come from the salt mines at Bex in Canton Wallis, Switzerland (plate 80, fig. 2). In clays of Tertiary age crystals are found at Halle in Prussia (plate 79, fig. 2), Hochheim and Flörsheim on the Main in Hesse-Nassau (plate 79, figs. 3 and 5), and in the railway tunnel near Mainz (plate 80, fig. 5). Groups of crystals are found in sand at Sperenberg near Berlin (plate 79, fig. 4), and at Smyrna in Asia Minor. From other rocks of Tertiary age come the large swallow-tail twins of Montmartre near Paris (plate 80, fig. 3). Fine crystals are found in the sulphur mines in the neighbourhood of Girgenti in Sicily. In England, well-shaped crystals are found embedded in clay at many places. Gigantic crystals measuring a yard in length have been obtained in large numbers from a cave at South Wash in Wayne Co., Utah; and recently crystals of the same length have been found in a copper mine near Cloncurry in Queensland.

Extensive beds of massive gypsum occur in Germany on the southern borders of the Harz Mountains and the Kyffhäuser-Berg, near Gotha and other places in the Thuringian Forest, on the Lower Neckar and on the Kocher. Similar deposits are extensively mined in Nottinghamshire, Sussex, Cumberland, and other counties in England; also in the neighbourhood of Paris, in Nova Scotia, and many other parts of the world.

The "tripe-stone" represented in plate 79, fig. 7, is from the Zechstein formation at Eisleben on the borders of the Harz Mountains; and similar material has been found at Wieliczka and Bochnia in Galicia, Austria. In plate 70, fig. 12, massive gypsum is shown as the matrix of boracite crystals from Lüneburg in Hanover, where it is the only rock outcropping at the surface. Massive gypsum also forms the matrix of embedded crystals of aragonite in northern Spain and southern France (plate 74, figs. 6 and 7); of crystals of ferruginous quartz (plate 52, figs. 8 and 9); of dolomite at Hall in Tyrol; whilst in Sicily the gypsum beds contain rich deposits of native sulphur (p. 142).

Owing to its wide distribution, gypsum is one of the minerals that supply sulphur for the building up of legumin and albumen. The presence of dissolved gypsum gives rise to a permanent hardness in water; when such water is evaporated the gypsum is deposited as a crust inside kettles and boilers, and this is more difficult to remove than a crust of calcium carbonate.

Applications of gypsum.— Alabaster is employed as an ornamental stone for inside sculptural decorations and for carving into a variety of small ornaments. The fibrous satin-spar is sometimes cut into beads, which, like those of other minerals with a finely fibrous structure (cat's-eye and tiger-eye) display a moving band of light on their surface. Gypsum in its natural state or when burnt is employed in agriculture as a manure for clover, linseed, and other leguminous crops. Here it has probably also an indirect action in the soil by liberating potash from its combination with silicates. Calcined gypsum, or plaster of Paris, finds extensive applications, for moulds, casts, stucco and plaster work of many kinds. Hydraulic gypsum is said to have been used by the ancient Egyptians as mortar in building the Cheops pyramid. It was also used in Germany in the old castles and cloisters; and, after falling into disuse, it is now again employed for technical purposes.

Anhydrite. Whilst gypsum occurs beautifully crystallized in a variety of forms, anhydrite, on the other hand, presents no very attractive appearance. Its crystals are rare and always small with but few rough and striated faces. They belong to the rhombic system with usually a short-prismatic development (plate 78, fig. 11). The character most apparent to the eye is that given by the three perfect cleavages. These are parallel to the three planes of symmetry, that is, to the three pinacoids, and they are therefore at right angles to one another. The crystals can be broken up into cuboidal cleavage fragments; but these differ from true cubes in possessing different physical characters on their different faces. The cleavages are not quite of equal quality; one is more perfect, giving smoother and brighter surfaces of fracture, than the two others. Thin cleavage flakes are always traversed by fine cracks at right angles to one another, due to the two cleavages that are perpendicular to the plate. These afford good material for adjusting the positions of the analyser and polarizer of the microscope, for in parallel light they give straight extinction parallel to these cleavage cracks. The specific gravity of anhydrite is 2·9—3·0, and the hardness 3—3¹/₂.

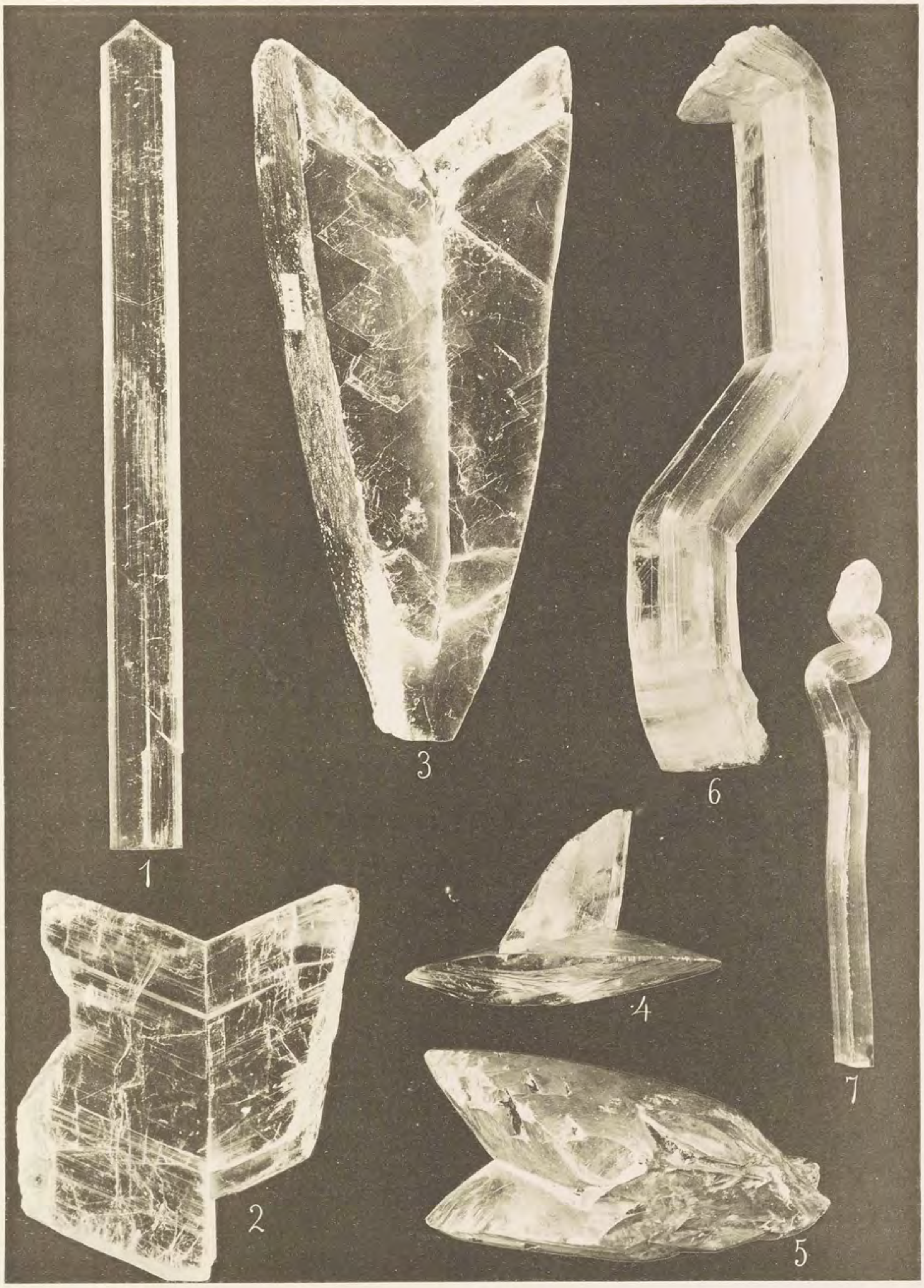
Usually the mineral occurs as finely granular masses; but occasionally the texture is coarser and in such sparry masses the cleavage is a prominent feature. It is colourless, grey, red, or of a delicate blue shade; and, except when colourless, it is only slightly translucent. The blue colour is not permanent, fading on exposure to the light, or when the anhydrite is transformed into gypsum.

PLATE 80.

Gypsum II.

Fig.

