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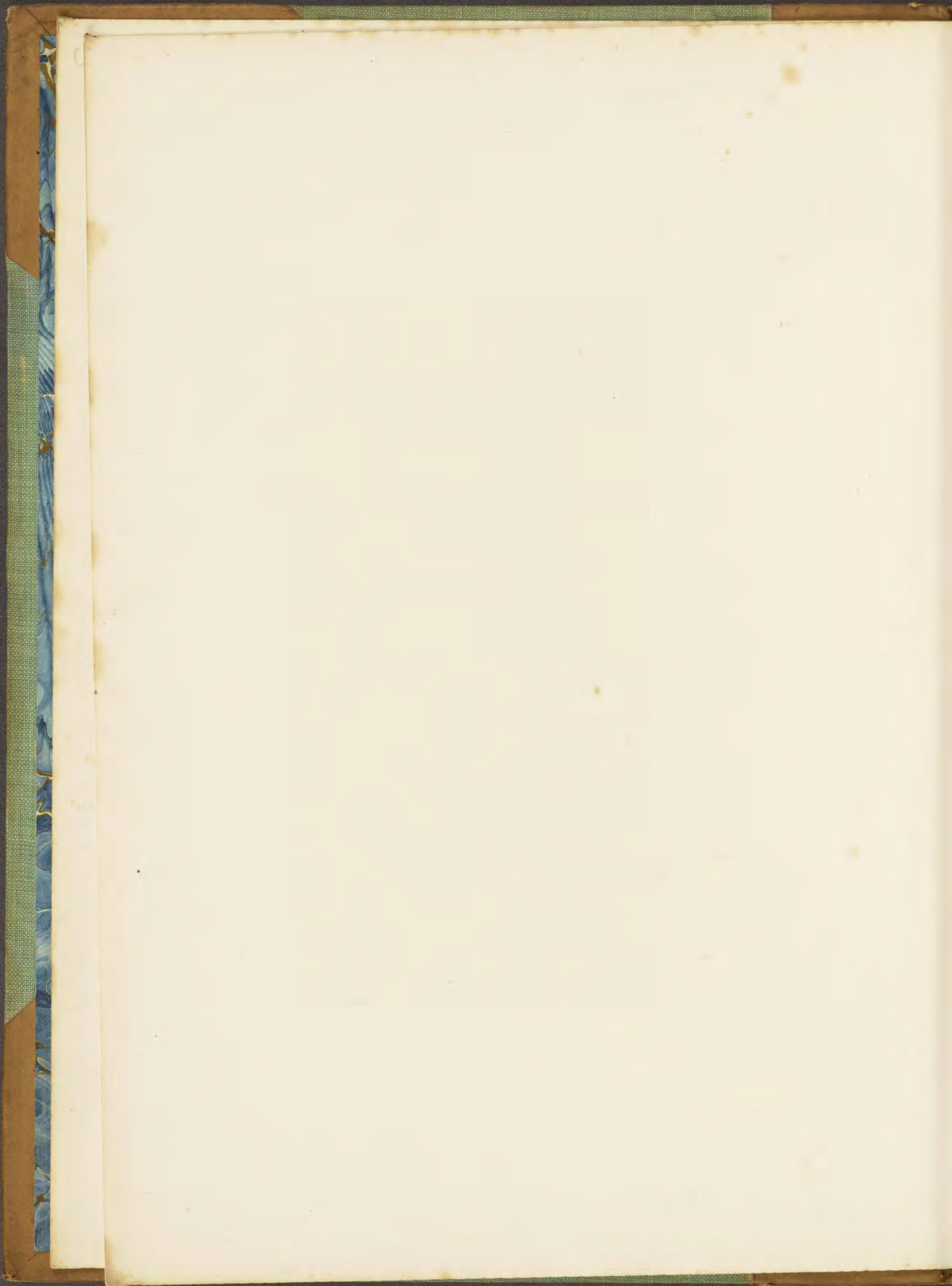
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FRONTISPIECE.

Smoky-quartz.

St. Gotthard, Switzerland (*from a specimen in the Karlsruhe collection*).



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THE
MINERAL KINGDOM

BY

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



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Translation of Author's Preface.

This book has been written for the admirers and collectors of minerals, and aims at increasing the number of persons interested in these natural objects. It is not a text-book of Mineralogy, but a popular book dealing with such parts of the science as are of general interest and usefulness. The most important minerals are represented in their natural form, colour, and size on 73 chromo-lithographic plates, and in addition there are 14 photographic reproductions, 4 art-plates, and numerous figures in the text.

It is not all minerals that are suited for pictorial representation; and in any case the specimens must be carefully selected, so that they will show to advantage any particular mineral without giving too much prominence to the associated materials. For this purpose a collection such as that in the University of Giessen does not suffice, and I have had to rely on the kind support of colleagues and friends. The specimens here portrayed belong to the Museums of the Universities of Bonn, Göttingen, and Marburg, the Natural History Museums of Stuttgart, Karlsruhe, and Hamburg, the Senckenberg Museum at Frankfurt, and that of the Mining Academy at Clausthal. To the custodians of these collections — namely, to Professors H. Laspeyres, T. Liebisch, M. Bauer, E. Fraas (and Dr. E. Schütze), M. Schwarzmann, C. Gottsche, W. Schauf, and A. Bergeat, respectively — my best thanks are due for the loan of valuable specimens; and also to Mr. Gustav Seligmann of Coblenz, who has placed at my disposal the treasures in his private collection. A few other specimens have also been loaned by Professors F. Berwerth of Vienna, V. Goldschmidt of Heidelberg, E. Kalkowsky of Dresden, A. Nies of Mainz, A. Sauer of Stuttgart, Mr. Hermann Stern of Oberstein, and the Brothers Görlitz of Idar. Most of the photographs reproduced on the plates and in the text-figures have been taken by Dr. Heineck, whilst those of the optical interference-figures were supplied by Dr. Hans Hauswaldt of Magdeburg. To all of these I express my hearty thanks. My thanks are also due to the publisher, who has spared no cost, and to the proprietors of the art-works of Wahler and Schwarz, who have spared no pains, in order that the result should be the best attainable. The improvement effected in the work during the three years necessary for the preparation of the plates may be seen from a comparison of plates 46 and 48, which were issued with the first part, and the frontispiece (smoky-quartz), which came out in one of the later parts of the book. The drawings of crystals for the text-figures have been taken from the well-known works of Dana, Groth, Koksharov, Naumann-Zirkel, Tschermak, and other authors. Except in a few special cases, references to the literature have not been given.

In the descriptions, I have endeavoured, so far as the subject-matter allows, to express myself as clearly and simply as possible; and I hope that the reader will be able to follow without further help.

The volume commences with a *General Part* in which is given a brief account of the more important characters of minerals — their crystalline form, physical properties,



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Introduction.

The Mineral Kingdom.

The Mineral Kingdom comprises the cold and lifeless stones which form the crust of our earth. Although these stones are themselves lifeless, yet the materials of which they are composed are essential to the existence of all things in which life has been awakened by the warmth of the sun. On this account alone then, the study of minerals will engage our serious attention. But apart from this claim on our interest, we are attracted by the beautiful colours, brilliant lustre and great hardness of certain minerals. Such stones as these have been used in all ages for personal ornament; they have not the fleeting beauty of flowers but are beautiful for all time. Not so with their imitations. However cleverly the imitation be made, it never equals the genuine stone in richness of colour or brilliancy of lustre, and after a very short period of wear it becomes scratched and dull, while the real stone retains its beauty unimpaired to delight the eyes of its possessor.

Precious stones are used only for ornament; they cannot therefore be said to have aided greatly in the slow growth of civilization. With metals, however, it has been far otherwise. What indeed would be the condition of the human race to-day if suddenly deprived of gold, silver, copper and iron? Here again, it is from the earth's crust that these valuable metals are obtained, not indeed in metallic form, but combined with other minerals and, as it were, disguised. The practised eye recognises these mineral combinations as metallic ores and they are won from the bowels of the earth by the patient and laborious efforts of the miner. The fruit of his labour furnishes the world with the material for the construction of tools and machinery, railways and telegraphs, and with gold, the precious metal which serves as a standard of currency. Glass, porcelain and oil-of-vitriol may be mentioned among the many substances prepared in the great centres of chemical industry from materials derived from the earth's crust. There is not a moment in our lives when we could dispense with the services rendered us by the mute and inanimate mineral kingdom.

The Limits of the Mineral Kingdom.

In a sense the Mineral Kingdom is universal, for it embraces not only the whole earth, but also meteorites, those celestial messengers which come to us out of the depths of the stellar universe. Some members of this immense kingdom have, as it were, taken up their abode in other domains, and like the colonies to the mother-country

retain only a loose connection with the mineral kingdom. Such are the fossils, those petrified remains of animals and plants which are found embedded in hard rock. While they show any trace of organised structure fossils are excluded from the mineral kingdom, for in that domain is included nothing which lives or has once lived. When, however, such changes in the fossil have taken place that it loses the shape and form originally impressed on it by the vital activity of the creature of which it formed a part, it ceases to be a fossil and is once more included in the mineral kingdom. The emigrant returns to the mother-country.

As an illustration, let us consider a slab of limestone (fig. 1), which when cut and polished as a table-top or other object shows markings which are easily recognised



Fig. 1.
Coral-limestone, from Bieber, Hesse.



Fig. 2.
Calcite in altered coral-limestone: Bieber, Hesse.

as sections of corals. The stone indeed consists almost entirely of remains of corals, and is therefore classified with the fossils. Such a limestone may, however, by changes in the earth's crust or on the surface undergo such a transformation in character that all trace of organic structure disappears, and instead we notice forms with sharp edges and plane surfaces which we call calcite crystals (fig. 2). The specimen represented by fig. 2 was collected from the same quarry as that shown in fig. 1. The original coral-limestone has been partly dissolved by the action of subterranean water percolating through it, and from this solution the carbonate of lime has been redeposited in the form of

crystals in the cavities of the rock. The two specimens are thus identical in substance, but different in form.

Fossils are separated from the mineral kingdom and form a domain which it is the business of the palaeontologist to explore. Together with living things they constitute the organic world, of which the lowliest member is the cell and the highest man.

Rocks and Minerals.

In contra-distinction to the organic world, the inorganic world is and has ever been without life; its members possess no organs, nor do they show the cells characteristic of living organisms. In the inorganic world we include both the rocks which form the greater part of the earth's crust, and the minerals distributed among these rocks. But then arises the question how to discriminate between a rock and a mineral, and which constituents of the earth's crust belong to the mineral kingdom in the narrower sense of the term.

The answer to this question has not always been the same, and with the advance of knowledge we are able now to draw a more sharply defined boundary between minerals and rocks. We may regard a mineral as an entity, as it were, of the inorganic kingdom. While a rock we regard as an association of mineral entities.

There is more difference between minerals and fossils, which belong to separate kingdoms, than between minerals and rocks, which are included in the same kingdom, a rock, indeed, being simply an association of minerals.

A rock which is familiar to all is granite. It is easy to see that this rock is composed of materials of different kinds: dark, shining scales; dull, reddish grains; and greyish grains shining like glass. The dark, shining scales consist of the mineral mica; the reddish grains of the mineral felspar; and the greyish grains of the mineral quartz. Granite is therefore a rock, the mineral constituents of which are mica, felspar and quartz.

It is not, however, always as easy to decide whether any given specimen should be regarded as a mineral or a rock, that is to say, whether it consists of a single mineral substance or of an association of minerals, and in such cases it may be necessary to enlist the aid of the microscope or of chemical analysis. When examined under the microscope the specimen, if a mineral, appears homogeneous; if a rock, it presents a heterogeneous appearance. The appeal to chemical analysis is even more decisive. The mineral will be found to consist of one element or of several, and if of several, the elements will be combined, in accordance with the law of chemical combination in multiple proportions, to form a chemical compound. The rock, on the other hand, will consist of elements which are not combined together in any definite proportions. In other words, rocks are not chemical compounds but are mixtures.

The answer to our question "What is a mineral and what is a rock?" can therefore be given as follows: —

Minerals are chemical elements or inorganic chemical compounds occurring in the earth's crust: rocks are mixtures of minerals.

Compounds prepared by the chemist in the laboratory although possessing all the characters of true minerals are yet not minerals, since they have not been formed in the earth's crust. Minerals are always natural products.

Thus metallic copper is found as a chemical element in the earth's crust, and as such is a mineral. But metallic copper which has been extracted from an ore of copper by smelting is not a mineral, since it has been produced by human agency. Again, iron-pyrites is a mineral; it is composed of the elements iron and sulphur combined in the atomic proportion 1:2. On the other hand, obsidian, although it is often homogeneous in structure, is not a mineral, since it is not a definite chemical compound. To take another example, sodium chlorate, though a definite chemical compound, is not a mineral, since it does not occur in nature. Pearls and corals are not minerals, for they have been formed by the agency of animals, and therefore belong to the organic kingdom. Amber in the same way is a product of the vegetable world, but, since the traces of its vegetable origin are lost and it is found in the ground, it is often regarded as a mineral. Following long-established custom, therefore, we shall include it with true minerals and treat of it in detail at the end of this volume.

The investigation of the characters and relationships of minerals belongs to the science of *mineralogy*, which deals also with the mode of occurrence of minerals, their origin and alterations. It is not our intention to deal with all minerals in this work, since many are very rare or have only a scientific interest, while others are so inconspicuous or occur in such small particles that they cannot be well represented in a figure or plate. We shall therefore describe in this place only the most important minerals, but before passing to their consideration it will be well to acquaint ourselves with the general characteristics of mineral species. As in the case of common objects, it is the most superficial characters which first strike the eye, so in considering minerals we will first turn our attention to their most salient characteristic, that is to say, to their external form, endeavouring at the same time to avoid any unnecessary calculations or formulae.

Every mineral possesses a certain set of characters which serve to distinguish it from all other minerals and to enable the mineralogist to recognise it under any conditions. Take, for example, the minerals of which granite is composed: the dark scales of mica are characterised by the fact that they are easily scratched with a knife and that they can be split up into thin leaves, and these again into still thinner leaves, the surface along which the splitting takes place being always smooth and brilliant. The reddish grains of felspar also show smooth cleavage surfaces, but it is only with difficulty that comparatively thick flakes of the mineral can be split off parallel to this surface, and it is with difficulty also that it can be scratched with a knife. From the grey grains of quartz only splinters, like splinters of glass, can be obtained, and the fractured surface is splintery instead of being smooth. Moreover, it is impossible to scratch quartz with a knife, and if the trial be made the knife loses its edge in the process. These three minerals therefore are distinguished by their different fractures and different degrees of hardness. By familiarising ourselves with some of the commonest characteristics of minerals we shall be enabled to recognise them under whatever conditions we meet them. The process of familiarising ourselves with the more obvious features of common minerals will be easier if we choose for observation, not rocks which are mixtures of minerals, but crystals consisting of one single mineral, the characters of which are sufficiently easy to decipher.