1. **Gypsum,** long, straight, twinned crystal.
   Reinhardsbrunn, Thuringian Forest.
2. **Gypsum,** cleavage flake of a crystal twinned on the ortho-pinacoid. The lines of the fibrous cleavage in the two individuals meet at the twin junction at an angle of 132° 28′.
   Bex, Wallis, Switzerland.
3. **Gypsum,** cleavage plate from a "swallow-tail" twinned crystal. The twin-plane is the negative ortho-dome $-P\bar{\infty}$, which truncates the edge of the negative pyramid $-P$. The faces at the edge are rounded.
   Montmartre, Paris.
4. **Gypsum,** a perfectly colourless, twinned crystal, twinned on the same plane as No. 3.
   Racalmuto, Sicily.
5. **Gypsum,** twinned crystal with curved faces; twin-plane as in No. 3.
   Mainz, Hesse.
6. **Gypsum,** bent, prismatic crystal; the bending is due to twinning.
   Reinhardsbrunn, Thuringian Forest.
7. **Gypsum,** prismatic crystal, bent at the end by twinning.
   Reinhardsbrunn, Thuringian Forest.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Anhydrite occurs in association with rock-salt, having been deposited together with this from concentrated sea-water. Indeed the presence of other salts is essential for the formation of anhydrite, since from a pure aqueous solution calcium sulphate separates as gypsum. The chlorides of potassium and magnesium also present in the concentrated sea-water exert a sort of attraction for the water, and constrain the calcium sulphate to crystallize as anhydrite (p. 353). In contact with water anhydrite is unstable, and it becomes altered into gypsum. This change is accompanied by an increase in volume of about 60 per cent., 1000 cubic metres of anhydrite giving rise to 1600 cubic metres of gypsum. This is, however, only true if no calcium sulphate is removed in solution by the waters effecting the change. Owing to this solution the actual increase in volume may be much less than above stated, but still sufficiently great to be in evidence, as indicated by the following examples: the crumpling of thin bands of anhydrite in tripe-stone (p. 402; plate 79, fig. 7); the closing up of fissures in the anhydrite cover of the rock-salt beds (p. 352); galleries driven through beds of anhydrite become gradually closed up, and must from time to time be enlarged; strata at the surface lying immediately over anhydrite beds become bulged upwards and cracked. Near the surface, beds of anhydrite soon become transformed into gypsum; beds lying deeper are preserved as pure anhydrite; whilst at an intermediate depth the beds consist of a mixture of the two minerals.

Small crystals of anhydrite bounded on all sides by faces are found embedded in kieserite at Stassfurt and Leopoldshall in Prussia (plate 78, fig. 11). Granular anhydrite showing a crystallized surface is known from Aussee in Styria and Berchtesgaden in Bavaria. Coarsely granular anhydrite of a red colour is found at Berchtesgaden and in the Salzkammergut. Blue, fine-grained material is from Sulz on the upper Neckar in Württemberg, and from Vulpino in Lombardy.

Anhydrite has also been observed, although rarely, in mineral-veins, as at Andreasberg and Kapnik; and in the lava flows of volcanoes, as at Vesuvius and Santorin.

One of the few applications of anhydrite is as a manure; but being less soluble than gypsum, or even than "dead burnt gypsum", it is of much less value than this. The blue, compact anhydrite of Vulpino, known as "vulpinite", is cut and polished for ornamental purposes.

Apatite.

Phosphoric acid, a substance essential for the nourishment of plants and animals, has already been mentioned on various occasions in the preceding pages; namely, as a by-product in the smelting of iron (p. 160), and as a constituent of the precious stone turquoise (p. 260) and of the lead ore pyromorphite (p. 124). The minerals just named are phosphates, and there are very many others belonging to this group, but only few of them are of much importance. Of these apatite easily takes the first place, for it forms the source of phosphoric acid for all other phosphate minerals and it supplies the phosphates present in soils. The extremely wide distribution of this important mineral was first recognized with the aid of the microscope; it having been found that minute crystals of apatite are present in almost all kinds of igneous rocks. Such rocks are met with at many places throughout the world, and when they are broken down by weathering agents their materials are scattered broadcast over the whole surface.

Apatite crystallizes in the hexagonal system, as is evident by a glance at the well-formed crystals represented on plate 81. The model-like crystal in fig. 6 is, for example, bounded by a hexagonal prism, a hexagonal pyramid of the same order, and the basal pinacoid. This pyramid is selected as the primary pyramid P, and its faces make with the base an angle of $139^3/_4{}^{\circ}$. The same combination of forms is also shown by the crystals in figs. 10 and 12; and those in figs. 7, 8, and 11 differ only in the absence of the basal pinacoid. The violet crystals in figs. 4 and 9 are bounded by only the prism and the base. The more complex crystals in figs. 1—3 are illustrated by the text-fig. 272. The hexagonal prism a and pyramid x, both of the first order, and the basal pinacoid c are the same as before. The small faces s lying directly over the prism edges are those of a pyramid of the second order. Between s and a, but only on one side (the left in the text-figure), there are other small faces u; these have the position of a twelve-sided double pyramid or a dihexagonal bipyramid, but with only the alternate faces developed. The six faces above together with the six parallel faces on the lower part of the crystal form a hexagonal bipyramid, which is described as a pyramid of the third order. Apatite thus belongs to the parallel-faced hemihedral or pyramidal-hemihedral class of the hexagonal system. The faces shown in the text-figure have the following Naumannian symbols: —

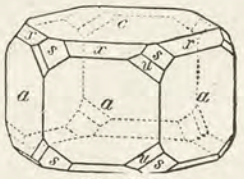

Fig. 272.
Crystal of Apatite.

$$a = \infty P,\ x = P,\ c = 0\,P,\ s = 2\,P\,2,\ u = \frac{3\,P\,\frac{3}{2}}{2}.$$

Comparing now these forms with the crystals on plate 81, in fig. 1 we have a large development of both the prism and the base, and on the edges between these are the narrow faces of two pyramids of the first order. The faces of the pyramids of the second and third order are very small: that of the third order, which just catches the light, is seen to lie on the right-hand side of the prism edge (i.e. on the opposite side to that shown in the text-figure). In fig. 2 the prism faces are short and the crystal consequently of a thick-tabular habit: here the faces of the pyramids of the second and third orders are rather larger, and that of the third order (again catching the light) is on the left of the prism edge. In this specimen several smaller crystals are attached to the main crystal in parallel position. In fig. 3 the comparatively large pyramid face of the second order reflects the full light, and there is no pyramid of the third order.

The crystals may vary in habit from tabular parallel to the base, to prismatic and columnar. The microscopic crystals seen embedded in igneous rocks are needle-like in form. Sometimes the edges of the larger crystals are curiously rounded presenting quite a fused appearance (figs. 5 and 7). Etched figures produced artificially by the action of acids on the basal plane show the same one-sided orientation as a pyramid of the third order; proving again the pyramidal-hemihedral symmetry of the crystals. Formerly apatite was confused with beryl and other minerals whose crystals present a columnar development; and on this account the mineral receives its name, from the Greek ἀπατάω, I deceive.

There is no distinct cleavage; but the crystals are frequently penetrated by fissures (plate 81) more or less irregular in direction but with a tendency to approximate to the basal plane. This indicates the presence of a poor cleavage parallel to the base, and is often to be seen more distinctly in rock-sections under the microscope. The outlines of these crystals as seen in section are either hexagonal, or elongated and more or less rectangular (plate 59, fig. 6). The former being perpendicular to the principal axis of the crystal remain dark in polarized light, whilst the latter show grey or white colours of the first order and extinguish parallel to their length. These microscopic crystals are colourless, but sometimes clouded by dusty enclosures in their centres. They were the first crystals to separate from the igneous magma, and were consequently caught up and enclosed in the later formed crystals. In plate 59, fig. 6, the small crystals are embedded in a large

PLATE 81.

Apatite.

Fig.

1. **Apatite,** hexagonal prism with base; on the edges are narrow pyramids of the same (first) order as the prism, and above the prism edges are small faces of a hexagonal pyramid of the second order; the small, obliquely-placed faces on the corners belong to a hexagonal pyramid of the third order, and indicate that the symmetry of apatite is pyramidal-hemihedral.
   Schwarzenstein, Zillerthal, Tyrol.
2. **Apatite,** parallel growth of crystals; the faces of the hexagonal pyramid of the third order are here unusually large (they are represented as bright faces at the front).
   Schwarzenstein, Zillerthal, Tyrol.
3. **Apatite,** the bright face in front belongs to the pyramid of the second order.
   Floitenthal, Zillerthal, Tyrol.
4. **Apatite,** violet; prism with base.
   Greifenstein, Ehrenfriedersdorf, Saxony.
5. **Apatite,** crystal with a fused appearance in limestone.
   Gouverneur, St. Lawrence Co., New York, U. S. A.
6. **Apatite,** reddish-brown; prism, pyramid and base.
   Renfrew, Ontario, Canada.
7. **Apatite,** prism with pyramid.
   Canada.
8. **Apatite,** prism with pyramid.
   South Burgess, Lanark Co., Ontario, Canada.
9. **Apatite,** violet crystals, prism with base, on matrix.
   Greifenstein, Ehrenfriedersdorf, Saxony.
10. **Apatite,** weathered and cracked crystal.
    Snarum, Norway.
11. **Apatite,** reddish veined crystal, tabular parallel to one pair of prism faces.
    Kragerö, Norway.
12. **Apatite,** red and green veined crystal.
    Eganville, Renfrew Co., Ontario, Canada.
13. **Phosphorite,** a massive, concretionary variety of apatite.
    Staffel, Limburg, Hesse-Nassau.