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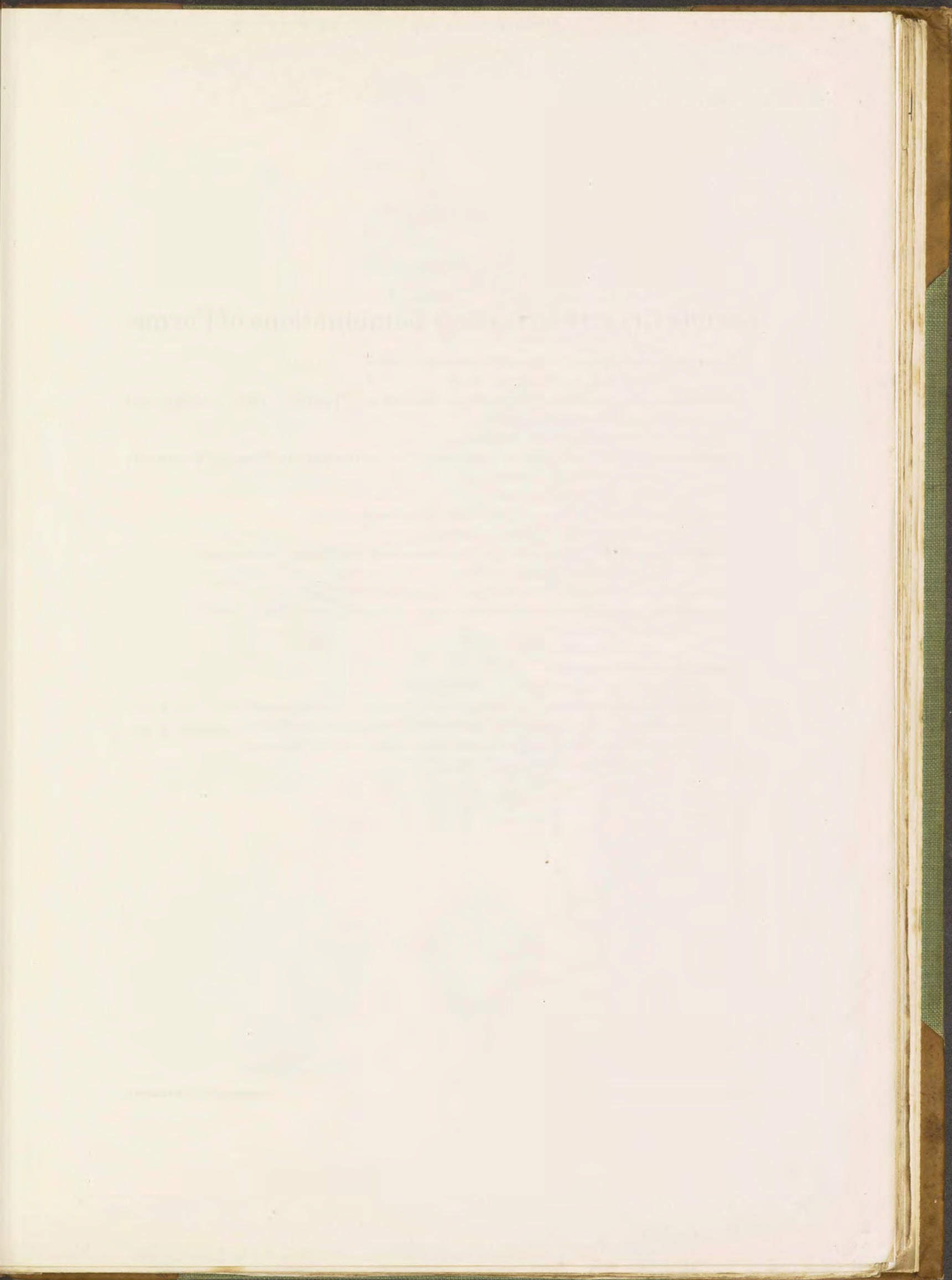


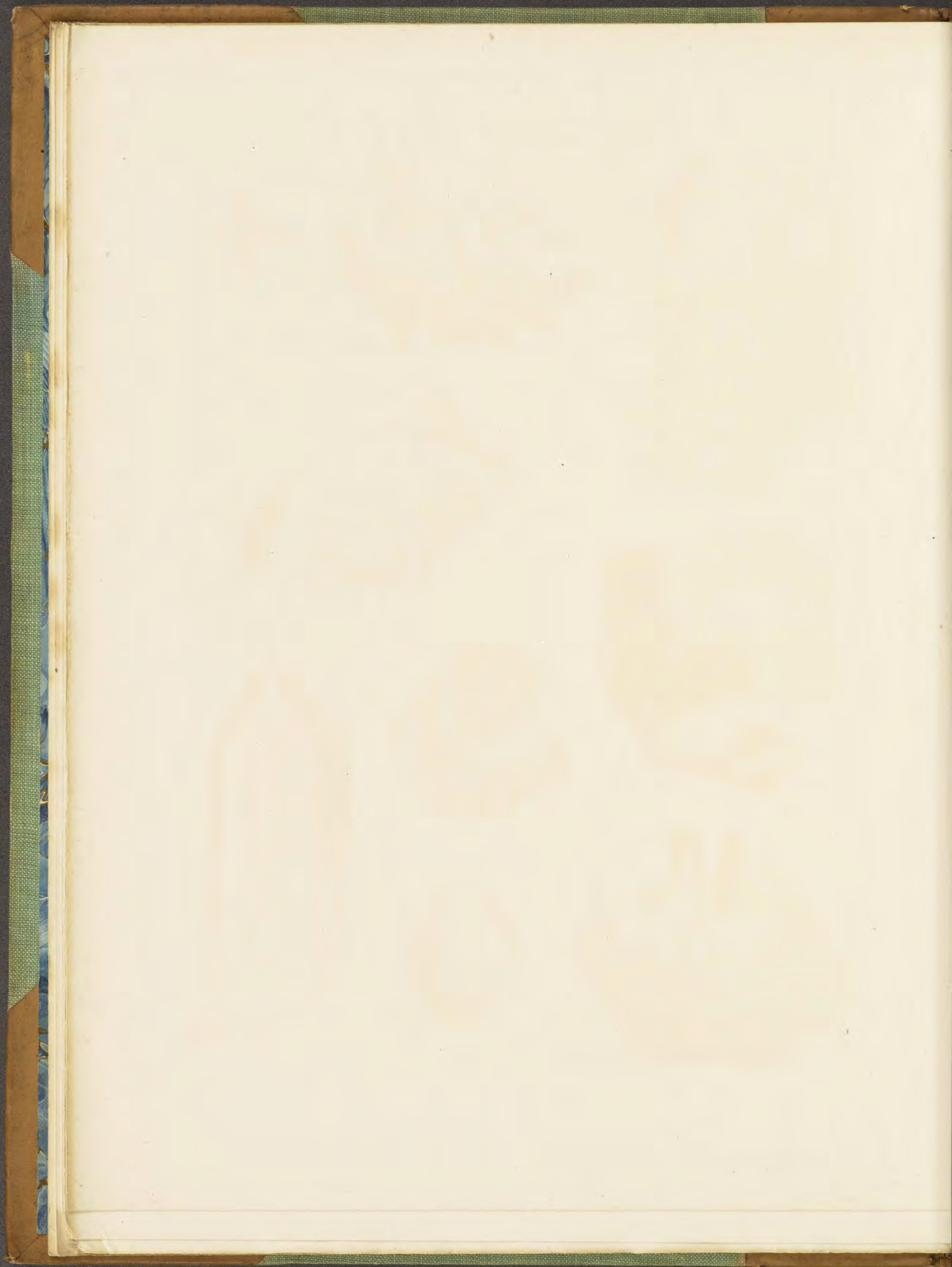
PLATE 1.

Simple Crystal-forms and Combinations of Forms.

Fig.

1. **Druse** of felspar (above) and quartz crystals (below) on granite.
Baveno, Lake Maggiore, Italy.
2. **Combination** of a six-sided prism with the basal plane. The prism faces are bright and the basal plane dull. Calcite.
Andreasberg, Harz, Germany.
3. **Combination** of the cube (bright faces) and the octahedron (dull faces). Fluor-spar; with brown crystals of chalybite.
Stolberg, Harz, Germany.
4. **Simple crystal-form.** Cube of fluor-spar with bright faces.
Weardale, Co. Durham, England.
5. **Simple crystal-form.** Octahedron of fluor-spar with dull faces; on felspar.
Baveno, Lake Maggiore, Italy.
6. **Cleavage-form.** Cleavage octahedron of colourless fluor-spar.
7. **Combination.** Light coloured prism with dark terminal faces. "Negro heads" of tourmaline on granite.
Island of Elba, Italy.
8. **Doubly-terminated crystal** of quartz.
Suttrop, near Warstein, Westphalia.
9. **Attached crystal** of quartz. A combination of striated prism faces with smooth terminal faces. The crystal has been broken away from the matrix to which it was attached, and is therefore bounded by faces at only one end.
Hot Springs, Arkansas, U. S. A.





The Form of Minerals.

Crystals.

In a granite quarry there are sometimes to be seen small cavities and clefts in the solid rock; these cavities not infrequently contain minerals firmly fixed to their walls. Here we recognise again the same minerals as before; the dull, cloudy felspar breaking with smooth fractures (shown in the upper part of fig. 1, plate 1), the hard glassy quartz (lower part of the same figure), and perhaps also shining scales of mica. But these same minerals, which we before saw as grains in the solid rock, have now quite a different form. They will be seen to be bounded by plane faces with sharp edges and corners. They have, indeed, quite the appearance of solid forms or models which have been cut and polished by the hand of man. But it is clear that they must have originated in the solid rock itself, for they were first brought to light when the cavities were broken into by the quarry-man: they had never before been seen by man nor touched by his hand.

The shapes of these bodies are different for each of the different minerals; indeed, this feature alone is sufficient to distinguish one mineral from another, as we found previously in the case of the other characters. The mica has the form of thin, six-sided plates, which, as before, can be easily split into thin leaves parallel to the surface of the plate. The felspar is less plate-like in form and exhibits several broad and dull surfaces. Lastly, the quartz is in the form of short columns with shining faces, the column being bounded by six striated faces and terminated by six smooth faces (see fig. 1, plate 1).

The question may naturally be asked how have these shapes originated and why are they different for each mineral. If we do not believe in mountain elves and goblins, the only answer can be that the minerals have of themselves grown in these shapes, just as a snail builds its own house. The material, though not possessed of life, has the power to form itself in shapes bounded by plane surfaces. On what character of the material this property depends we do not know. Since the destruction of the form requires the exertion of some force, we must assume that some force has acted in the production of the form, this force being inherent in the substance. Such a form, bounded by plane surfaces, which a mineral assumes of its own accord, we call a *crystal*. This word is derived from the Greek, and originally signified ice. The name was at first applied to the transparent quartz found in cavities in the granite of the Alps, under the belief that it really was ice, which by prolonged exposure to intense cold had become so hard that it could not be again thawed. This belief found some support in the fact that the quartz contained green needle-like enclosures suggestive of grass (fig. 9, plate 54). Later, the word crystal came to be applied to all the regular forms which minerals assume.

Other substances, besides minerals, possess this property of forming themselves into crystals; a fact which may be demonstrated by a very simple experiment. This is performed by dissolving ordinary alum in warm water, the liquid being stirred and the alum added in a powdered form until no more will dissolve (100 parts by weight of water will dissolve 12 of alum). The saturated solution is allowed to stand overnight, and in the morning there will be seen, at the bottom of the liquid, crystals of alum with plane and bright surfaces. These are crystals, just as much as are the shapes assumed by minerals; the only difference lies in their mode of origin. The alum

substance has been artificially prepared by the chemist, and the conditions necessary for its formation into crystals have been supplied by this very simple experiment. Minerals, on the other hand, have been formed in the earth's crust, and their crystals have grown under natural conditions without the intervention of man. Crystals of minerals we call for this reason natural crystals, as distinct from artificial crystals. It is to be borne in mind, however, that the latter are only artificial in so far as man has so controlled the conditions that crystals are capable of being formed; in other words, the crystal really makes itself when the conditions necessary for its growth are present.

We may then define a crystal as a body bounded on all sides by plane faces, and of such a form as is assumed by the substance itself.

In performing our experiment with alum, we will have noticed that the crystals were at first quite small, and that they gradually grew larger and larger. As the liquid cools or evaporates it is no longer capable of holding in solution so much alum, and this is then deposited on the growing crystals. All natural crystals of minerals have also grown in exactly the same manner; originally they were quite small, and they have reached their present size by slow growth during long periods of time.

Simple Crystal-forms and Combinations of Forms.

On closer inspection we see that all the faces of a crystal are not exactly alike. In the case of a crystal of quartz (fig. 1, plate 1), for example, it will be seen that the six faces of the column or prism are marked by horizontal lines, whilst the six faces forming the pointed end of the crystal are smooth and without such striations. Or again, on a crystal of mica the six surfaces at the edges of the plates are very rough, but the large face is perfectly smooth: it will also be noticed that the plates can be split up parallel to the large face only, and not to those at the edge. Numerous other examples of this kind might readily be given. For instance, the crystals of calcite represented in fig. 2, plate 1, consists of a six-sided prism with smooth and bright faces, terminated by a single face which is dull and white. The crystal of fluor-spar shown in fig. 3 of the same plate, consists of six bright faces perpendicular to one another, and of eight dull and rough faces with a triangular outline. That this difference in the surface markings of these two sets of faces on fluor-spar is not accidental, but is an essential character of the crystal, is proved by the fact that flakes may be split off the crystal parallel to the dull faces, but not parallel to the bright faces.

On the other hand, there exist also crystals bounded by faces which do not differ in surface characters. An excellent example of this is again afforded by fluor-spar. Fig. 4, plate 1, represents a crystal consisting of six bright faces perpendicular to one another, while the crystal shown in fig. 5 of the same plate is bounded by eight dull faces. From each of these eight faces of fluor-spar we can split off plates parallel to the faces, and all of them with the same degree of ease; the resulting form still consists of eight similar faces, but these are now bright and smooth, being in reality cleavage faces. A cleavage-form of fluor-spar obtained artificially in this way from a colourless crystal is shown in fig. 6, plate 1.

A crystal bounded by faces which are all alike, in the manner just explained, is said to represent a simple crystal-form (figs. 4, 5 and 6, plate 1). One which is

bounded by two sets of faces differing in character is said to be a combination of forms (fig. 2, 3 and 8).