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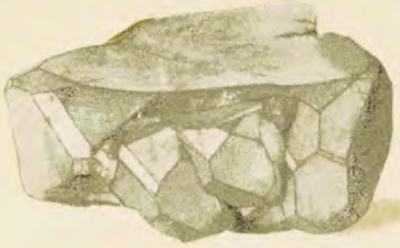

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crystal of augite which forms part of the rock mass. The refractive power of the crystals is moderately strong, the index for the ordinary ray being $\omega = 1{\cdot}646$ and for the extraordinary ray $\varepsilon = 1{\cdot}642$ (for sodium-light): on this account the crystals stand out in relief, and are thus readily distinguished from crystals of nephelite which have the same form.

The colour of apatite extends over a considerable range; and the crystals represented in plate 81 were partly selected with the view of illustrating this. The crystals may be colourless, yellowish-green, bluish-green, greenish-blue, violet, rose-red, mouse-grey, etc. The nature of the colouring material is not known. The specific gravity is 3·2; and the hardness, No. 5 on the scale, is about the same as that of window-glass.

In chemical composition apatite is a calcium phosphate, but in addition to phosphoric acid and lime it also contains chlorine or fluorine or both of these elements. The exact manner in which these constituents are combined is not known, and the formula may be written in different ways; here we give it as representing a double salt $3\,Ca_3P_2O_8 \cdot Ca(Cl, F)_2$. The mineral contains: phosphorus pentoxide (P_2O_5) 41—42, lime (CaO) 54—55$^1/_2$, fluorine (F) 0—3·8, chlorine (Cl) 0—6·8 per cent. Apatite is strictly isomorphous with pyromorphite (p. 124) and mimetite (p. 125), possessing an analogous chemical composition and very nearly identical crystalline form. For the purpose of identifying the mineral and distinguishing it from others of similar appearance it is often advisable to test for the presence of phosphoric acid: this is most conveniently done with a solution of ammonium molybdate in nitric acid, which after standing for a little time gives with phosphoric acid a characteristic canary-yellow precipitate.

Being a calcium salt, apatite is subject to alteration when exposed to weathering agents, giving place to the more stable calcium carbonate. It becomes dull, white, and softer, and often fissured. The crystal in plate 81, fig. 10, has been partly altered in this manner; here water has also been taken up and these crystals are known as "hydroapatite".

The occurrence of apatite as microscopic crystals in igneous rocks has already been mentioned. Larger, but still indistinctly-formed crystals occur embedded in crystalline schists. Bright crystals of a thick-tabular habit and rich in faces are found in drusy cavities in gneissose rocks (plate 81, figs. 1—3) and in veins of tin ore (figs. 4 and 9). The large crystals of prismatic habit (figs. 5—8) usually occur embedded in crystalline limestone.

A few of the more important localities for crystallized apatite are the following. The tin mines at Ehrenfriedersdorf in Saxony (plate 81, figs. 4 and 9). At Schwarzenstein (figs. 1 and 2) and Floitenthal (fig. 3) in the Zillerthal, Tyrol: beautiful, water-clear crystals of the same type occur with epidote at the Knappenwand in Untersulzbachthal, Salzburg. As large masses in connexion with gabbro at Bamle, Kragerö (fig. 11), Arendal, and Snarum (fig. 10) in southern Norway. Rich deposits, sometimes reaching ten feet in thickness, occur in crystalline limestone in Ontario and Quebec, Canada; here large crystals, often with rounded "fused" edges (figs. 6, 7, 8, and 12), are found in great abundance. Similar occurrences are also met with at Gouverneur in St. Lawrence Co., New York (fig. 5) and elsewhere in the United States.

In southern Norway and Canada crystallized apatite occurs in sufficient abundance to be won by mining and used for the manufacture of artificial manures.

Phosphorite and **Rock-phosphates.** Calcium phosphate also occurs in great variety as fine-grained, compact or earthy masses; and materials of this nature have been distinguished by a number of special names, according to differences in character or mode of origin. The true phosphorite forms concretionary and stalactitic masses with a mamillated surface and internally a minute radially-fibrous structure. It occurs as a filling in veins and pockets in limestone, particularly in Quercy, France, and in Estremadura, Spain. Material of this kind from Staffel in Hesse-Nassau has received the special name staffelite (plate 81, fig. 13). In addition to calcium phosphate, such material contains calcium carbonate, iron, alumina, and fluorine. Its value depends on the presence of phosphoric acid, but this, being in an insoluble form, cannot be readily assimilated by plants. The raw material has to be chemically treated; and this is now extensively done by the process first suggested by Liebig. By the action of sulphuric acid the insoluble tricalcium phosphate is converted into the soluble monocalcium salt, the remainder of the calcium combining with the sulphuric acid and water with the formation of gypsum. This reaction is represented by the following equation:—

$$\overset{\substack{\text{Tricalcium}\\\text{phosphate}}}{Ca_3(PO_4)_2} + \overset{\substack{\text{Sulphuric}\\\text{acid}}}{2\ H_2SO_4} + \overset{\text{Water}}{4\ H_2O} = \overset{\substack{\text{Monocalcium}\\\text{phosphate}}}{CaH_4(PO_4)_2} + \overset{\text{Gypsum}}{2\ (CaSO_4\ .\ 2\ H_2O)}.$$

The product, consisting of a mixture of monocalcium phosphate and gypsum, is known as *superphosphate*. Since large quantities of sulphuric acid are consumed by this process, the artificial manure works often include a plant for the manufacture of this acid, as is also the case in the Leblanc soda works (p. 357). The ordinary superphosphate contains 14—18 per cent. of phosphoric acid soluble in water, together with much gypsum. A richer product, known as double superphosphate, and containing 40—50 per cent. of soluble phosphoric acid, is manufactured by the action of a solution of phosphoric acid on a more readily decomposed phosphorite; the solution of phosphoric acid required in this process being itself prepared by the action of dilute sulphuric acid on phosphorite. The fluorine contained in the phosphorite is set free as hydrofluoric acid, which together with other objectionable fumes must be carried away through very high chimneys. The presence of iron has an injurious effect in these artificial manures, since it combines with the phosphoric acid forming an insoluble iron phosphate.

The deposits of the so-called Lahn phosphates occurring at Weilburg on the Lahn in Germany are now almost exhausted, that still remaining being of little value owing to the presence of much iron. The English deposits are also now exhausted: here the material — the so-called coprolites — consisted largely of the fossil excrements of saurians and other extinct animals. Extensive deposits of phosphorites and rock-phosphates of various kinds are now worked in Estremadura in Spain, on the Somme in France, in Algeria and Tunis, and more especially the rich deposits in Florida and South Carolina. The Florida phosphate, treated in large quantities at Biebrich on the Rhine and elsewhere, contains about 80 per cent. of calcium phosphate, together with 2—5 per cent. of fluorine, 1 per cent. of ferric oxide, and 1 per cent. of alumina.

A rock-phosphate of comparatively recent formation, and known as sombrerite, occurs on the island of Sombrero in the West Indies. This has been formed by the action on the coral-limestone of phosphatic solutions leached from the overlying deposits of guano.

Another source of phosphoric acid made use of for artificial manures is the Thomas slag (basic slag) from iron furnaces (p. 160). The Thomas meal prepared from this contains 12—23 per cent. of phosphoric acid; this is not present in a form soluble in water, but the larger part is dissolved by weak acids, such as citric acid.

Superphosphate is used principally for the manuring of grain crops; and Thomas meal, being slower in its action, for pastures and vineyards. By mixing superphosphate with ammonium and potassium salts and with saltpetre the various brands of artificial manures suited for different crops are prepared. Enormous quantities of phosphates are consumed for agricultural purposes. In Germany alone the annual consumption amounts to about 500,000 tons of superphosphate, 400,000 tons of slag phosphates, and 70,000 tons of bone-meal and guano, of the total value of about five million pounds (compare p. 373).

Monazite.

This mineral, first discovered in 1829, took its name from the Greek word μονάζειν 'to be solitary', because of the rarity of its singly-occurring crystals; and for many years afterwards it was regarded as a mineral of rare occurrence. When, however, with the development of incandescent gas lighting, a commercial demand was created for substances which occur as constituents of this mineral, it was found in considerable quantities; and new occurrences of the mineral are now eagerly sought for to meet the increasing demand for this purpose.

The mineral as found in large quantities and used commercially has the form of small grains, being known as monazite-sand. Distinctly shaped crystals are rare (plate 82, figs. 1 and 2); they belong to the monoclinic system. In text-fig. 273 the large face to the front is the ortho-pinacoid ($a = \infty P \bar{\infty}$); above and below this are two ortho-domes ($x = -P \bar{\infty}$, $w = P \bar{\infty}$); at the sides the vertical prism ($M = \infty P$); and above the prism there is a pyramid ($v = P$). All of these faces are distinctly shown by the crystal in fig. 2: that in fig. 1 is bounded at the end by a large obliquely-placed cleavage surface. Twinned crystals of monazite, with the ortho-pinacoid as twin-plane, sometimes occur.

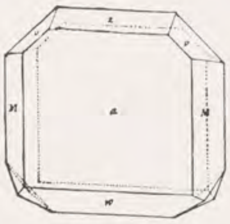

Fig. 273.
Crystal of Monazite.

The colour of the crystals is usually reddish-brown, and that of monazite-sand resinous yellow. The larger crystals are dull and opaque; but small crystals and grains are bright and translucent. The high specific gravity of 4·7 to 5·25 is an important character; for it enables the mineral to be readily separated from other lighter minerals by a process of washing in water, and in nature it has caused the accumulation of the heavy grains of monazite in certain deposits of sand.

Chemically, monazite is a phosphate of the rare metals of the cerium group, the formula being (Ce, La, Di) PO_4. But in addition to cerium, lanthanum, and didymium, it often contains some yttrium and thorium. The amount of thorium oxide (thoria, ThO_2) may range from 1 to 11 per cent. The variations in the amounts of these earths are illustrated in the following table of partial analyses of material from various localities.

	Raade, Norway.	Goyaz, Brazil.	Minas Geraes.	North Carolina.
Cerium earths $(Ce, La, Di)_2O_3$ . . .	56·86	64·1	51·0	40·86
Yttria (Y_2O_3)	2·76	5·1	2·2	13·98 (+ ZrO_2)
Thoria (ThO_2)	9·03	7·6	2·4	1·43

Monazite is of wide distribution as an accessory constituent of granite, diorite, gneiss, and other crystalline rocks. Usually, however, it is present in only very small amount; and its presence can only be detected by crushing the rock, separating the heavy minerals by washing in water, and examining the heavy residue so obtained under the microscope. With the weathering and breaking down of the rocks this concentration of the monazite is effected naturally; the grains collecting in the alluvial deposits of rivers, and in certain cases on the seashore. This mode of occurrence is exactly like that of gold and platinum in alluvial sands and of precious stones in gem-gravels; and it is such deposits that supply the commercial material.

Monazite-bearing sands formed in the manner just mentioned have been recorded from all parts of the world; but it is only in Brazil and North Carolina, and to a lesser extent in South Carolina, that they occur in sufficient abundance to be worked on a commercial scale. In the Carolinas the alluvial deposits are worked in the valleys of several streams that rise in the South Mountains. The sands contain from traces up to 1 or 2 per cent. of monazite, and they are concentrated by the ordinary methods of the gold miner. The heavy residue contains the monazite mixed with a variety of other minerals, such as gold, zircon, rutile, garnet, corundum, magnetite, etc. The gold is separated by amalgamation with mercury, and magnetic minerals are separated with the help of the electro-magnet. The resulting product contains 65—75 per cent. of monazite. In Brazil the monazite-bearing sands are found at certain spots on the seashore near Alcobaca and Prado in the southern part of the State of Bahia, and also at various points along the coast of the States of Espirito Santo and Rio de Janeiro. Much of this sand has been shipped as ballast.

Larger crystals of monazite are found embedded in the felspar of the pegmatite veins in the Ilmen Mountains in the southern Urals, and at several places in the south of Norway. In the Norwegian felspar quarries the crystals are at times quite large (plate 82, fig. 1); they occur singly, and are collected to the extent of about one ton per annum. Tiny, brilliant crystals of monazite are found in the crevices of the gneissic rocks of the Alps and of the slates at Tintagel in Cornwall.

Monazite is by far the most important source of the thorium and cerium compounds used for the manufacture of the mantles for incandescent gas lighting. The fact that certain rare earths give out a brilliant light when strongly heated was discovered by Auer von Welsbach in 1880. Of these the most important is thoria; but pure thoria itself is not effective, and it requires to be mixed with some cerium earths to produce the best result. The commercial salt prepared from monazite for use in the manufacture of the incandescent mantles is thorium nitrate containing some cerium. Owing to the increased demand and production of this salt its price fell within a few years from £50 to £3 per kilogram.

As to the output of monazite-sand no very exact statistics are available. The amount exported annually from Brazil is about 5000 tons; and in the Carolinas the production is slowly decreasing, amounting now to about 200 tons per annum. The price varies with the percentage of contained thoria; for lower grades it was (about ten years ago) £30 per ton, and for sands containing over 6 per cent. thoria £60 to £65 per ton; since that time the prices have fallen considerably.

In this place we may mention a few other minerals which contain the rarer elements. *Columbite* is a niobate of iron $FeNb_2O_6$, in which the iron is in part replaced by manganese and the niobium by tantalum. It forms black, rhombic crystals, which occur embedded in granite at Bodenmais in the Bavarian Forest, Miask in the Ilmen Mountains in the Urals, Haddam in Connecticut, etc. With the replacement of niobium by tantalum there is a gradual passage from columbite to the closely allied rhombic mineral *tantalite*, $FeTa_2O_6$. This is of rarer occurrence, but within recent years it has come to be of considerable importance as a source of the metal tantalum, now extensively used for the metallic filaments of incandescent electric lamps. *Yttrotantalite* is a tantalate of yttrium and erbium with calcium and ferrous iron; it is found as black masses at Ytterby and Finbo in Sweden. *Koppite* forms small cubic crystals in limestone at Schelingen in the Kaiserstuhl, Baden; it contains niobic acid in combination with cerium, lanthanum, didymium, calcium, ferrous iron, potassium, and sodium. *Eudialyte* occurs as rose-red to brownish-red, rhombohedral crystals and compact masses in nepheline-syenite at Kangerdluarsuk in Greenland and the Kola peninsula in Finland; it contains silica, zirconia, ceria, ferrous oxide, lime, soda, and chlorine. *Gadolinite* is found as large rough crystals and as compact masses with a black colour and pitchy appearance. It is found in granite at Ytterby and Falun in Sweden, Hitterö and Sætersdalen in Norway, in Llano Co., Texas, and Mohave Co., Arizona. Crystals sometimes reach a weight of 40 pounds, and compact masses as much as 200 pounds. This mineral is a silicate of yttrium earths, beryllium, and ferrous iron; and it has been worked as a source of the rare yttrium and erbium earths used in the Nernst lamp. Optically isotropic and birefringent varieties of the mineral occur; the former when heated suddenly glows brightly and is transformed into the birefringent variety.

Hydrous Phosphates.

Struvite. After the great fire of Hamburg in the year 1842, large numbers of beautiful, colourless to yellow crystals were found in peaty earth intermixed with cattle-dung amongst the foundations of the St. Nicholas church. These were named struvite, after the Russian minister then at Hamburg. Since that time similar crystals have frequently been found in old dung-heaps and sewers, and, under more natural conditions, in deposits of guano. Chemical analysis led to the surprising result that these crystals were identical in composition with a substance which had long been known to chemists, and obtained by them in the ordinary course in the analysis of magnesium salts, namely ammonium magnesium phosphate $(NH_4)MgPO_4 . 6 H_2O$.

These crystals (plate 82, figs. 3 and 4) attract attention by reason of their curious coffin-like shape. They belong to the rhombic system, but being differently developed at their two ends they fall in the hemimorphic class of this system (like hemimorphite, p. 131). At one end of the vertical axis they are bounded by a large basal plane, and at the other end by dome faces. As we have already seen (pp. 131, 246) crystals which show such a hemimorphic development are pyro-electric, the two ends becoming charged with positive and negative electricity with changes of temperature.

On exposure to the air the crystals become dull, white, and opaque (fig. 4), owing to loss of water and ammonia; and for this reason they should be preserved in sealed vessels. The material is insoluble in water, especially in the presence of ammonia; and on this property depends the use of this compound for the quantitative determination of magnesium. Before the blowpipe it fuses, with the evolution of water and ammonia. The specific gravity is 1·7, and the hardness between that of talc and gypsum.