Simple crystal-forms are distinguished by special names. For instance the eight-faced form of fluor-spar is called an octahedron, and the six-faced form a cube. The fluor-spar crystal first mentioned (fig. 3) is a combination of the cube and the octahedron. Other names for the simple crystal-forms will be given later on.

Character of Crystal-faces.

From what has just been said, we see that it is of some importance whether the faces of a crystal are bright or dull, striated or unstriated. Not only do these differences indicate whether the crystal is simple or a combination of forms, but they often tell us other secrets of the crystal. It is often said that the faces of a perfectly developed crystal should be absolutely plane and smooth. But such an ideally perfect crystal would show few of the surface features which help towards an elucidation of its internal structure. Nature avoids the ideally perfect, and even the lifeless crystals show individuality in their surface characters. As a matter of fact, however, perfectly smooth and bright faces do occur on some crystals, especially on those of small size; and they are then of special value to the crystallographer. But more often the faces are dull, drusy or striated. The faces of crystals of different minerals but of the same simple crystal-form often differ widely in character. For example, the faces of a cube of fluor-spar (fig. 4, plate 1) may be smooth; the faces of a cube of iron-pyrites (fig. 1, plate 26) are striated parallel to one edge; those of zinc-blende (fig. 4, plate 20) are striated parallel to one diagonal; those of galena (fig. 2, plate 16) parallel to both edges. In all these cases, although the form of the cube remains the same, there is an essential difference in the character of the crystals. Later we will have more to say as to the significance of these various markings on the faces of crystals.

The essential characters of Crystal-forms.

As yet we have considered the forms of crystals only so far as they are readily seen on a first inspection of minerals. It has been pointed out that different minerals have different forms of crystals. We must now inquire what constitutes the essential characters of crystals, and wherein lies the differences between crystals of different kinds. Clearly the actual size of a crystal is not a character of importance; for as we saw in our experiment with alum both small and large crystals were formed, and that the small ones gradually grew into large ones without any other change than that of their actual size. It is obvious also that the actual size of individual faces is of no essential importance, for this varies with the size of the crystal. The actual outline of the faces must also depend on the relative sizes of the neighbouring faces. If all the faces of a simple form are of the same size they will also have the same shape of outline, but this will not be the case when the faces differ in size. This may be seen from our crystals of alum. It is clear that the crystals, having all grown together, are essentially identical, but their actual shapes depend really on the position in which they have lain in the solution: the rate of growth may be hindered in certain directions by contact with other crystals or with the vessel containing the solution.

This same variation in the actual size of faces belonging to the same simple form is also well illustrated by cubes of transparent rock-salt. Plates may be split off the cube parallel to each of its faces, and with equal ease in all three directions. The

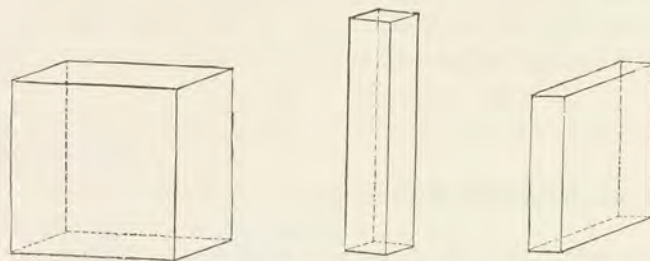


Fig. 3.

Cubic cleavage-forms of rock-salt.

resulting form is the cleavage-form of rock-salt. Now by splitting off plates of different thicknesses from different faces other cleavage forms differing widely from a geometrical cube may easily be obtained. As represented in the accompanying figures (fig. 3) the cleavage, form of rock-salt may be a true geometrical cube, or a long rectangular prism, or a rectangular plate.

Of course, by further cleaving these latter forms to suitable amounts they may be reduced to true geometrical cubes. Now it is of the utmost importance clearly to understand that from a crystallographical point of view all these forms are in reality cubes. The difference between them depends only on the relative sizes and outlines of the faces, features which are quite accidental. In all cases the faces are perpendicular to one another, the angles between them being 90° , and they are all identical in their physical characters. The crystal-form as well as the cleavage-form of rock-salt is thus a simple cube, but owing to accidental causes the actual form may not be that of a regular geometrical cube.

Although the actual sizes and outlines of a crystal may vary without essential modification of the crystal, there can be no variation in the angles between the edges and between the faces. This we have already seen to be the case in the cleavage-forms of rock-salt. And, as a matter of fact, all crystals of the same kind of mineral have always the same angles between the faces, whilst in general for different minerals the angles will be different.

A rough but convincing proof of this fact can readily be demonstrated with the help of two crystals of quartz. If we place one of the crystals against the other in such a position that two striated faces are in contact and the striations on each parallel, we shall then see that corresponding to each face on the one crystal there is a similar face on the other crystal exactly parallel to the first; this could only happen if the angles between corresponding faces be identical in the two crystals. Again, if we place a rhomb-shaped cleavage plate of gypsum over a second such plate, it may readily be seen that both the obtuse and the acute angles are the same on both plates. The same will also be true of cleavage pieces of calcite when superimposed: when one pair of faces and edges are parallel all the remaining faces and edges of the two pieces will be exactly parallel, proving conclusively that the angles between the edges and faces of one piece are identical with the corresponding angles of the other piece. If, however, we place the cleavage piece of gypsum on the cleavage piece of calcite, the two may be turned about into all positions, but never will more than one face and one edge on each piece be simultaneously in parallel positions: this clearly results from the fact that angles of gypsum differ from those of calcite.

In the examples just given we have judged of the equality or difference of the angles by the eye alone, but when exact measurements of the angles of crystals are to be made a special instrument is used. Such an instrument is called a goniometer, or angle measurer, and the angles measured with it are the angles between the faces of the crystals. The construction of the more exact forms of this instrument is based on the

laws of reflection of light, and these are called reflecting goniometers. On such an instrument the angles of a good crystal with bright and smooth faces can be accurately determined to within a few seconds. A description of these instruments is given in the text-books on crystallography.

A more simple form of instrument, and one based on another principle, is that known as the contact goniometer, so called because portions of the instrument are laid in contact with the faces of the crystal to be measured. This form of instrument is especially useful for the measurement of large and rough crystals with which the reflecting goniometer is not applicable. A contact goniometer (fig. 4) is usually constructed of metal, and consists of a semicircular arc divided into 180° . An axis at the centre of the arc carries two bars, which may be clamped by means of a screw.

One of these bars is fixed to the arc, but the other (the upper one in the figure) moves about the central axis over the graduated arc. In order to measure the angle included between any two faces of a crystal, for example, between the prism faces of the quartz crystal represented in fig. 9, plate 1, the fixed bar is first brought into contact with one face, and then the movable bar is turned round until it comes into contact with the second face. It is important to bear in mind that while this is being done the plane of the instrument must be perpendicular to the two faces, and this will be

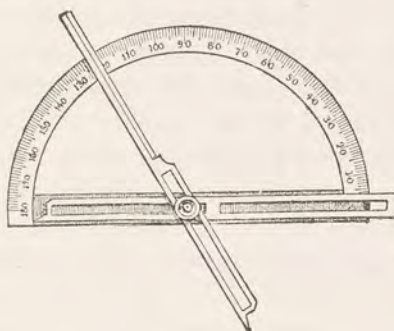


Fig. 4.
Contact goniometer.

the case when the bars are perpendicular to the edge formed by the intersection of the two faces. The reading on the graduated arc will then give the angle between the two faces: in the figure the angle reading is 120° , this being the angle between the two faces of the crystal shown in fig. 9, plate 1.

By measuring the angles of a crystal with a goniometer in this way, it will be found that between corresponding faces on the same or on different crystals of the same mineral the angles are always identical. On quartz, for example, any pair of adjacent faces at the end of the crystal will always be found to be inclined at an angle of $133^{\circ} 44'$. On calcite two adjacent cleavage faces enclose an angle of $105^{\circ} 4'$, or the supplement of this, namely $74^{\circ} 56'$; and on a cleavage plate of gypsum the obtuse angle on the bright cleavage plane is $113^{\circ} 46'$. It is therefore possible by means of this measurement of angles to recognise the kind of mineral, and to distinguish different minerals one from another. It is also possible, when knowing the angle, to determine the forms of a crystal, in cases where the relations between them are obscured by irregularities of growth.

This constancy of the angles between corresponding faces of crystals of the same substance is of prime importance, and is in fact the fundamental law of the science of crystallography. The fact was first announced in 1669 by Nicolaus Steno, a Danish physician.

Distortion or Irregular Growth of Crystals.

From the example of the cleavage-form of rock-salt quoted above, we have seen that the faces, though identical in physical characters, may be very different in size; so that the cube may be bounded by large or small faces of varying shapes, but

always with a square or rectangular outline. A crystal on which all the faces with the same physical characters are developed of the same size is said to be an ideal crystal. In diagrams and models of crystals it is usual to represent the form with this ideal development, with similar faces all of the same size. In nature, however, such ideally perfect crystals are rarely if ever met with: usually the similar faces show small variations in size, and often this variation is very considerable. But in all cases the angles between the faces, whatever their size, are always the same.

The crystal of quartz (rock-crystal) represented in fig. 9, plate 2a, has the six faces of the prism of very nearly the same size, so that here we have a nearly ideally perfect hexagonal prism. The angle between two adjacent faces, measured over the vertical edges shown in the figure, is 120° . In the crystal of quartz shown in fig. 1 of the same plate the prism is much distorted; and, owing to the very large development of one pair of parallel faces and the small size of the four remaining faces, the crystal has the shape of a plate rather than of a prism. Here again, however, the faces are inclined to one another at the same angle of 120° , and they are marked by the same horizontal striations as on the more perfect crystal.

An almost ideally developed octahedron is shown in fig. 1 of plate 2; it is bounded by eight faces with the outlines of equilateral triangles which do not differ appreciably in size. The angle between any pair of adjacent faces of the octahedron is $109^{\circ} 28' 17''$. Distorted octahedra are well represented in figs. 3 and 4, plate 29, where the faces though similar in physical characters differ greatly in size, but are inclined to each other at the same angle of $109^{\circ} 28' 17''$.

The crystals shown on the plates accompanying this volume are represented with all their natural distortions and irregularities of growth. It will not be difficult, however, by an effort of the imagination to call up a picture of what the crystal in its ideal form would be. The latter are given as outline drawings in the text, and these should be compared with the plates.

The relations existing between the positions of the faces of a crystal.

The faces of a crystal are not distributed in a haphazard manner, but are arranged according to a definite plan. The existence of some plan in their arrangement becomes obvious when we note the directions of the edges between the faces of the crystal. It will be seen that for the same crystal the directions of the edges are fixed and unalterable. In the case of a quartz crystal (fig. 9, plate 1), for example, the edges between the striated prism faces and the smooth faces at the end of the crystal are parallel to the striations on the prism faces and perpendicular to the edges of the prism: when the prism faces are placed vertically, as in the figure, the edges in question will be horizontal. In the case of the fluor-spar crystal consisting of a combination of the cube and octahedron (fig. 3, plate 1), which we have already considered, the edges between these two sets of faces will be seen to be parallel to a diagonal of the cube faces. On the calcite crystals shown in fig. 2, plate 1, the dull face at the end is perpendicular to the smooth faces forming the prism.

It will also be noticed that the faces which together form a combination often intersect in parallel edges. For example, the small face shown at the upper left-hand side of the striated prism face of the quartz crystal in fig. 9, plate 1, intersects the two adjoining faces in edges which are parallel. Again in the quartz crystal shown in fig. 8

of the same plate the upper and lower edges of the prism faces are parallel: and all the six edges between the prism faces themselves are parallel to one another. Faces which intersect in parallel edges in this way are said to lie in a *zone* on the crystal; and by a zone is understood all those faces which would, if prolonged, intersect in parallel edges. For example, the six prism faces of quartz (fig. 8, plate 1) constitute a zone, since they intersect in parallel edges. Another zone on the same crystal is formed by a prism face and the terminal faces above and below it, and the corresponding faces on the other side of the crystal also lie in the same zone: on quartz crystals there are three such zones.

As a consequence of this arrangement of the faces of crystals in zones certain other relations between the faces will follow, and it is possible to express the positions of the faces by symbols or by numbers. For the latter purpose it is necessary to fix the position of certain faces and then find the relations of the other faces to those selected. There are various methods of doing this, and we will now describe one of the simplest which can be readily followed.

Consider that in the interior of a crystal we draw three straight lines intersecting at the centre. These lines are called the crystallographic axes, or simply axes; and they are chosen parallel to three edges, not all in the same plane, on the crystal. Any three lines might be arbitrarily chosen, but as we already have the edges in which the faces intersect in zones and we wish to find the relation existing between these edges and zones of faces, it will be far more convenient to choose such edges for axes. Next consider how each face on the crystal intersects these three axes; the ratios of their intersections on the axes will fix their relative positions.

With a cube of fluor-spar (fig. 4, plate 1) the axes most convenient to select are those parallel to the three edges of the cube (fig. 5). Since the three faces of the cube are similar, so must the three sets of edges in which the faces intersect be also similar to one another, and consequently the three axes must be all the same. We have therefore for the cube three axes at right angles to one another and of the same length; and each of these axes we may briefly indicate by the letter *a*. Consider now the relation of one of the faces of the cube with reference to this system of axes: it is intersected

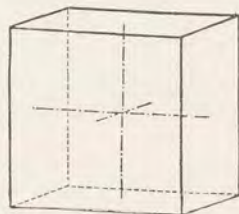


Fig. 5.
Cube with axes.

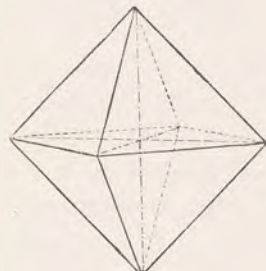


Fig. 6.
Octahedron with axes.

perpendicularly in its centre by one axis, and it is parallel to the other two axes, or in other words meets them at an infinite distance. The position of this face of the cube may then be expressed by the ratio of its intercepts on the three axes, namely $a:\infty a:\infty a$. And in the same way the other five faces of the cube will have the same symbol, which is thus the symbol for the whole form.

An octahedron face of fluor-spar (fig. 3, plate 1) intersects all three edges of the cube, and consequently it will intersect the three axes drawn parallel to the edges of the cube. Further, it may be seen that the face will cut the axes at equal lengths, since the edges between the cube and the octahedron faces are parallel to the diagonals of the cube faces. The same also easily follows from the fact that the octahedron face is equally inclined to the adjacent cube faces at equal angles. The position of the octahedron face is therefore given by the ratio of the axial intercepts $a:a:a$. This is

clearly the simplest ratio in which any face can intersect the three axes and the length a is therefore taken as unit length. The octahedron face is therefore taken as the unit face or parametral face, while the whole form composed of eight octahedral faces is spoken of as the primary form. This form is shown in fig. 6, where the axes are seen joining the opposite corners of the octahedron, and each face cuts all three axes at equal lengths. All other faces on a crystal will intersect the three axes in a ratio different from that of the primary form.