Crystals of struvite have also been found in dung pits at Homburg-vor-der-Höhe, Brunswick, and Marburg; in sewers at Dresden; in bat-guano in the Skipton Caves near Ballarat in Victoria, Australia; and in the guano deposits of the island of Ichaboe, on the west coast of Africa. At the last-named place the crystals are associated with another similar compound, namely "salt of phosphorus", $HNa(NH_4)PO_4 . 4 H_2O$, which as a mineral is known as stercorite.

Vivianite. This is the most abundant of the several minerals which contain iron in combination with phosphoric acid. Crystals were first found in Cornwall and were sent by J. G. Vivian in 1817 to A. G. Werner, who accordingly named them vivianite. Previously the mineral had been known only as a blue, earthy material under the name "blue iron earth".

The crystals are monoclinic and isomorphous with those of erythrite (p. 177); they are usually small, and occur singly as attached crystals, or they may form radially fibrous or almost globular aggregates (plate 82, fig. 6). There is a perfect cleavage parallel to the plane of symmetry: fig. 5 of plate 82 shows a cleavage fragment from an unusually large crystal. The hardness is the same as that of gypsum, and the specific gravity is 2·6. The colour ranges from bluish-green to deep indigo-blue; the crystals are, however, originally colourless, and only acquire the blue colour on exposure to the air. This change in colour is due to a chemical alteration of the material of the crystals. Pure vivianite is a hydrated phosphate of ferrous iron, $Fe_3(PO_4)_2 . 8 H_2O$, but when exposed to the air for some time the ferrous oxide becomes partly oxidized to ferric oxide. The amount of the ferrous oxide may diminish from 43 to 10 per cent., with a corresponding increase in ferric oxide from 1 to 38 per cent.

Cleavage flakes of vivianite are well suited for demonstrating the phenomenon of dichroism. A fragment from a blue crystal when rotated with the stage of the microscope over the polarizing nicol shows a change from almost colourless to deep indigo-blue.

By blowpipe tests all the constituents of the mineral can be easily detected. Heated in a bulb-tube, the mineral gives off water; fused on charcoal, it gives a black magnetic bead (proving the presence of iron), and it imparts a green colour, characteristic of phosphoric acid, to the flame.

Vivianite is a mineral of secondary origin, and often occurs in association with organic remains. Crystals are sometimes found inside fossil shells, as at Kerch in the Crimea, and in bones in the peat-bogs of Ireland and Laibach. The crystallized group in fig. 6 is from the lignite deposits of late Tertiary age at Weckesheim in the Wetter valley in Hesse; and the specimen in fig. 5 is said to be from Moldova in Hungary. Fine crystals were formerly found in cavities in iron-pyrites and pyrrhotite at Wheal Jane, near Truro in Cornwall; and recently at Leadville in Colorado. More frequently, vivianite is met with as a pale sky-blue powder, or as a mere stain, in peat-bogs and deposits of bog-iron-ore.

Of the several other minerals which contain iron in combination with phosphoric acid or arsenic acid, the following may be briefly mentioned. They are usually associated with limonite (brown iron-ore). *Scorodite*, $FeAsO_4 . 2 H_2O$, forms small rhombic crystals of a sage-green colour; it has been found in many of the Cornish mines as a product of the alteration of mispickel. *Strengite* is the isomorphous phosphate, $FePO_4 . 2 H_2O$, occurring as small globular aggregates of minute crystals of a characteristic pale violet colour. *Pharmacosiderite*, a hydrated basic ferric phosphate, forms small, sharp cubes occasionally in combination with the tetrahedron, and of a bright green colour. This also occurs in the Cornish mines as an alteration product of mispickel.

Wavellite. This mineral was first found by Dr. W. Wavell at the end of the eighteenth century in crevices of a black slaty rock near Barnstaple in Devonshire. Crystals are rhombic, but only very rarely are they distinctly developed. As a rule the mineral forms radially-fibrous aggregates with a hemispherical or globular exterior. The hemispherical masses occur attached by their flat surface to the rock; and the globular masses are sometimes grouped together like a bunch of grapes. Again, if the mineral has grown in a confined fissure it gives star-like groups on the flat surface of the rock. Such forms are extremely characteristic of the mineral wavellite. The colour is often a delicate shade of green, passing at times into white, grey, or yellowish. The specific gravity is 2·3, and the hardness $3^1/_2$—4. In composition, wavellite is a hydrated basic phosphate of aluminium with the formula $4 AlPO_4 . 2 Al(OH)_3 . 9 H_2O$.

Wavellite is found in crevices of sedimentary rocks: for example, in clay-slate in Devonshire and Co. Cork; in quartz-slate at Langenstriegis near Freiberg in Saxony; in sandy greywacke at Cerhovic near Beraun in Bohemia. In association with iron ore, it is found in the Rothläufchen mine at Waldgirmes near Wetzlar, and at Oberscheld near Dillenburg in Nassau. The specimen represented in plate 82, fig. 9, is from Montgomery Co., Arkansas.

Lazulite. This mineral, popularly known as blue-spar, receives its name from the characteristic sky-blue colour. Care must be taken not to confuse this name with the very similar name lazurite (p. 258) applied to quite a different mineral. The crystals are monoclinic, and usually consist of a combination of two hemi-pyramids, producing a form very similar to a rhombic pyramid (plate 82, fig. 8). When one of these hemipyramids is more largely developed the habit of the crystals may be prismatic (fig. 7). From the shape of its crystals, lazulite can always easily be recognized: crystals are, however, rare and the mineral is more often massive and granular. The colour is bluish-white, sky-blue, or indigo-blue, and the material is only slightly translucent. Attached crystals have brilliant surfaces, but embedded crystals are dull and rough. The specific gravity is 3·1, and the hardness 5—6. Lazulite is composed mainly of aluminium phosphate, but in addition to this it contains ferrous oxide (2—12 per cent.), magnesia (8—13 per cent.), and some water, the formula being $(Fe,Mg)O \cdot Al_2O_3 \cdot P_2O_5 \cdot H_2O$. The best known localities are Werfen in Salzburg, and Graves Mountain in Lincoln Co., Georgia (plate 82, figs. 7 and 8).

Wavellite and lazulite find no practical applications. Other hydrated aluminium phosphates are turquoise (plate 82, figs. 10—12) and variscite (plate 82, fig. 13): these have already been described (p. 260).

◆

Organic Compounds.

Honey-stone or Mellite. Like the minerals just considered, this also contains alumina, but instead of being combined with a so-called mineral acid we have here an organic acid or carbon compound. This acid, is known as mellitic acid, and the mineral is a hydrated mellitate of aluminium, with the chemical formula $Al_2C_{12}O_{12}\,.\,18H_2O$. The name honey-stone was first given by A. G. Werner in 1789, on account of the honey-yellow colour of the mineral; and the name mellite, derived from the Greek, has the same meaning.

Crystals of honey-stone are very simple in their form. They belong to the tetragonal system, and are bounded by a single square pyramid (plate 82, figs. 14 and 16), or this pyramid in combination with a prism of the second order (fig. 15). The faces of the pyramid are inclined to one another at an angle of $118^1/_4{}^\circ$; this is chosen as the primary pyramid *P*, and the symbol of the prism then becomes $\infty P \infty$.

The colour is straw-yellow or honey-yellow to brownish, rarely white; and the transparency of the crystals is usually impaired by internal cracks. The specific gravity is 1·6, and the hardness slightly over 2. The mineral is readily soluble in nitric acid and in hydrochloric acid. When heated in a bulb-tube it gives off much water; and before the blowpipe it becomes charred and leaves a white residue of alumina.

Honey-stone is found embedded in lignite (brown-coal) at Artern in Thuringia (plate 82, fig. 14), and Luschitz in Bohemia; and in an earthy black coal at Malovka in government Tula, Russia (figs. 15 and 16).

Whewellite. This is the calcium salt of another organic acid, the well-known oxalic acid of frequent occurrence in the vegetable kingdom: it is a hydrated oxalate of calcium with the formula $CaC_2O_4.H_2O$. The mineral was named after William Whewell (1794—1866), philosopher and historian of science, who for a time was professor of mineralogy at Cambridge. The small monoclinic crystals are beautifully developed with a profusion of bright facets, and often form pretty heart-shaped twins resembling those of calcite. They are colourless and water-clear and possess a double refraction very nearly as strong as that of calcite.

Whewellite is found in the crevices or joints of the rocks, and sometimes in the coal itself, of coal mines; these crevices are partly filled with calcite, dolomite, barytes, and other minerals. It is known only from a few localities in Saxony (Burgk near Dresden, and Zwickau) and Bohemia (Brüx, and Schlan), and at Markirch in Elsass.