On cubes of fluor-spar, for example, there are sometimes six small faces on each of the eight corners of the cube (fig. 7). Each one of these small faces is obliquely inclined to the three edges of the cube, and therefore also to the axes; further it intersects the axes at different lengths, and its intercepts may be expressed generally by the ratio $a : ma : na$, where m and n are different whole numbers. The value of m and n which gives the lengths of the intercepts cannot be judged by the eye alone, but has to be calculated from the angles between the faces according to methods it is unnecessary to enter into here. In fig. 7 the values of m and n are 4 and 2 respectively, so that the symbol of the small faces is $a : 4a : 2a$.

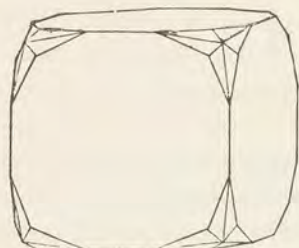


Fig. 7.
Cube in combination with
hexakis-octahedron.

Now an important relation between the faces of crystals lies in the fact that in all cases the values of m and n can always be expressed by simple whole numbers or by simple fractions, such as 2, 3, 4, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, etc. They are never irrational numbers such as 1.27386... This law is known as the *rationality of intercepts*, and is one of the important laws of crystallography. It may be expressed as follows:

The faces of all crystals of any one substance are related to one another in such a manner that the ratio of their intercepts on the axes compared with the axial intercepts of the primary form can always be expressed by simple rational numbers.

The ratios of the intercepts on the axes of any face are known as the parametral ratios of that face; and the ratios of the intercepts of the primary face are called the axial ratios of the crystal. The simple rational numbers, which multiplied with the axial ratios give the parametral ratios of any particular face, are referred to as the indices of that face.

In this regularity in the distribution of the faces of a crystal lies the essential difference between crystals and other solid bodies bounded by plane faces, such as those artificially made by grinding. We recognise here again the influence of the force which has given origin to the crystal. In the same manner that chemical elements combine to form chemical compounds according to the law of multiple proportions, so also the faces of a crystal are related to those of the primary form in such a way that the axial intercepts of the one are simple multiples of those of the other. The structure of crystals thus conforms to laws of the utmost simplicity.

When, as in the octahedron, the three axes of the primary form are all of equal lengths the axial ratios may be expressed by the same letter, $a : a : a = 1 : 1 : 1$. When, however, the three axes of the primary form are of different lengths they have to be expressed by different letters, for example, $a : b : c$. The numbers which these letters represent can be calculated from the angles measured on the crystal, and they are irrational. For example, in aragonite the axial ratios are $a : b : c = 0.6224 : 1 : 0.7206$; that is the primary face cuts the three axes in lengths having these ratios. Any other face on a crystal of aragonite will have intercepts which are simple multiples of these numbers.

In many crystals the three crystallographic axes intersect at right angles, but in others this is not the case, and it is then necessary to determine the angles (α , β , γ) between the axes before the crystal can be completely determined.

In crystallographic descriptions it is usual to place one axis vertically, another from right to left, and the third directed towards the observer. The first is called the vertical axis, and the two others the lateral axes.

When the primary form of the crystals of a mineral is known, it is possible to determine the position of all the other faces on the same mineral by comparing their axial intercepts with those of the primary form. A notation serving this purpose was early devised by the mineralogist Christian Samuel Weiss; and this particular notation has an advantage over others in being readily comprehended.

Another system of notation is that proposed by C. F. Naumann, which has the advantage of brevity. Here the primary form is indicated by its initial letter; the regular octahedron by *O*, a pyramid by *P*, and a rhombohedron by *R*. For the other faces the numbers representing the multiple intercepts on the vertical axis are placed before these letters, and those for the lateral axis after the letters. The cube with the axial intercepts $a : \infty a : \infty a$ has therefore the Naumannian symbol $\infty O \infty$.

In a third system of notation known as the Millerian, since it was developed by W. H. Miller, the late Professor of Mineralogy at Cambridge, the intercepts of faces are given as fractional parts of the intercepts of the primary face, instead of as multiples thereof; thus

$$a : 2b : 4c \text{ becomes } \frac{a}{4} : \frac{b}{2} : \frac{c}{1},$$

and the symbol of the face is written as (421). These numbers (read four, two, one) are spoken of as the indices of the face. They refer to the intercepts on the *a*, *b* and *c* axes respectively; that is, the *a* axis is cut at one-fourth its length, the *b* axis at one-half, and the vertical *c* axis at its whole length. When a face is parallel to an axis, the corresponding index is zero, since $\frac{a}{0} = \infty a$.

The following examples will help to explain these symbols and indices:

$$a : a : a = \frac{a}{1} : \frac{a}{1} : \frac{a}{1} = 111$$

$$a : \infty a : \infty a = \frac{a}{1} : \frac{a}{0} : \frac{a}{0} = 100$$

$$a : 2a : 4a = \frac{a}{4} : \frac{a}{2} : \frac{a}{1} = 421.$$

The Millerian notation is the one most commonly used by crystallographers, since it readily adapts itself to calculations; but the Naumannian notation is perhaps easier to grasp when it is not intended, as in the present volume, to enter very far into crystallography. We will therefore here make use of the latter notation.

Crystal-Systems.

According to the number of their similar faces and to the frequency of repetition of the same angle between the faces, crystal-forms possess different degrees of regularity, or as it is better expressed, of symmetry. We have already seen that this is the case from the striations on the cube faces of crystals of different minerals. A smooth cube

face, as that in fig. 4, plate 1, can be divided by lines coincident with the two diagonals, or by lines parallel to each of the two edges, in such a manner that the one half is an exact repetition or mirror-reflection of the other half. On the other hand, a cube face which is striated parallel to one of its edges (fig. 6, plate 3) can only be symmetrically divided by lines parallel to and perpendicular to these striations, and not by lines following the diagonals of the face. A cube face which is striated parallel to one of its diagonals (fig. 2, plate 19) can be divided symmetrically by the two diagonals of the face, but not by lines parallel to the edges.

In the examples just given we have the symmetry of a face with respect to a line, but for the whole crystal the symmetry is with respect to a plane. We can imagine the crystal cut by a plane into two halves in such a manner that one half is the mirror-reflection of the other half. If one half be placed with its cut surface against a mirror we apparently see the whole crystal. A plane which in this way divides a crystal into two similar halves is called a *plane of symmetry*. The number of planes of symmetry possessed by any one crystal varies for different kinds of crystals, and according to their number we are able to distinguish different degrees of symmetry in crystals.

A cube with smooth faces will be seen to have nine planes of symmetry. The crystal may be divided into equal and similar halves by each of the three planes parallel to the faces of the cube; and it may also be symmetrically divided by each of six planes coincident with the diagonals of the cube and the diagonals of the faces, that is, parallel to the narrow faces in fig. 8. A cube which has its faces striated parallel to one edge can be symmetrically divided by only three planes, namely those parallel to the faces of the cube. Again, a cube with faces striated parallel to one diagonal is symmetrical with respect to the six planes passing through the diagonals. These three cubes thus differ not only in their surface characters, but also in the degrees of symmetry which they possess.

Nine planes of symmetry, as in the cube with smooth faces, is the greatest number possible in any crystal. Other crystals may have seven, six, five, four, three, two, one, or no planes of symmetry. The more important of the different types of symmetry are illustrated in figs. 8—13.

The crystal represented in fig. 9 has seven planes of symmetry; one is perpendicular to the prism faces, three more intersect in the edges of the prism and the pyramid, and the remaining three bisect the faces of the prism and of the pyramid; the first one being horizontal and the six others vertical in position. In fig. 10 there are five planes of symmetry: one horizontal and perpendicular to the prism faces lettered *a* and *m*; two vertical ones bisecting the faces *s* and *m*; and two vertical ones bisecting the faces *a* and *e* (in the figure those shown to the front and to the right). In fig. 11 the crystal possesses three planes of symmetry: one is horizontal through the horizontal edges between the pyramid planes *P*; the second is vertical passing through the front edges of *P* and over *c*; and the third, also vertical, passes through the faces *n* and *c*. The single plane of symmetry of the crystal in fig. 12 is vertical and bisects the faces *c*, *a*, *r'* and *r*. Finally the crystal represented in fig. 13 has no plane of symmetry.

Another kind of regularity in the distribution of the faces of a crystal is evident from the fact that two or more similar faces may be present about one edge or corner. If therefore the crystal be rotated about an axis passing through this edge or corner, these similar faces will be interchangeable in position. During a complete revolution of 360° about such an axis some crystals will occupy such a covering position only twice, others will do so three, four or six times. An axis about which a crystal may be

so rotated is called an *axis of symmetry*, and it may be two-, three-, four-, or six-fold in character. The crystal represented in fig. 11 possesses three axes of two-fold symmetry; the three similar faces meeting in a corner in fig. 8 are symmetrical about a three-fold axis; in fig. 10 there is one axis of four-fold symmetry; and in fig. 9 one of six-fold symmetry.

Finally, it will be seen with most crystals, which are completely bounded on all sides by faces, that corresponding to each face there is on the opposite side of the crystal, a parallel face similar in character to the first. Such crystals are said to possess a *centre of symmetry*.

In some crystals the only element of symmetry is a centre of symmetry; in others there may be one plane of symmetry, one axis of symmetry, and a centre of symmetry. The highest degree of symmetry possible in any crystal results from the

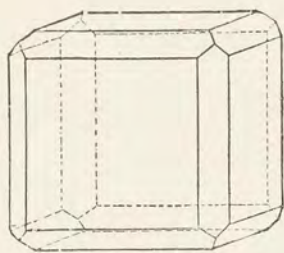


Fig. 8.

Crystal with 9 planes of symmetry.

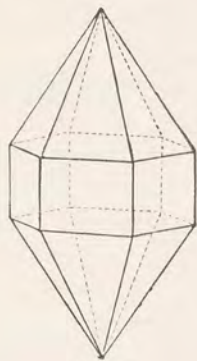


Fig. 9.

Crystal with 7 planes of symmetry.

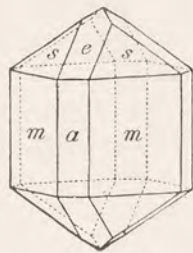


Fig. 10.

Crystal with 5 planes of symmetry.

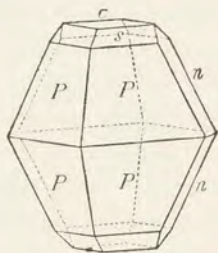


Fig. 11.

Crystal with 3 planes of symmetry.

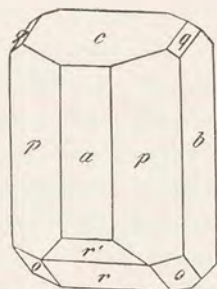


Fig. 12.

Crystal with one plane of symmetry.

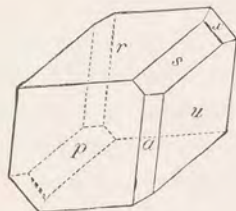


Fig. 13.

Crystal with no plane of symmetry.

association of nine planes of symmetry, thirteen axes of symmetry, and a centre of symmetry. Other crystals lie between these extremes in the degree of symmetry which they exhibit.

In this way all crystals may be divided into thirty-two classes, each having a different degree of symmetry. It is unnecessary in this place to enumerate these thirty-two classes of symmetry, since we do not wish to burden the reader with too many technical terms. All that we need give here are the six systems into which they may be grouped. These six systems may be defined by the lengths and mutual inclinations of the crystallographic axes.

1. *Cubic system*. — With three equal crystallographic axes (a, a, a) all at right angles to one another.

The highest degree of symmetry possible in this system is given by 9 ($= 3 + 6$) planes of symmetry, 13 ($= 3 + 4 + 6$) axes of symmetry, and the centre of symmetry.

2. *Hexagonal system.* — With three equal axes (a, a, a) lying in a horizontal plane at 60° to one another, and a fourth, vertical axis of different length (c) perpendicular to this plane. The highest possible symmetry is here, 7 ($= 1 + 3 + 3$) planes of symmetry, 7 ($= 1 + 3 + 3$) axes of symmetry, and the centre of symmetry.

3. *Tetragonal system.* — With two equal horizontal axes (a, a) and a vertical axis of different length (c), the three axes being perpendicular to one another.

The highest possible symmetry is here, 5 ($= 1 + 2 + 2$) planes of symmetry, 5 ($= 1 + 2 + 2$) axes of symmetry, and the centre of symmetry.

4. *Rhombic system.* — With three unequal axes (a, b, c) at right angles to one another.

The highest possible symmetry is, 3 ($= 1 + 1 + 1$) planes of symmetry, 3 ($= 1 + 1 + 1$) axes of symmetry, and the centre of symmetry.

5. *Monoclinic system.* — With three unequal axes (a, b, c), two of which (a, c) are inclined to each other at an oblique angle (β) and the third (b) is perpendicular to the first two.

The highest possible degree of symmetry is, 1 plane of symmetry, 1 axis of symmetry, and the centre of symmetry.

6. *Anorthic system.* — With three unequal axes (a, b, c) all inclined at oblique angles (α, β, γ).

The highest degree of symmetry possible in this system is only that given by the presence of a centre of symmetry.

Holohedrism and Hemihedrism.

Each of the six systems of crystals just enumerated embraces several classes of crystals differing from one another in their higher or lower degrees of symmetry, but all referable to a common type of axes. The crystals belonging to the several classes of the same system differ externally in the characters and number of their faces.

The simple form which possesses the highest degree of symmetry possible in each system is called the holohedral form of that system, since we have here the full number of faces that can be associated together with the particular arrangement of axes. The regular octahedron is, for example, a holohedral form, since it consists of eight faces each intersecting the axes in the ratios $a : a : a$, and no more are possible.

In other classes of the same system, in which the degree of symmetry is lower, the simple form may be developed with only half or one-quarter of the full number of faces. Such forms are called hemihedral (or half-faced) forms and tetartohedral (or quarter-faced) forms, respectively. They are related to the holohedral (or full faced) form according to definite rules; and the faces which are present have the same position on the crystal. The regular tetrahedron, for example, is a hemihedral form: it is related to the regular octahedron and can be derived from this by the omission of alternate faces of the octahedron. In a combination of forms the faces of the octahedron truncate all the corners of the cube, but the tetrahedron truncates only alternate corners. The tetrahedron is thus the hemihedral form of the octahedron.