Amber, or Succinite, represents the resin which oozed from the pine-trees of past ages; this has been preserved in a fossil condition, whilst the trees themselves have vanished, leaving behind no more than mere traces of their former presence. Being of vegetable origin, this fossil resin is not, strictly speaking, a mineral; nevertheless it is usually regarded as such, for it is found in the rocks of the earth's crust and it shows no organic structure. Further, it has always, even in prehistoric times, been much in favour as a gem-stone for

PLATE 82.

Phosphates, Honey-stone, Amber.

Fig.

1. **Monazite,** large crystal.
Moss, Norway.
2. **Monazite,** small, sharp crystal.
Moss, Norway.
3, 4. **Struvite,** fresh and weathered crystals.
Hamburg, Germany.
5. **Vivianite.**
Moldova, Banat, Hungary.
6. **Vivianite,** group of small crystals forming a nodule in lignite.
Weckesheim, Bad Nauheim, Hesse.
7. **Lazulite,** isolated crystal.
Graves Mountain, Lincoln Co., Georgia, U. S. A.
8. **Lazulite,** crystals embedded in quartz-rock.
Graves Mountain, Georgia, U. S. A.
9. **Wavellite,** nodular with radially fibrous structure.
Montgomery Co., Arkansas, U. S. A.
10. **Turquoise,** in reddish-brown sandstone.
Wadi Meghâra, Sinai Peninsula.
11. **Turquoise,** in weathered, clayey porphyry.
Columbus district, Nevada, U. S. A.
12. **Turquoise,** in rock.
New Mexico, U. S. A.
13. **Variscite.**
Eastern slopes of the Rocky Mountains, Utah, U. S. A.
14. **Honey-stone** (Mellite), dark yellow pyramid.
Artern, Thuringia.
15. **Honey-stone,** tetragonal pyramid with prism of the second order.
Malovka, govt. Tula, Russia.
16. **Honey-stone,** tetragonal pyramid.
Malovka, govt. Tula, Russia.
17—22. **Amber.** 17, Shelly amber. 18, Pit amber. 19, insect in amber (enlarged 3 times).
20, Cloudy amber. 21, Osseous amber. 22, Amber drop.
Samland, Baltic coast of Prussia.


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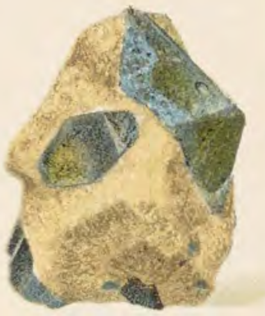
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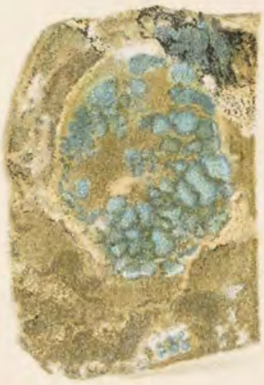
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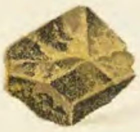
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personal ornament. But being a resin it shows no regular crystalline form such as we associated with true minerals. It acquires only such forms as are produced by the flow of a viscous substance; as seen, for example, in the drops of resin which exude from pine-trees and cherry-trees at the present day.

Occasionally there are found well-defined drops or "tears" of amber (plate 82, fig. 22), but usually the material is found as irregular masses ranging from a gram to ten kilograms in weight. Sometimes the material shows a platy or shelly structure ("shelly amber", plate 82, fig. 17), due to the material having become partially hardened in the intervals between successive flows. Such material can be easily broken along these layers: it is always clear and frequently encloses foreign bodies. As distinct from this we have "massive amber", which may be either clear, transparent, and uniformly coloured, or more or less cloudy and opaque and with an irregular distribution of colour. "Clear" amber is perfectly transparent and pale yellow to reddish-yellow in colour; but this is of rare occurrence. "Cloudy" amber is separated into the following varieties: "bastard", "osseous", and "frothy"*).

The "bastard" variety is distinguished by the high degree of polish it is capable of taking. According to the distribution of the cloudiness, several sub-varieties are recognized. In the "true bastard" the material is uniformly clouded throughout. In "clouded bastard" (plate 82, fig. 20) coloured cloudy patches are distributed through a clear groundmass. In the variety known as "flomig" the cloudiness is distributed as a fine dust throughout the material. A further subdivision of "bastard" is based on differences in colouring. Pieces of a pure white to greenish-yellow shade are described as "pearl-coloured"; and of these the paler are known in the trade as "blue" amber, and the yellower as "kumst-coloured" (Kumst being an East Prussian name for cabbage or Sauerkraut).

"Osseous amber" or "bone" is opaque, softer than "bastard", and less capable of taking a polish. It resembles bone or ivory in appearance, and ranges in colour from white to brown (plate 82, fig. 21). "Frothy amber" is opaque, very soft, and not susceptible of a polish.

Cloudy and "flomig" amber, but not the "osseous", can be clarified by heating the material in oil. The tiny pores in the amber become filled with oil and allow the free passage of the light rays without these being scattered. Much of the material is ruined by the process; the heating and cooling have to be effected very gradually, and care must be taken not to reach the boiling point of the oil. The product so obtained, especially that given by the "blue" trade variety, is as clear as glass, and it has been used for making magnifying lenses, spectacles, prisms, and burning glasses. An amber burning glass fires powder much more quickly than one made of glass. The fact that clarified amber possesses a higher refractive power than raw amber is explained by the presence of the oil. This process of clarifying amber was known to the ancients; Pliny mentions that amber when boiled in fat acquires a greasy appearance like that of a sucking-pig.

During the operation of clarifying amber there are often developed in the interior of the stone peculiar cracks bearing a resemblance to fish scales, which produce an iridescence or the total reflection of the light. These cracks are known to the amber workers as "sun-spangles".

Cloudy amber can also be rendered clear by the application of dry heat. The pieces are embedded in sand and heated for a long time at a temperature over 100° C.; this process being similar to that adopted for changing the colour of amethyst and topaz. The resin thereby becomes softened and the pores closed up.

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*) On the trade varieties of amber see R. Klebs, "Die Handelssorten des Bernsteins." Jahrb. der königl. preuss. geologischen Landesanstalt, for 1882.

This property of softening, possessed by amber when warmed, is made use of for the purpose of uniting small fragments into larger pieces. By heating the material away from the air and under a pressure of 3000 atmospheres, objects of all shapes and sizes and with a highly polished surface can be moulded. This product is known as pressed amber or ambroid.

Enclosures of foreign bodies in amber are of special interest, and fossil insects are often beautifully preserved in this material. Those most commonly met with are diptera (plate 82, fig. 19, and text-fig. 274, both enlarged three times), and less frequently orthoptera, neuroptera, coleoptera, etc., and arachnida (a spider is shown in text-fig. 275). Plant remains, such as pine-needles, catkins, etc., are also found enclosed in clear amber. The forms of these enclosures indicate that at the time they became embedded the resin must have been quite fluid. The bodies of the insects have perished, leaving only impressions with a little of the chitinous material preserved. Minute crystals of iron-pyrites also occur embedded in amber, particularly in the osseous variety.

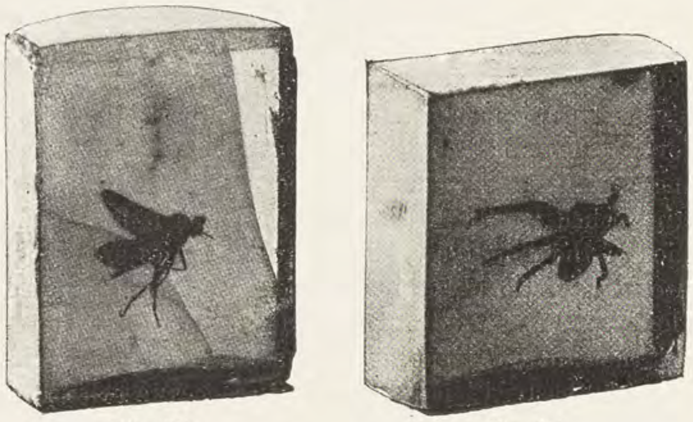

Fig. 274. Fig. 275.

Insects enclosed in Amber.

Amber is composed of carbon (79 per cent.), hydrogen (10·5 per cent.), and oxygen (10·5 per cent.); and this percentage composition can be expressed by the formula $C_{10}H_{16}O$. It is to be remembered, however, that amber is not a definite chemical compound, as might be suggested by the above formula. As proved by the selective action of various solvents, it is an intimate mixture of different substances. Alcohol dissolves 20—25 per cent. from clear amber, and ether 18—23 per cent.; the insoluble portion consists of succinine or amber-bitumen (44—60 per cent.) and succinic acid (3·2—8·2 per cent.).

The physical characters of amber present certain remarkable features. It has long been known that the material becomes electrified when rubbed, then attracting to itself particles of dust and other light objects. On this account the Greek name *elektron* (ἤλεκτρον) for amber is probably derived from ἕλκητρον, the drawer; and the modern word electricity is from the same root. The hardness is low, being rather less than that of calcite; still the material is capable of taking a high polish. The specific gravity amounts to no more than 1·08, being just the same as that of sea-water; and for this reason amber is readily raised and transported from its bed in the sea. For the Röntgen rays amber is one of the most transparent of substances. Certain specimens, especially those from Sicily, are strongly fluorescent, appearing bluish-green by reflected light, in a manner similar to petroleum.

Amber melts at 287° C., then decomposing and giving off succinic acid and other volatile constituents. The black substance that remains behind dissolves in linseed-oil and is used for amber-lac and amber-varnish. At a higher temperature amber burns with a bright white flame, and gives a pleasant aromatic odour. The German name "Bernstein" for amber, derived from the old German "börnen", to burn, means a stone that burns.

The home of the true amber is the Prussian coast of the Baltic Sea, where since prehistoric times the material has been collected. It is also found in quite small amount on the Simeto river near Catania in Sicily, and in a few other districts; but the fossil resins of other localities present certain points of difference from the true amber or succinite. Prussian amber occurs embedded in a stratum in the older portion (the Oligocene) of the Tertiary formation. The sandy material of this bed is rich in grains of bluish-green glauconite, and it is consequently known as a greensand or as the "blue earth" (not to be confused with the "blue ground" which forms the matrix of diamond in South Africa). This amber-bearing bed crops out on the coast of East Prussia and extends northwards beneath the sea. In the latter case the bed may be disturbed by storms, and the amber washed out and cast up on the shore. In former times also the bed was disturbed by running water and moving ice, and the amber transported and laid down again in later deposits: in this way amber has come to be distributed, though only sporadically as isolated pieces, over a wide area in the alluvial and glacial deposits of northern Germany.

The amber won in open pits or by underground mining in the blue earth is known as "pit-stone" or "earth-amber". Material collected on the seashore or drawn from the sea with the masses of seaweed is called "sea-stone" or "drawn-stone". Formerly, the amber was also collected from the floor of the sea by divers, and at one time by dredging in the Kurisches Haff. Occasionally the "earth-stone" is also found in the later Tertiary and glacial deposits; and in this case the material is covered with a thick weathered crust. This crust can be readily detached, when the fresh but reddened amber beneath is seen to be marked by numerous shallow pittings (exactly as represented in plate 82, fig. 10, although this specimen is stated, perhaps erroneously, to be a piece of "pit-amber"). Pit-amber always shows on its surface a thin white crust with a dusty weathered appearance.

During former centuries the "sea-stone" was by far the most important product, although "pit-stone" had also since very early times been obtained by digging on the land. These conditions were to some extent reversed when in 1836 the inhabitants were given the freedom of collecting amber for themselves, and a large number of open workings were then commenced. The "pit-stone" came to be of still greater importance when by the government enactment of June 1st, 1867, collecting on the shore was separated from workings on the land, and the latter were leased to the highest bidders. Mining for amber then came to be developed on a large scale at Palmnicken and Kraxtepellen in Samland, and this had an important influence on the industry. Owing to the presence of an opaque crust on the surface of the "pit-stone" the quality of the material cannot be estimated for the market, and it is necessary to first clean the product. The adhering earthy material is first removed by a stream of water, and the stones then agitated in a large vat with broom and brushwood, and lastly with sand and water in rotating barrels. In this way the impurities and the crust are removed and the product then presents exactly the same appearance as the clean "sea-amber".

For many years the winning of amber has been controlled by the firm of Stantien and Becker, and the trade varieties of amber introduced by them are universally recognized. The four main varieties depend on the size and shape of the pieces and their suitability for different classes of work. As given by the amber expert R. Klebs they are as follows.

The "flat" varieties, including the so-called "tiles" (Ger. Fliesen) are the most valuable: here the pieces of sound amber have a thickness of at least $5^1/_2$ centimetres and a length and breadth of 25 cm. Such pieces are used preferably for making cigar-holders, the larger in Vienna, which is the principal centre of the amber working industry, and the smaller in Nürnberg and other German towns. Similar to these in form but not so thick are the "plates" (Ger. Platten), which are mostly used for making the mouthpieces of wood or meerschaum cigarette-holders; also for the so-called "manelles" consisting of a flat polished disc with a hemisphere in the centre; and the so-called "horse-corals" or flat beads which are much worn in Russia.

The "medium" varieties, in which the "shelly amber" finds a place, are worked mostly as beads. Such material is especially valuable when clear pieces enclose well-shaped insects.

The "round" varieties form the material for different kinds of beads, including the elongated "olives" and "Zotten", and the spherical beads proper.

Amber beads have been used as personal ornaments at all periods and by all races. In many districts in Germany the well-to-do peasant women regard a string of amber beads (known as corals) as the most valuable of ornaments; and the same is the case in Persia, China, Tartary, and many other countries. Or again, in the form of rosaries, the beads are used for religious purposes. The Mohammedan rosary is a string of ninety small beads and one large bead, and 70,000 such strings are sold each year. The beads are also sometimes cut with facets and mounted as brooches and various other ornaments, or used for the decoration of mirrors and picture-frames.

The variety known as "varnish" consists of the smallest pieces not large enough for making into beads. Such material is fused for the preparation of amber-varnish and lac.

The production of amber during the year 1896 amounted to about 440 tons. By far the larger part of this was obtained by the firm of Stantien and Becker from the mines at Palmnicken and Kraxtepellen. Small quantities were obtained by dredging and were collected on the seashore. During 1890, as stated by Klebs, 90,000 cubic metres of the blue earth were raised, yielding about 202,000 kilograms of amber, of the value of about £90,000. The amber industry in East Prussia gives employment to some 1200 persons.

Ozocerite. The last substance to be described here shows a close similarity to wax and paraffin, and is hence known as mineral wax or native paraffin. The more common name ozocerite, derived from the Greek, means to smell of wax. It forms brownish or greenish, translucent masses, and readily melts and burns like wax or paraffin. At Boryslaw in Galicia and Slanik in Roumania it occurs together with petroleum in considerable quantities, and is there won by mining. The crude material is purified by treatment with sulphuric acid; and the product, known as ceresine, employed for the manufacture of candles, tapers, artificial honeycomb, etc. The annual production amounts to about 8000 tons. Ozocerite is a mixture of various hydrocarbons and cannot therefore be regarded as a mineral species. Still less can petroleum, asphaltum, and coal find a place amongst simple minerals. These have originated from vegetable or animal remains, and they are not definite chemical compounds. Although they are of such great economic value, we must here exclude them from the mineral kingdom, in which we have treated only of simple minerals of definite chemical composition and of inorganic origin.

Appendix.

The Formation of a Collection of Minerals.

The pictures given on the accompanying plates cannot of course entirely take the place of the actual minerals. In a way they are comparable with the show specimens exhibited in a public collection, which can be viewed only at a distance through the glass panes, but cannot be handled and examined more closely. In order to acquire a true knowledge of minerals it is necessary that their actual material should be handled and studied. Here the student possesses an advantage over the amateur in having access to the teaching collections and students' series; but even he will become more intimately acquainted with minerals and take a greater interest in them, if the specimens form part of his own collection. It is not at all necessary to acquire fine and expensive pieces. A simple specimen is sufficient to show the prominent and essential characters of a species, and help to impress them upon the mind. A comparison of such specimens with the pictures and descriptions in this volume will also be of assistance.

A keen collector will find that his collection quickly grows, and not necessarily with the expenditure of much money. Specimens of inferior quality collected at an early stage will gradually become replaced by better examples of the same species from the same locality. If, however, such inferior specimens have been collected by oneself they possess a personal interest and are valuable in giving a reliable record of the locality at which they were found; furthermore, they help to remind the collector of the place of origin and the mode of occurrence. In very nearly all districts minerals of one kind or another can be collected or purchased from quarrymen or miners. Others may be acquired by exchange from the collectors in other districts; and still others from the mineral dealers. The object of collecting is not to satisfy the mere greed for possession, but to supply the collector with material which will always be at hand for purposes of study and comparison, and with specimens of whose beauty he can never tire.