In the present work, where we do not intend to enter very far into crystallography, it will be simpler to consider the holohedral, hemihedral and tetartohedral forms of each system rather than describe in detail the exact symmetry of each class.

All the crystals, to whatever mineral they belong, which fall into any one class possess the same degree of symmetry and have the same distribution of faces in

accordance with this type of symmetry. In certain cases it is possible that the form may have the same number of faces although belonging to different classes of the same system; and then it is only possible to recognise the lower or higher degree of symmetry by the surface characters of the faces or by the help of special physical characters.

The three regular cubes already mentioned (p. 18) have the same number of faces, but as shown by the characters of their faces they possess different degrees of symmetry. The smooth faced cube belongs to the holohedral class of the cubic system with nine planes of symmetry; the cube which has its faces striated parallel to one of the edges is hemihedral with three planes of symmetry; and the cube with faces striated parallel to one diagonal is hemihedral with six planes of symmetry.

Determination of the Symmetry of Crystals.

We have now learnt that the crystals of different systems and classes differ in the degree of symmetry which they possess, but how are we to recognise and to determine what the degree of symmetry is in each case?

We have already seen that this is possible to a certain extent by observing the number of the faces, their positions and their surface characters. In very many cases the symmetry of a crystal may be readily and correctly determined in this way, and the crystal may be assigned to one or other system or class. The three cubes of fluor-spar, iron-pyrites and zinc-blende, though identical in the number and positions of their faces, we have already determined by the aid of the characters of the faces. But suppose the faces had all been smooth and as far as we could judge by inspection the same in character, how are we to proceed?

In such a case there may really exist a difference, although it cannot be easily detected without the help of experiment. An experimental method which is here often of great help towards determining the symmetry of crystals consists in observing the effect of corrosion. If a crystal or a cleavage fragment of a crystal be placed in dilute acid or some other solution capable of slowly dissolving the material, it will be found that after a short time the faces of the crystal have become marked by a number of small pits or depressions. The surface markings so produced are called *etched figures* or corrosion figures, and they are often regularly and beautifully formed. In all cases they will exhibit the same degree of symmetry as that possessed by the face on which they occur. These etched figures are usually of only microscopical dimensions, but sometimes when produced naturally they are sufficiently large and distinct to be readily visible to the naked eye, for example, on the front prism face of the crystal of quartz shown in fig. 3 of plate 55. It will be noticed that these are set obliquely to the edges of the prism and that they are not symmetrical with respect to any line, either parallel to or perpendicular to the prism edges. From this it follows that neither a vertical nor a horizontal plane of symmetry is perpendicular to the prism planes of a crystal of quartz. But as far as can be judged from the crystal shown in fig. 8, plate 1, and in text-figure No. 9 quartz might possess both such planes of symmetry. The etched figures therefore prove that a quartz crystal really possesses a lower degree of symmetry than it apparently exhibits; and as a matter of fact quartz is hexagonal without any planes of symmetry.

Description of Crystal-forms.

In describing a simple crystal-form we will consider it to be ideally developed, having all the faces which are physically identical of the same size. We must then make out from the outlines of the faces and the angles between them what is the relation between the faces and their positions with respect to the crystallographic axes of reference. Sometimes with actual crystals this can be determined on a mere inspection of the crystal, but more often it is necessary to actually measure the angles between the faces.

In a combination we have to deal with two or more sets of faces which are physically different from each other and which may differ more or less considerably in size. The larger faces of the predominating form determine the habit of the crystal; and in describing a combination it is convenient to state how this predominating form is modified by the other forms which are present. Thus it is usual to say that a corner or edge is truncated (figs. 21, 22), an edge bevelled or replaced by two planes (fig. 23), or a corner replaced by two or more planes (fig. 24). We have already seen, for example, that the crystal shown in fig. 3, plate 1, is a combination, and it may be described as a form in which the cube predominates and in which the corners of the cube are truncated by the octahedron.

To which forms these smaller modifying faces belong can easily be made out, after a little practice, from their positions on the crystals or by determining their relations to the crystallographic axes.

Cubic System.

In crystals of the cubic system the three crystallographic axes are of equal lengths and are all at right angles to one another. We shall first consider the holohedral forms of the system, and afterwards the hemihedral forms which may be derived from them.

The holohedral forms possess nine planes of symmetry, three parallel to the cube faces, and six parallel to the faces of the rhombic-dodecahedron. In addition there are thirteen axes of symmetry and a centre of symmetry. The following seven different kinds of forms fall into this class.

1. *The octahedron* (fig. 14). This is identical with the regular octahedron of geometry, and is bounded by eight equilateral triangles, with angles of $109^{\circ} 28' 16''$ between the faces. The crystallographic axes join opposite corners of the figure, and the faces intersect these axes in the ratios $a : a : a$. The octahedron is therefore the primary form and is distinguished by the Naumannian symbol O . Examples, fluor-spar and magnetite.

2. *The cube* (fig. 15) is bounded by six similar faces at right angles to one another. The axes are parallel to the edges and intersect the faces in their centres. Each face is therefore parallel to two of the axes and cuts the third, and the ratios of the intercepts is $a : \infty a : \infty a = \infty O \infty$. Example, fluor-spar.

3. *The rhombic-dodecahedron* (fig. 16) is bounded by twelve rhomb-shaped faces. The angle between two adjacent faces which meet in an edge is 120° . Each

face cuts two axes at equal lengths and is parallel to the third, and the symbol is therefore $a : a : \infty a = \infty O$. Example, garnet.

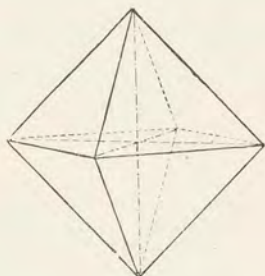


Fig. 14.
Octahedron.

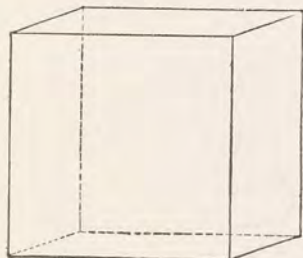


Fig. 15.
Cube.

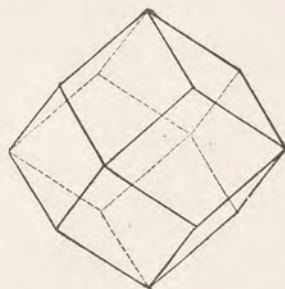


Fig. 16.
Rhombic-dodecahedron.

4. A *trikis-octahedron* or *three-faced octahedron* (fig. 17) bounded by twenty-four isosceles triangles, and resembling an octahedron with a triangular pyramid on each of its faces. Each face intersects two of the axes at equal lengths and the third at a greater distance from the centre; for example, $a : a : 2a = 2O$. This is rarely met with as a simple form.

5. A *tetrakis-hexahedron* or *four-faced cube* (fig. 18) bounded by twenty-four isosceles triangles, and resembling a cube with a square pyramid on each of its faces.

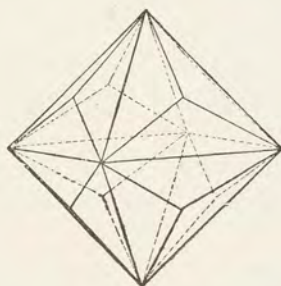


Fig. 17.
Triakis-octahedron or three-faced
octahedron.

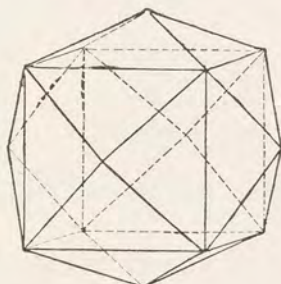


Fig. 18.
Tetrakis-hexahedron
or four-faced cube.

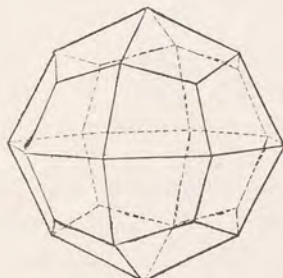


Fig. 19.
Icositetrahedron.

A face cuts two axes at different lengths and is parallel to the third; for example, $a : 2a : \infty a = \infty O2$. Example, native copper (fig. 2, plate 10).

6. An *icositetrahedron* (fig. 19), bounded by twenty-four four-sided (deltoid) faces. Each face intersects two of the axes at equal lengths and the third axes at a shorter distance from the centre; for example, $2a : 2a : a = 2O2$. Example, analcite.

7. A *hexakis-octahedron* or *six-faced octahedron* (fig. 20), bounded by forty-eight scalene triangles. A face intersects the axes in three different lengths; for example, $a : 2a : 4a = 4O2$. This is rare as a simple form.

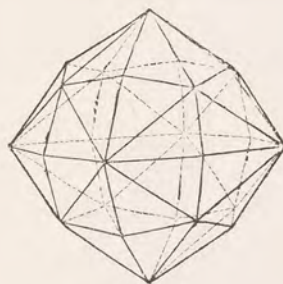


Fig. 20.
Hexakis-octahedron
or six-faced octahedron.

Combinations of forms in holohedral cubic crystals.

Taking the *octahedron* as the predominating form of the combination, its corners are truncated by the cube (fig. 21), and its edges truncated by the rhombic-dodecahedron (fig. 22). The triakis-octahedron bevels the edges of the octahedron (fig. 23), and

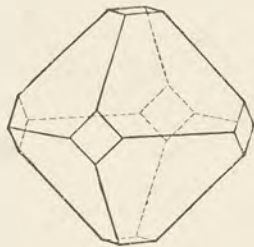


Fig. 21.
Octahedron with cube.

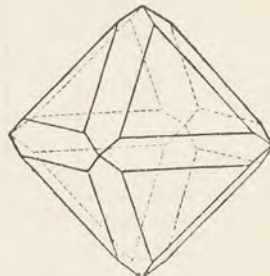


Fig. 22.
Octahedron
with rhombic-dodecahedron.

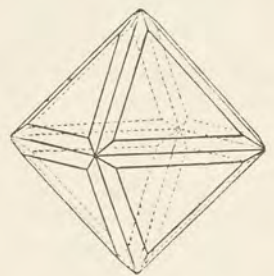


Fig. 23.
Octahedron
with triakis-octahedron.

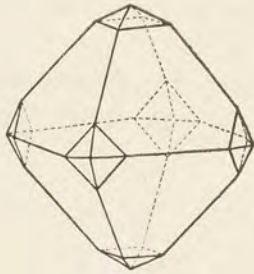


Fig. 24.
Octahedron with icositetrahedron.

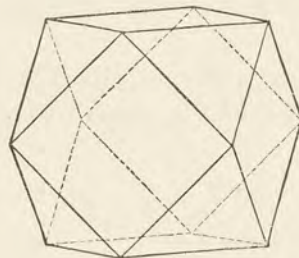


Fig. 26.
Cubo-octahedron.

the icositetrahedron replaces each of the corners by four faces (fig. 24).

It may happen that in a combination the faces of the different forms are developed to about the same extent as regards their size, and in such cases it cannot be said that either one or the other of the forms predominates. A case of this kind is illustrated in fig. 26, which

is a combination of the octahedron and the cube in which neither predominates: this is called a cubo-octahedron.

When the *cube* predominates, its corners may be truncated by the octahedron (fig. 25), or its edges by the rhombic-dodecahedron (fig. 27). Its edges are bevelled by

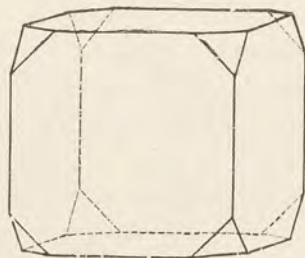


Fig. 25.
Cube with octahedron.

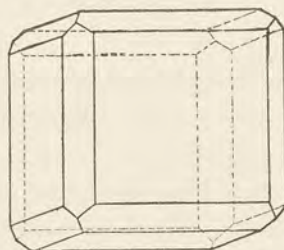


Fig. 27.
Cube with rhombic-dodecahedron.

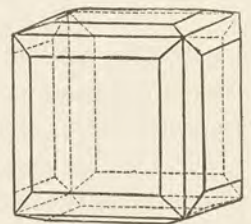


Fig. 28.
Cube with tetrakis-hexahedron.

the tetrakis-hexahedron (fig. 28); and its corners replaced by three faces by the icositetrahedron (fig. 29), or by six faces by the hexakis-octahedron (fig. 30).

With the *rhombic-dodecahedron* as the predominating form, its three-edged corners are truncated by the octahedron (fig. 31), and its four-edged corners are truncated by the cube. The icositetrahedron with the symbol $2O2$ truncates the edges (fig. 32), and the hexakis-octahedron $3O\frac{3}{2}$ bevels the edges (fig. 33): fig. 34 is a combination of

the rhombic-dodecahedron with both these forms, in which each edge is replaced by three faces.

Other combinations may occur, but they are of less importance.

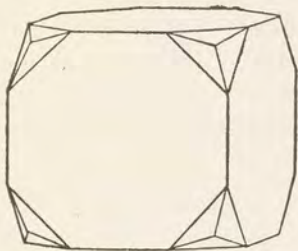


Fig. 29.
Cube with icositetrahedron.

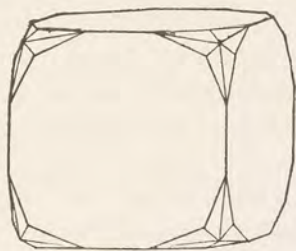


Fig. 30.
Cube with hexakis-octahedron.

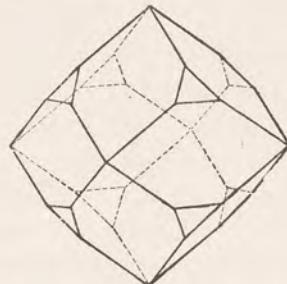


Fig. 31.
Rhombic-dodecahedron with octahedron.

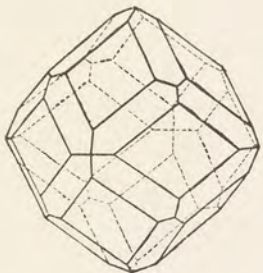


Fig. 32.
Rhombic-dodecahedron with icositetrahedron.

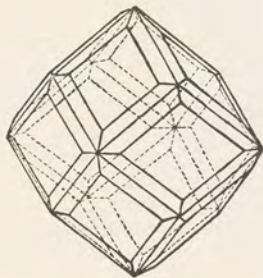


Fig. 33.
Rhombic-dodecahedron with hexakis-octahedron.

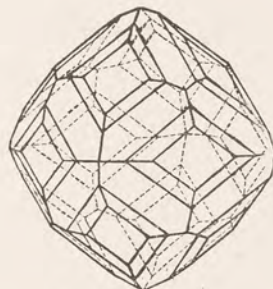


Fig. 34.
Rhombic dodecahedron with icositetrahedron and hexakis-octahedron.