In his young days nothing gave the author greater pleasure than to sit before his collection and regard the specimens. His earliest acquired minerals were treasured in matchboxes kept in a small cupboard; they next occupied the inside of an old clavichord; and when this became too small for the collection his parents gave to him a real mineral cabinet with forty drawers. During the school holidays be was allowed by Professor Dunker to visit the mineral collection in the university of Marburg; entering with a feeling of awe every time he found the door open, and bitterly disappointed when he found it closed. Passing from case to case admiring the displayed treasures, he little dreamt that one day he would become an assistant in that collection with the privilege of seeing the specimens every day.

Anyone interested in minerals should not miss an opportunity of visiting a public collection. A comparison of the specimens with the pictures in this book will help much to impress upon the memory the characters of minerals. It will be found that the specimens represented on the coloured plates are all very good examples;*) and if these were brought together as a type collection they would no doubt serve a useful purpose in connexion with the set of plates. But such a collection could not replace a collection of one's own; it shows the most typical and best examples, and places an ideal before the private collector.

The cleaning, labelling, and setting out of the specimens in a collection are points of importance. No very definite rules can, hovever, be laid down, and much must be left to individual taste and judgment.

For cleaning and dusting the specimens a soft painter's-brush and a brush with shorter and stiffer bristles — a plate-brush is excellent — will be found useful. In many cases the specimens may be washed in water or placed under the tap; but care should be taken not to use hot water as cleavage cracks may be developed in the crystals. A lather of soap may be applied with a soft shaving-brush; and some specimens may be scrubbed with a hard nail-brush. The use of acids should be avoided, except in very special cases, for some of the associated minerals may be decomposed or tarnished, and the specimen would then no longer be in its natural condition.

The specimens may be trimmed to a suitable and presentable shape with a small hammer. Here great care is required, for the crystals on the surface are very liable to be fractured along the cleavage by the concussion. Crystals should stand out to advantage on the matrix; but the mistake is often made of reducing the specimens to too small a size, or even of detaching the crystals from their matrix. The associated minerals should always be preserved, since they tell much as to the origin of the minerals.

Care must be taken that the specimens are not allowed to knock one against another, otherwise the edges of the crystals will be bruised and the specimens ruined. To avoid this, each specimen should be carefully laid in a separate card-tray. The inner part of a match-box serves this purpose; or trays can be easily made at home out of cardboard pasted round with paper. Neater card-trays are supplied very cheaply by the mineral dealers and box makers. A glazed paper used for lining the trays has the advantage that it can be readily wiped free from dust; but at the same time the specimens slide about more easily. The card-trays should be of such a size that when placed in rows they exactly fill the drawer, thus preventing any movement as the drawers are opened and closed. Depending on the size of the drawers, a unit size of card-tray must be selected and all others made of multiple or sub-multiple sizes; so that a larger tray may be replaced by two, four, or more smaller ones as the specimens require. The depth of the trays may be $^1/_2$—$^3/_4$ inch. Small isolated crystals are conveniently kept in corked glass-tubes.

An important duty is the careful labelling of the collection, Each specimen should be accompanied by a neatly written label — a thin card with a black line border is effective. On this should be recorded the name of the mineral, the locality where found, the source of the specimen (by whom collected, or the name of the donor), and the date. If desired, further information may be given respecting the associated minerals present on the specimen,

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*) In the original German edition of this work it is stated in the explanations of the plates in which collection each of the specimens figured is to be seen. This information, being of less immediate value to English readers, has been omitted in the present edition. The collections named include those at Bonn, Clausthal, Frankfurt, Giessen, Göttingen, Hamburg, Karlsruhe, Marburg, and Stuttgart, and the private collections of Professor V. Goldschmidt at Heidelberg, Professor A. Nies at Mainz, and Dr. G. Seligmann at Coblenz.

the forms of the crystals, the mode of occurrence, etc. Original labels should always be carefully preserved and kept with the individual specimens to which they refer; they often afford important evidence as to the authority for the statement of locality. A difficulty with loose labels is the danger of their being interchanged, and, when mixed, to discover to which specimens they really belong. The only way to avoid this is to attach a small label to the specimen itself. This may give a brief statement of the locality and other essential details, or simply a number; the same number is written on the loose label, and if desired also in a catalogue or register of the collection.

An attempt should be made to represent at least the more important varieties of each species, its different forms of crystals, modes of occurrence, associations, etc. The common or massive forms of a mineral should be represented in addition to rarities in the way of crystals. The classification followed may be taken from the text-books; and it will be found extremely instructive to re-arrange the collection according to different systems of classification. The subdivision of each species is best made according to the localities where the specimens were found, commencing with those nearest home. But when the collection has grown to this extent the collector will find himself compelled to specialize on certain lines. He may restrict his collection to the minerals of a particular district or country, to certain groups of minerals, or even to a single species; an exhaustive collection of calcite, for example, might fill a whole museum.

When setting out to collect minerals in the field a certain amount of equipment must be carried. At least two hammers are required; a larger one weighing about 1$^1/_2$ pounds and a smaller one of a few ounces, the former being for ordinary use, and the latter for trimming the specimens. The hammer-head is square at one end and chisel-shaped at the other, and of steel specially hardened at the ends. A chisel with a hard edge is also required. A third still larger hammer — a sledge-hammer — is often useful for breaking large blocks of stone. Other items include a canvas collecting-bag with several pockets, a magnifying lens, a map, and note-book, and last but not least plenty of packing material. An acid bottle is often of assistance in recognizing carbonate minerals and limestone rocks.

For packing material old newspapers are the best, and for any specially delicate specimens a few small boxes should be carried. The specimens must not be allowed to rub against one another in the collecting-bag, but each one must be carefully and separately wrapped up. At the same time a temporary label, indicating the spot where the specimen was found should be enclosed in the wrapping. Some collectors prefer to mark a number on the specimen or on the wrapping, and a corresponding entry in a note-book. When several specimens are collected at the same spot these may be conveniently placed together in a paper bag with a note on the bag, each specimen being separately wrapped. Each collector has of course methods in detail of his own, and he soon finds out those best suited to his particular purpose. When away on a collecting trip for several days, the results of each day's work should be labelled in more detail after the evening meal. A good plan is to place thin adhesive labels written in ink on each specimen (the gummed paper from the edge of postage stamps is excellent for this purpose). It may then be convenient to send the specimens home by post or rail, when they will have to be more carefully packed. Plenty of crumpled newspaper forming a cushion round each specimen is the best. Delicate specimens should be wrapped first in tissue-paper and surrounded by a layer of cotton-wool before the wrapping of newspaper; and it is often advisable to place these in a separate box before packing them with other specimens. A point of the utmost importance is that the box of specimens should be completely filled and tightly packed, all the spaces being filled with paper, hay, or straw, before nailing down the lid. If this is not done the specimens will become displaced and damaged during transit.

When the collector returns home with his treasures he can proceed to clean and trim the specimens and examine them at his leisure. Small crystals of some rare mineral not noticed before in the field may perhaps be then detected with the aid of a lens. Before the specimens can be completely labelled, the minerals present must be determined. This can be done by observing their prominent characters, such as crystalline form, hardness, lustre, cleavage, etc., and if need be they can be examined before the blowpipe (p. 63). Reference may be made to books and tables on determinative mineralogoly; and in case of difficulty an earnest student will always find willing help from his teacher or from the curators of public collections.

Only in exceptional cases are mineral specimens of any value to be found amongst the weathered materials on the surface of the ground. Search must be made at spots where unweathered rocks are exposed, as in mines, pits, quarries, railway cuttings, etc., or where there have been recent falls of cliffs. In particular, many good specimens are often to be found on the waste heaps from metalliferous mines. Further' it is mostly amongst the older sedimentary rocks and those of igneous and metamorphic origin that crystallized minerals are to be found. For this reason there is very little of interest in the way of minerals to be found in the neighbourhood of London; but the mining districts of the west and north of England, particularly in Cornwall and Cumberland afford many opportunities for collecting.

In the original German edition of this work an account is given of the several places in the neighbourhood of Giessen where minerals may be found and collected. But here we must leave the collector to plan out for himself the collecting trips which may be made in his own neighbourhood. Detailed information as to mineral localities in the British Isles will be found in R. P. Greg and W. G. Lettsom, 'Manual of the Mineralogy of Great Britain and Ireland' (London, 1858), and T. M. Hall, 'The Mineralogist's Directory' (London, 1868). Other useful books are: J. H. Collins, 'Handbook to the Mineralogy of Cornwall and Devon' (Truro, 1871), with supplement in the Journal of the Royal Institution of Cornwall, 1911, vol. LVII; M. F. Heddle, 'The Mineralogy of Scotland' (2 vols., Edinburgh, 1901). Similar works on topographical mineralogy have been written for other countries.

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