Minerals which crystallize in this holohedral division of the cubic system are: gold, silver and copper; galena (plate 16), magnetite (plates 29 and 29a), garnet (plate 47), sodalite (plate 62), analcite (plate 63), rock-salt (plate 70) and fluor-spar (plate 71).

Tetrahedral Hemihedrism.

Some crystals of the cubic system may have a form closely resembling the octahedron, but with adjacent faces differing in character (fig. 35): for example, some

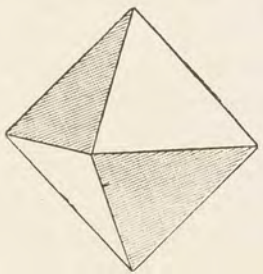


Fig. 35.
Octahedron with dissimilar faces (a combination of two tetrahedra).

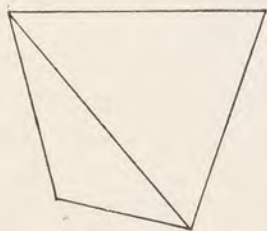


Fig. 36.
Tetrahedron.

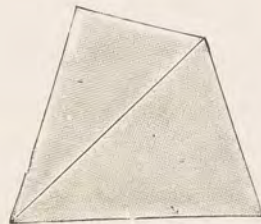


Fig. 37.
Complementary tetrahedron.

of the faces may be bright and smooth and the alternate ones dull and pitted, as in zinc-blende. When the faces differ also in size, as in a crystal of tetrahedrite (fig. 1,

Brauns' Mineral Kingdom.

plate 12), the difference in the form becomes more marked; and in certain cases the alternate faces may be altogether absent. We have then a new form, which is known as the *tetrahedron* (fig. 36), and may be considered as the half-form or hemihedral form of the octahedron. Naumann's symbol for the tetrahedron is therefore $\frac{O}{2}$. From an octahedron there can, of course, be derived two such half-forms, by the suppression of either one or other set of alternate faces. These two forms, the tetrahedron (fig. 36) and the complementary tetrahedron (fig. 37) are often distinguished respectively as the positive tetrahedron and the negative tetrahedron. In combination they give an octahedron (fig. 35).

In a similar manner, the hemihedral form of an icositetrahedron is a *triakis-tetrahedron* or three-faced tetrahedron, of which there are again two forms, a positive and a negative. Hemihedral forms may also be derived from the triakis-octahedron

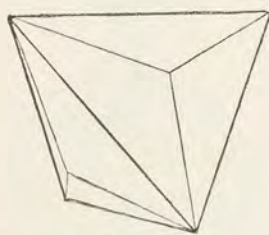


Fig. 38.
Triakis-tetrahedron or three-faced
tetrahedron.

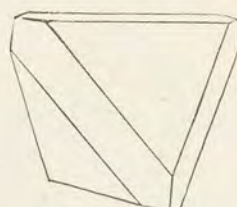


Fig. 39.
Tetrahedron with cube.

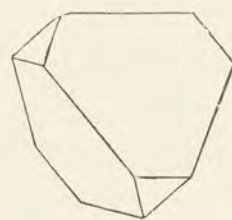


Fig. 40.
Tetrahedron with complementary
tetrahedron.

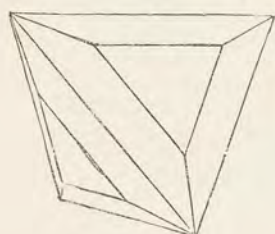


Fig. 41.
Tetrahedron with triakis-
tetrahedron.

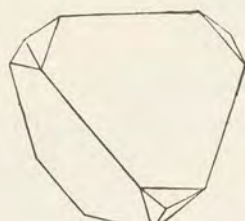


Fig. 42.
Tetrahedron with rhombic-
dodecahedron.



Fig. 43.
Cube with tetrahedron.

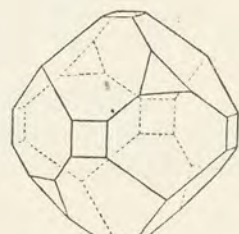


Fig. 44.
Rhombic-dodecahedron with
cube and tetrahedron.

and the hexakis-octahedron, but these are of less importance. The cube, the rhombic-dodecahedron and the tetrakis-hexahedron remain unaltered in their external form, but they display a difference in character on their faces; for example, the faces of the cube of zinc-blende (plate 20, fig. 4) are striated parallel to only one of their diagonals.

Crystals of this hemihedral class of the cubic system possess only six planes of symmetry, namely those parallel to the faces of the rhombic-dodecahedron: the three planes of symmetry parallel to the cube-faces are here absent. These crystals may be distinguished by the fact that faces in alternate octants are similar in character, and differ from those in adjacent octants.

Combinations. — The tetrahedron has its edges truncated by the cube (fig. 39), and its corners truncated by the complementary tetrahedron (fig. 40). Its edges are bevelled by a triakis-tetrahedron of the same sign (that is in the same octant) (fig. 41), but a triakis-tetrahedron of opposite sign will replace the corners by three faces. In combination with the rhombic-dodecahedron the tetrahedron has each of its corners replaced by three faces (fig. 42).

The cube has alternate corners only truncated by the tetrahedron (fig. 43); and in the rhombic-dodecahedron the alternate three-edged corners are truncated (fig. 44). In this last figure the faces of the cube are present in addition to those of the rhombic-dodecahedron and the positive tetrahedron.

The best examples of this class of crystals are afforded by the minerals tetrahedrite (plate 12) and zinc-blende (plate 20).

Pentagonal Hemihedrism.

Iron-pyrites is frequently found as crystals which are bounded by twelve five-sided faces, and this form is called the pentagonal-dodecahedron (fig. 5 and 6 of plate 26, and text-figure 45). A face of this form intersects the crystallographic axes in the same

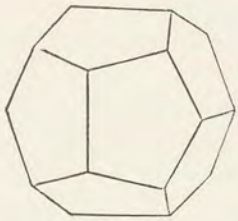


Fig. 45.
Pentagonal-dodecahedron.

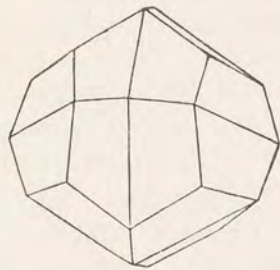


Fig. 46.
Dyakis-dodecahedron or diplohedron.

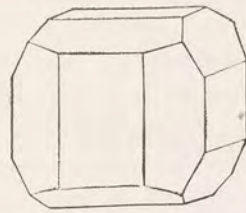


Fig. 47.
Cube with pentagonal-dodecahedron.

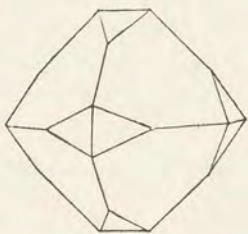


Fig. 48.
Octahedron with pentagonal-dodecahedron.

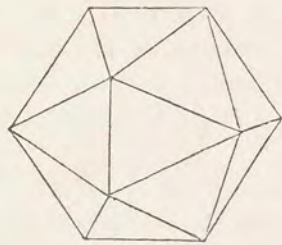


Fig. 49.
Octahedron and pentagonal-dodecahedron with faces of equal sizes.

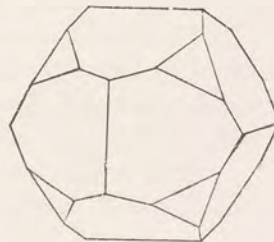


Fig. 50.
Pentagonal-dodecahedron with octahedron.

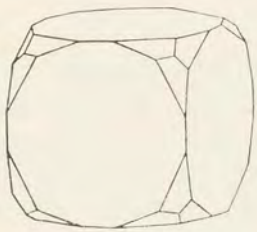


Fig. 51.
Cube with dyakis-dodecahedron.

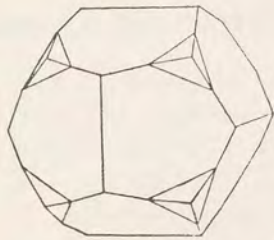


Fig. 52.
Pentagonal-dodecahedron with dyakis-dodecahedron.

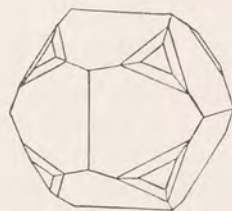


Fig. 53.
Pentagonal-dodecahedron with dyakis-dodecahedron and octahedron.

ratios as does a face of the tetrakis-hexahedron, which form is bounded by twenty-four faces. The pentagonal-dodecahedron is therefore a hemihedral form of the tetrakis-hexahedron, and its symbol may be written as $\frac{\sim O 2}{2}$.

Other crystals of iron-pyrites are bounded by twenty-four faces, which intersect the three axes in unequal lengths, $a:3a:\frac{3}{2}a$. This form is then the hemihedral form of the hexakis-octahedron, which has twice the number of faces with the same intercepts; it is called the dyakis-dodecahedron or diplohedron (fig. 46), and it has the symbol $\left[\frac{3O\frac{3}{2}}{2}\right]$. This hemihedral form of the hexakis-octahedron is distinguished from the tetrahedral-hemihedral form with the same symbol by enclosing its symbol in square brackets.

The remaining forms, the octahedron, cube, etc., are the same in this hemihedral class as in the holohedral class of the cubic system; but their lower degree of symmetry is often indicated by the striations on the faces. For example, the cube of iron-pyrites is striated parallel to only one of its edges (plate 26, fig. 1).

Crystals of this class possess only three planes of symmetry, these being parallel to the faces of the cube. They may be distinguished from tetrahedral-hemihedral crystals by the fact that they have parallel faces; in the tetrahedral-hemihedral class similar faces are not parallel. Here also similar faces occur in adjacent octants.

Combinations. — The faces of the pentagonal-dodecahedron truncate obliquely the edges of the cube (fig. 47), and replace the corners of the octahedron by two faces (fig. 48). When the pentagonal-dodecahedron is the predominating form in combination with the octahedron, the latter truncates the three-edged corners of the former (fig. 50). In some crystals of iron-pyrites the faces of these two forms — the pentagonal-dodecahedron and the octahedron — are equal in size, and we then have a figure bounded by twenty ($= 12 + 8$) triangular faces (fig. 49): this is sometimes called an icosahedron, but it is distinct from the regular icosahedron of geometry, since its faces are not all similar and are not all equilateral triangles.

The dyakis-dodecahedron replaces each corner of the cube by three obliquely placed faces (fig. 51); it may also replace by three faces the three edged corners of the pentagonal-dodecahedron (fig. 52). Fig. 53 resembles the last combination with the addition of the octahedron.

Iron-pyrites (plate 26) and cobaltite (plate 36) furnish the best examples of minerals crystallizing in this class of the cubic system.

Tetragonal System.

Crystals of the tetragonal, or quadratic, system have similar characters in two directions at right angles to one another, but in the third direction, at right angles to the two similar directions, they have other characters. A cross-section of the crystal will as a rule be square in outline, and for this reason this system is sometimes called the quadratic. The three crystallographic axes are chosen in accordance with this development of the crystals: they are all at right angles, and two of them are equal, whilst the third has a greater or lesser length than the other two. The equal axes (a) are placed horizontally, and the third or principal axis (c) is placed vertically.

Crystals belonging to the holohedral class of this system have five planes of symmetry. One is perpendicular to the principal axis, and is called the horizontal or the principal plane of symmetry. The remaining four planes are vertical and all pass through the principal axis: two contain also the horizontal axes a , and the other pair

are inclined at 45° to these axes. In this class there are five kinds of forms, namely square pyramids and prisms, eight-sided pyramids and prisms, and the base. One of the square pyramids has to be chosen from the crystals of each kind of mineral to be the primary or fundamental pyramid with the axial intercepts $a : a : c$, and the symbol of the form is written as P . The positions of other forms on the same crystal are referred to this pyramid.

In this primary pyramid (fig. 54) the crystallographic axes join the opposite corners, and all other square pyramids whose faces intersect on the three axes in this way are called *pyramids of the first order*.

According to whether these are steeper or lower pyramids, the faces intersect the vertical axis at a correspondingly greater or shorter distance from the centre than do the faces of the primary form. The symbols of such pyramids must then be $2P$, $3P$, or $\frac{1}{2}P$, $\frac{1}{4}P$, etc.

We may also have square pyramids whose faces intersect in only one of the horizontal a axes, and are parallel to the second (fig. 55); these are called *pyramids of the second order*, and they have the symbols $P\infty$, $2P\infty$, $\frac{1}{2}P\infty$, etc.

Corresponding with the pyramids of the first order we have the *prism of the first order* (fig. 56), which may be considered as a pyramid of such enormous steepness that it only intersects the vertical axis at an infinite distance (i. e., its faces are parallel to the vertical axis): the symbol is therefore ∞P . In the same way we have, associated with the pyramids of the second order, the *prism of the second order* (fig. 57), the faces of which are parallel to one of the horizontal axes and to the vertical axis: this form has the symbol $\infty P\infty$.

The faces of both these tetragonal prisms are inclined at 90° ; and the cross-sections of the forms are square, as is also the case with the tetragonal pyramids of both orders. The forms of the first and second orders therefore do not differ from each other in their shape, but only with respect to their positions on the crystal; and it is only in combinations that they can be distinguished.

The *eight-sided pyramids and prisms* can readily be recognized by the number and positions of their faces. The faces cut the two horizontal axes in unequal lengths; the symbol $\infty P3$ for an eight-sided prism indicates that the intercept on one horizontal axis is three times as great as on the other. A common eight-sided pyramid has the symbol $3P3$.

The *base*, or basal pinacoid, consists of a pair of horizontal planes parallel to the a axes of the crystal, and, being like a very flat pyramid, has the symbol $0P$.

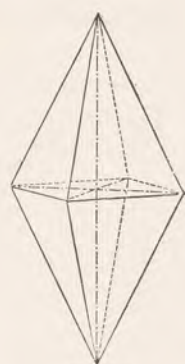


Fig. 54.
Tetragonal pyramid of
the first order.

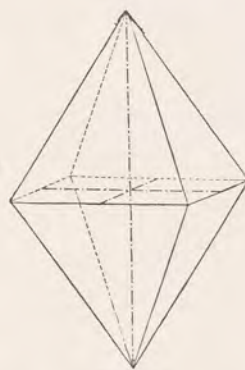


Fig. 55.
Tetragonal pyramid of
the second order.

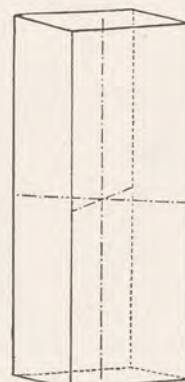


Fig. 56.
Tetragonal prism of the
first order.

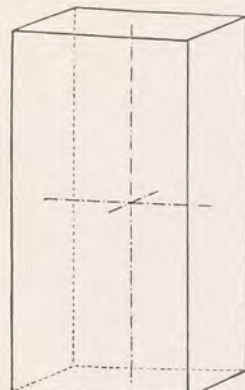


Fig. 57.
Tetragonal prism of the
second order.

In combinations of these tetragonal forms, forms which are of the same order occur one above the other and intersect in parallel horizontal edges. If the forms are of different orders then one set of faces will truncate or replace the edges and corners of the other. Before we can determine all the forms of a combination, it is necessary to decide which is to be the primary pyramid: In fig. 58 the faces lettered *s* may be chosen as the primary pyramid *P*: the prism *m* will then be the prism of the first order, ∞P ; the pyramid *e* truncating the edges of the first pyramid is a pyramid of the second order with the symbol $P\infty$; and *a* is the prism of the second order, $\infty P\infty$.

Fig. 59, representing a crystal of zircon is a combination of the primary pyramid *o*; another pyramid *s* also of the first order and with the symbol $3P$; the

prism *M* of the first order; and the eight-sided pyramid *x*. The symbol of the last form is $3P3$, since each face intersects the axes in the ratios $a:3a:3c$, that is a face *x* intersects the vertical axis at three times the length that *o* intersects the same axis. This relation cannot be made out from a mere inspection of the crystal, but has to be calculated from the angles measured between the faces.

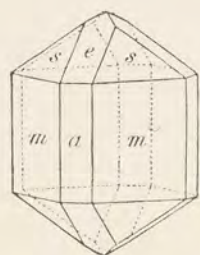


Fig. 58.
Tetragonal crystal (Cassiterite).



Fig. 60.
Tetragonal tetrahedron.

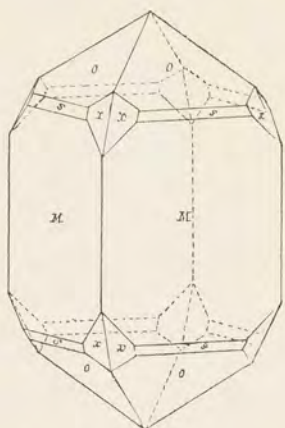


Fig. 59.
Tetragonal crystal (Zircon).

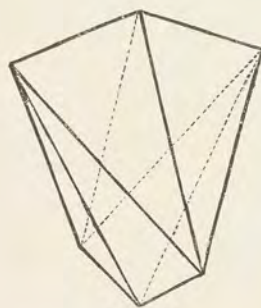


Fig. 61.
Tetragonal scalenohedron.

Examples of minerals crystallizing in this holohedral class of the tetragonal system are cassiterite (plate 38), rutile and anatase (plate 39), idocrase (plate 49) and phosgenite (plate 17).

There are several hemihedral and tetartohedral classes of the tetragonal system, but in this place mention need only be made of one of the most important. This is the *tetrahedral-hemihedral* class, corresponding to the tetrahedral-hemihedral class of the cubic system. From a tetragonal pyramid two tetragonal tetrahedra

(fig. 60) may be derived, just as two regular tetrahedra are derived from the octahedron. These forms each consist of four equal isosceles triangles, and have the symbols $+\frac{P}{2}$ and $-\frac{P}{2}$. From an eight-sided tetragonal pyramid two so-called tetragonal scalenohedra (fig. 61) may be derived. Hemihedral forms of this kind are met with in copper-pyrites (plate 11).

Hexagonal System.

Holohedral crystals of the hexagonal system have a sixfold arrangement of their faces, and cross-sections of simple forms will be regular hexagons. Corresponding to this type of symmetry we must select for crystallographic axes three equal axes

(a) lying in the horizontal plane and with angles of 60° between them, and a fourth vertical axis (*c*) of a length different to the other three: the latter is called the principal axis and it is an axis of hexad symmetry.

These crystals possess seven planes of symmetry. One of them is perpendicular to the principal axis and therefore horizontal. The six others are vertical and contain the vertical axis; they are arranged in two sets of three, those of one set being parallel to, and those of the other set perpendicular to, the horizontal crystallographic axes.

As in the tetragonal system, there are also here five types of simple forms, but the faces are in sets of six instead of four. These simple forms are the hexagonal pyramids and prisms, the twelve-sided pyramids and prisms, and the base. One of the hexagonal pyramids has to be selected as the primary pyramid for each mineral which crystallizes in this system. The four crystallographic axes join opposite corners of this pyramid (fig. 62) of which the symbol is written *P*. Other forms are referred to the same system of axes and their relation to the primitive form determined, just as in the tetragonal system.

Pyramids of the first order are those in which the axes join opposite corners; the symbols are *P*, $2P$, $\frac{1}{2}P$, etc.

Pyramids of the second order have one of the horizontal axes passing through the centre of each of their horizontal edges, the two other horizontal axes being intercepted at twice the distance. The symbols are therefore $P2$, $2P2$, etc.

Pyramids of the two orders do not differ in form, but only in the lie of their faces with respect to the crystallographic axes; and it is only in combinations that they can be distinguished.

Corresponding to each of these two orders of pyramids there are also hexagonal prisms with faces parallel to the vertical axis, and angles of 120° between the faces.

The *prism of the first order* has the axes passing through the edges of the prism, and the symbol is ∞P . The hexagonal prism shown in fig. 63 is placed in a position corresponding to the pyramid in fig. 62, and is therefore the prism of the first order.

The *prism of the second order* has the symbol $\infty P2$; here the axes pass out through the centres of the faces. Drawn in the position adopted for the accompanying figures, there will be an edge of this prism directed towards the observer; this may be seen from a comparison of figs. 70 and 71, in which the two prisms are of the first and second orders respectively.

The *twelve-sided pyramids and prisms* are easily recognized by the number and positions of their faces. The faces intersect in unequal lengths on the horizontal axes. The commonest twelve-sided pyramid is that with the symbol $3P\frac{3}{2}$, and the corresponding prism is $\infty P\frac{3}{2}$.

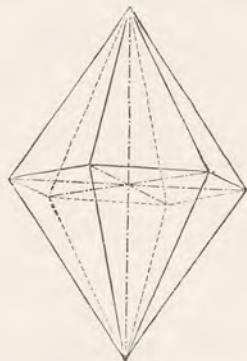


Fig. 62.
Hexagonal pyramid of the first order.

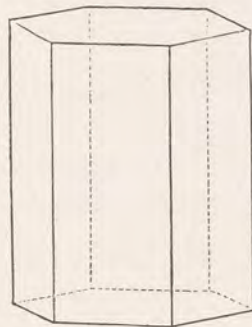


Fig. 63.
Hexagonal prism of the first order.

The *base*, or basal pinacoid, consists of a pair of parallel faces placed at opposite ends of the crystal, and, like the prisms, can only exist in combinations. The symbol is $0P$.

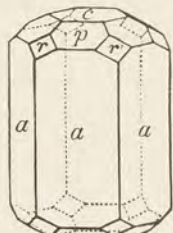


Fig. 64.
Hexagonal crystal
(Beryl).

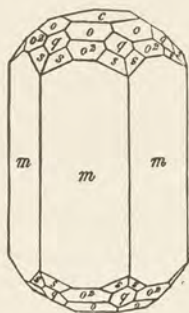


Fig. 65.
Hexagonal crystal
(Beryl).

In *combinations*, forms of the same order lie one above the other, whilst forms of different orders truncate or replace the edges and corners of each other.

In fig. 64, the faces p are chosen as belonging to the primary pyramid; a is then the prism of the first order, r a pyramid of the second order, and c the base. The symbols are $P, \infty P, 2P2, 0P$.

In fig. 65, taking o as the primary pyramid P , o^2 is then a steeper pyramid $2P$ of the same order, m the prism of the first order ∞P , q a pyramid of the second order $2P2$, s a twelve-sided pyramid $3P\frac{3}{2}$, and c the base.

To this holohedral class of the hexagonal system the mineral beryl belongs (plate 44, and text-figs. 64 and 65).

Hemihedral forms.

Very few minerals crystallize in the holohedral class of the hexagonal system, but there are several important minerals which crystallize in hemihedral or tetartohedral classes of this system. The lower degree of symmetry characteristic of these classes is not, however, always obvious. The crystals of amethyst represented in plate 56, figs. 1 and 4 are, for example, apparently a combination of a hexagonal prism with a hexagonal pyramid. Here it must be pointed out that the apparent hexagonal pyramid is really a combination of two forms: this may be seen in fig. 2 of the same plate,

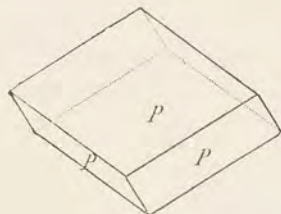


Fig. 66.
Rhombohedron.

where three of the faces are bright and smooth and the three others alternating with the first three are quite rough. Or again in fig. 3, the three alternate faces of one set are large, whilst the other three are small; in fig. 5 these latter faces are still smaller, and in certain cases they may be completely absent. We then have the crystal terminated by only three faces, and at the other end of a completely developed crystal there would be three faces each parallel to those at the top. A simple form derived in this way by suppressing alternate faces of a doubly terminated hexagonal pyramid is known as a *rhombohedron*. And the type of hemihedrism is called *rhombohedral hemihedrism*. A rhombohedron (fig. 66) is bounded by six similar rhomb-shaped faces, opposite pairs of which are parallel. The form can readily be obtained by breaking up any crystal of calcite, since this mineral splits with ease along three plane directions parallel to the faces of a rhombohedron. Over the six edges (three at each end) which intersect in the vertical axis of the crystal the angles between the faces are obtuse, but over the other six zig-zag edges around the equatorial portion of the crystal the angles are acute. The three horizontal crystallographic axes pass out at the centres of these zig-zag edges.

For the reason that far more minerals crystallize as rhombohedra than as hexagonal pyramids, Naumann gave a special symbol (R) to that rhombohedron which may be selected as the primary rhombohedron: in calcite the cleavage rhombohedron is selected. Now, there may be two sets of rhombohedra: those which have their faces turned the same direction as the primitive rhombohedron, or in other words are of the same order, are called positive rhombohedra, e. g., $+4R$, $+\frac{1}{4}R$, etc.; and those of the second order truncating the edges or corners of the first order, which are called negative rhombohedra, e. g., $-2R$, $-\frac{1}{2}R$, etc. In the figures here given the positive rhombohedra are drawn with an upper face towards the observer (fig. 66), and the negative rhombohedra with an upper edge (fig. 67) towards the observer.

It will now be clear that the three larger and brighter terminal faces forming the apparent hexagonal pyramid of amethyst (plate 56) belong to a rhombohedron which we may call $+R$, and that the three smaller and dull faces belong to the negative rhombohedron $-R$.

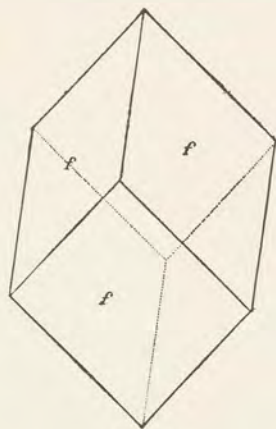


Fig. 67.
Rhombohedron.

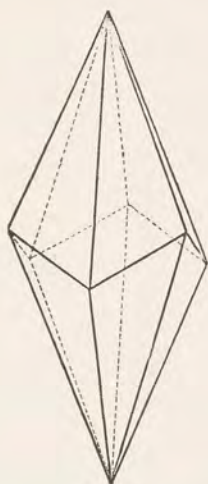


Fig. 68.
Scalenohedron.

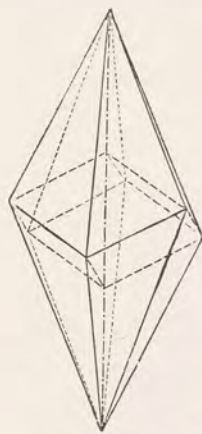


Fig. 69.
Scalenohedron with enclosed
rhombohedron.

In this hemihedral class there is, besides the rhombohedron, an important form known as the *scalenohedron* (fig. 68). This may be derived from the twelve-sided hexagonal double pyramid by suppressing alternate faces. In this form there is also a threefold arrangement of the faces about the vertical or principal axis, which is an axis of threefold or trigonal symmetry. The form is bounded by twelve similar faces, or six pairs of parallel faces, with the form of scalene triangles. There are thus three sets of edges, and the angles between the faces are different over the dissimilar edges. The six edges meeting the vertical axis at the top and the six meeting it below are alternately longer and shorter, and the angles over them are alternately obtuse and acute. The six median edges forming a zig-zag belt round the crystal coincide with the corresponding edges of a rhombohedron, as shown in fig. 69. This figure represents a scalenohedron with the primary rhombohedron drawn inside; and it may be seen by placing a rule over the figure that the steeper faces of the scalenohedron intersect the vertical axis at three times the distance that the rhombohedral faces intersect the same axis. The intercepts on the horizontal axes are the same; so that the scalenohedron represented in fig. 69 has the symbol $R3$. Each rhombohedron, whether positive or negative, may have scalenohedra associated with it in this way: for example, with

the negative rhombohedron $-2R$ there may be the negative scalenohedra $-2R2$, $-2R3$, etc.

In this type of hemihedrism it is only the hexagonal pyramids of the first order and the twelve-sided pyramids of the hexagonal system which have the number of their faces reduced. The hexagonal pyramids of the second order still remain as such with the symbols $P2$, $2P2$, etc. The hexagonal prism of the second order is given the symbol $\infty P2$; but the hexagonal prism of the first order and the base are now referred to as ∞R and $0R$ respectively, since they may be considered as very steep or very flat rhombohedra.

Combinations. — Combinations of a rhombohedron with a hexagonal prism differ in appearance according to whether the prism is of the first or of the second order. Fig. 70 shows a combination of a negative rhombohedron $-\frac{1}{2}R$ with the prism of the first order ∞R : here the faces of the rhombohedron lie respectively above and below alternate faces of the prism. Fig. 71 shows a combination of a positive rhombohedron R with the prism of the second order $\infty P2$: here the faces of the rhombohedron lie opposite the edges of the prism, and on the crystal there are three zones, each

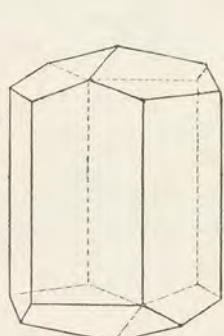


Fig. 70.
Prism of first order with
rhombohedron.

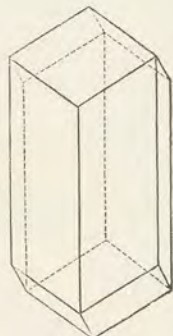


Fig. 71.
Prism of second order
with rhombohedron.



Fig. 72.
Prism and pyramid of second
order with rhombohedron and
base (Corundum).

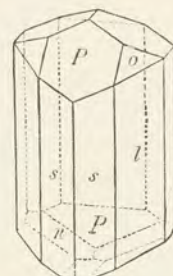


Fig. 73.
Hemimorphic-rhombo-
hedral crystal
(Tourmaline).

containing four rhombohedron faces and two prism faces. (Another zone on this crystal is that of the six prism faces.) A combination of a negative rhombohedron with the prism of the second order shows also the same relations.

Fig. 72 is a combination of the primary rhombohedron R , the prism l of the second order, a hexagonal pyramid n also of the second order, and the base o .

Combinations of positive and negative rhombohedra are of frequent occurrence, and often the faces of one truncate the edges of the other. When the latter is the case, the truncating rhombohedron has half the intercept on the vertical axis that the truncated rhombohedron has: thus the rhombohedron $-\frac{1}{2}R$ truncates the edges of R , R truncates the edges of $-2R$, and $-2R$ truncates $+4R$, etc. The scalenohedron also frequently occurs in combinations. The best examples are given by crystals of calcite (plates 72 and 73). Other minerals which crystallize in this class are corundum (plate 42) and haematite (plate 28).

Some of the other classes of the hexagonal system must be briefly mentioned here, since they are especially characteristic of certain minerals: these are illustrated in the next five figures.

Fig. 73 shows a characteristic form of tourmaline crystal, in which the three-fold symmetry about the vertical axis is apparent, but here the crystal is bounded at

the two ends by faces of different forms and these faces are not parallel. Crystals which are differently developed in this manner at their two ends are said to be hemimorphic. And the class to which tourmaline belongs is called the *rhombohedral-hemimorphic*: it may be considered as a hemihedral form of the rhombohedral class or as a tetartohedral form of the holohedral hexagonal class. The rhombohedra here become triangular pyramids with only one end, that is, they are not doubly terminated like the hexagonal pyramids of the holohedral class. In the figure the three faces P at the top form such a triangular pyramid, which may be taken as the primary form with the symbol $+R$: the faces o will then be $-2R$ since the edges between them are truncated by the faces P . At the other end of the crystal there is a second pyramid P also with the symbol $+R$ (the combination of these two together would give a rhombohedron) with the pyramid $-\frac{1}{2}R$. The three faces of the prism l belong to those of the prism of the first order ∞R ; whilst the six faces of the prism s are those of the second order, which is not affected by the hemimorphism. Crystals of tourmaline which have grown with one end attached to their rocky matrix will not, of course, show this different development at the two ends, but they will still show the faces of the triangular prism of the first order: and this triangular outline of the prisms of tourmaline is an especially characteristic feature of the mineral.

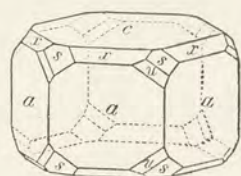


Fig. 74.
Pyramidal-hemihedrism
(Apatite).

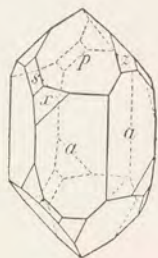


Fig. 75.
Trapezohedral-tetartohedrism (Quartz).

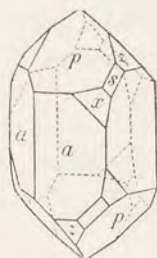


Fig. 76.

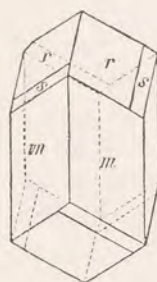


Fig. 77.
Rhombohedral-tetartohedrism (Diopside).

Fig. 74 represents a crystal of apatite (see also plate 81, fig. 2), which belongs to the *pyramidal-hemihedral* class of the hexagonal system. Here there is a sixfold symmetry or repetition of the faces around the vertical axis. The crystal is a combination of the base $c = 0P$, a hexagonal pyramid of the first order $x = P$, a hexagonal pyramid of the second order $s = 2P2$, and the hexagonal pyramid u . The faces of the last form have the same positions as half of the faces of the twelve-sided double pyramid (s in fig. 65) $3P\frac{3}{2}$ of the holohedral class: their symbol is therefore written as $\frac{3P\frac{3}{2}}{2}$.

Figs. 75 and 76 represent crystals of quartz, in which p is the rhombohedron $+R$ and z the rhombohedron $-R$, the two together being equivalent to a hexagonal pyramid of the first order. The prism faces a belong to the hexagonal prism of the first order. In addition there are the small faces s and x placed on alternate corners between the rhombohedron and prism faces. The six faces s belong to a double triangular pyramid derived from a hexagonal pyramid of the second order (as in fig. 74) by the omission of half of the faces: those of x , also six in number, have the positions of one-quarter of the faces of a twelve-sided double pyramid of twenty-four faces. These six faces x would in a simple form give a figure which is called a

trapezohedron; and, as this is a quarter-faced or tetartohedral form of the twelve-sided double pyramid, this type of crystal belongs to the trapezohedral-tetartohedral class of the hexagonal system. In fig. 75 the trapezoidal faces x lie to the left of p , and in fig. 76 to the right: we must therefore distinguish two kinds of quartz crystals respectively as right-handed and as left-handed crystals. These are related to one another in the same manner as the right hand to the left hand, one being the mirror-reflection of the other: they cannot be brought into coincident positions. Such pairs of crystals are said to be enantiomorphous.

In Fig. 77, representing a crystal of diopase, r is again the primary rhombohedron $+R$, and m is the hexagonal prism of the second order (compare fig. 71). In addition we have the faces s of another rhombohedron placed on alternate edges between the faces of r and m . If there were similar faces on all the edges between r and m the form would be a scalenohedron: this form is therefore a hemihedral form of the scalenohedral, and consequently a tetartohedral form of the twelve-sided double pyramid. This class of tetartohedrism is therefore called rhombohedral-tetartohedrism.

Rhombic System.

Crystals of the rhombic system may be referred to a set of crystallographic axes which are all at right angles to one another, but are all of unequal lengths. The vertical axis is denoted by the letter c . The longer of the two horizontal axes is placed from right to left and is called the macro-diagonal or macro-axis; this is lettered b . The shorter horizontal axis is directed towards the observer, and is called the brachy-diagonal or brachy-axis, with the letter a . In the holohedral class of this

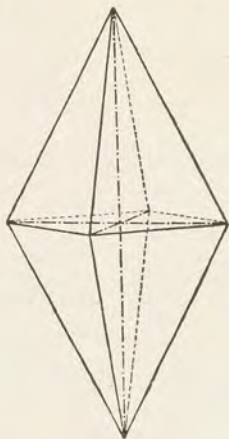


Fig. 78.
Rhombic pyramid.

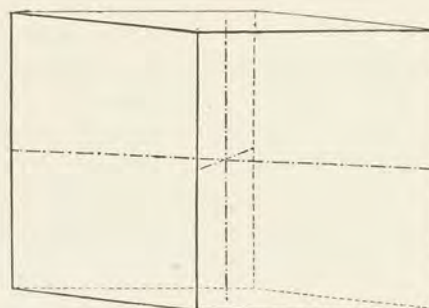


Fig. 79.
Rhombic prism.

system there are three planes of symmetry, which are at right angles to each other. There are only three different kinds of forms; namely, pyramids, prisms and pinacoids. A cross-section of the two first of these forms is a rhomb; hence the name of the system.

Rhombic pyramids (fig. 78) are bounded by eight similar triangular faces with unequal sides. The faces cut the three axes at unequal lengths, the primary pyramid P cutting them in the ratio $a:b:c$. Lower pyramids will have the symbols $\frac{1}{2}P$, $\frac{1}{3}P$, etc.,

and steeper pyramids the symbols $2P$, $3P$, etc. Other pyramids may cut the horizontal axes at distances which are multiples or sub-multiples of a or b ; and their symbols may be $P\bar{2}$, $P\bar{2}$ etc., according as the a or b axis is cut at a different length.

Rhombic prisms consist of four faces parallel to one or other of the three axes. When the faces are parallel to the vertical axis the form is called a vertical prism (fig. 79) with the symbol ∞P , $\infty P\bar{2}$, $\infty P\bar{2}$, etc., according to the intercepts of the faces on the two horizontal axes. A set of four faces parallel to the \bar{a} axis is called a brachy-prism or a brachy-dome, since the two upper sloping faces are like the roof of a house: here the symbols may be $P\infty$, $\frac{1}{2}P\infty$, etc. When the four faces are parallel to the \bar{b} axis, the form is called a macro-prism or macro-dome, and the symbols are $P\infty$, $2P\infty$, etc. The form $P\infty$ for instance intercepts the \bar{b} axis at an infinite distance and the other two axes \bar{a} and \bar{c} at the same distances as the primary pyramid: the form $2P\infty$ intercepts the vertical axis at twice the length c .

The *pinacoids*, or end faces, consist of a pair of parallel faces on opposite sides of the crystal and parallel to two of the axes. That pair parallel to the vertical axis and the macro-axis \bar{b} is called the macro-pinacoid, with the symbol $\infty P\infty$; and the other vertical pair parallel to the brachy-axis \bar{a} is the brachy-pinacoid, with the symbol $\infty P\infty$. The third pinacoid with horizontal faces parallel to the two horizontal axes is called the basal pinacoid or base, and has the symbol $0P$.

Combinations of forms in rhombic crystals can readily be made out after it has been decided which of the three axes is to be the vertical axis, and which pyramid is to be the primary pyramid.

In the crystal of native sulphur represented in fig. 80, the set of eight large faces P may be taken as the primary pyramid P ; s is then a flatter pyramid of which the symbol is $\frac{1}{3}P$; n is a brachy-dome $P\infty$; and c the base $0P$. In fig. 81, representing a crystal of celestite, no pyramid faces are present: m may be taken as the vertical prism ∞P ; b is then the brachy-pinacoid $\infty P\infty$, o the brachy-dome $P\infty$, d the macro-dome $\frac{1}{2}P\infty$, and c the base $0P$.

Several minerals crystallize in this holohedral class of the rhombic system: for example, barytes and celestite (plates 76–78), aragonite (plate 74), topaz (plate 46), sulphur (plate 25), stibnite (plate 23), atacamite (plate 14). Hemihedral forms are of less importance.

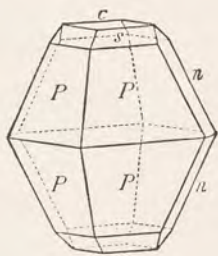


Fig. 80.
Rhombic crystal (Sulphur).

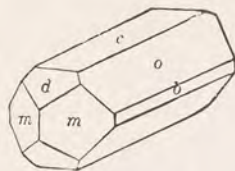


Fig. 81.
Rhombic crystal (Celestite).

Monoclinic System.

Crystals of this class may be readily distinguished by the fact that they possess only a single plane of symmetry. Of the three crystallographic axes only one is fixed in position with respect to the symmetry of the crystal: this being the axis perpendicular to the plane of symmetry, which is called by Naumann the ortho-axis \bar{b} , and is placed horizontally from right to left. The other two crystallographic axes lie in the plane of symmetry, and are arbitrarily chosen parallel to any prominent or convenient edges of the crystal. These are, of course, both perpendicular to the ortho-

axis, but are inclined to one another at an oblique angle (β). One of them is placed in a vertical position and marked b ; the other will then be directed towards the observer in a sloping position, and is therefore called the clino-axis a . The crystal is also so placed that the larger (obtuse) of the two oblique angles β is to the front and above. The three axes a , b and c being of different characters, will also be of different lengths. The different faces on a monoclinic crystal are defined by their positions with respect to these axes.

Pyramids are forms whose faces intersect all three axes; they consist of only four faces (two pairs of parallel faces) which intersect each other in parallel edges, like the prisms of the rhombic system. For this reason they are more properly called hemi-pyramids. Naumann again gives the symbol P to such forms, distinguishing between those which lie to the front or to the back of the crystal as $-P$ and $+P$ respectively.

Climo-domes, or clino-prisms, also consist of a set of four faces intersecting in parallel edges and with a rhombic cross-section. These are arranged parallel to the clino-axis, and have the symbols $P \infty$, $2P \infty$, etc.

Ortho-domes, or ortho-prisms, are again the same, but are parallel to the ortho-axis b . The symbols are $-P \infty$ or $+P \infty$ according to whether they are at the front or the back of the crystal; or $-\frac{1}{2}P \infty$, $+2P \infty$, etc. according to the length intercepted on the vertical axis.

Vertical prisms also consist of a set of four faces intersecting in parallel edges, which edge is in this case parallel to the vertical axis. The symbol ∞P is that of the unit vertical prism.

The *clino-pinacoid* consists of a pair of faces parallel to the plane of symmetry, and therefore parallel to the vertical axis and the clino-axis. Its symbol is $\infty P \infty$.

The *ortho-pinacoid* also consists of a pair of parallel faces placed at the front and the back of the crystal, being parallel to the vertical axis and the ortho-axis. Its symbol is $\infty P \infty$.

The basal pinacoid or *base* consists of a pair of faces parallel to the axes b and a ; the symbol is $0P$.

In this system it is clear that none of the simple forms described above can completely enclose space; all monoclinic crystals are therefore combinations of forms. Further, it is obvious that there

is only one form, namely the clino-pinacoid, which is fixed in position for us, this being parallel to the plane of symmetry. The other faces will belong to one or other of the forms detailed above, according to our choice of the vertical axis and the clino-axis. For each mineral it is necessary therefore to make an arbitrary selection of these axes, and having made the selection to adhere to it for the same mineral.

In the crystal of augite shown in fig. 82, the face marked b is one of the

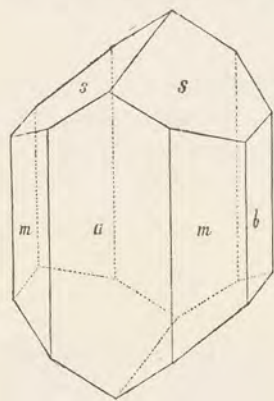


Fig. 82.
Monoclinic crystal (Augite).

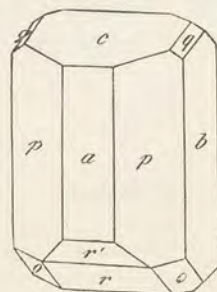


Fig. 83.
Monoclinic crystal (Felspar).

two parallel faces of the clino-pinacoid and is parallel to the plane of symmetry of the crystal. The ortho-axis will be perpendicular to this face; and for vertical axis we may select an axis parallel to the edge between the faces m and b (or a and m); and for

the clino-axis an axis parallel to the edge between s and s . The face a will then belong to the ortho-pinacoid; the four faces m will be the vertical prism; and the form s a clino-dome. It is more usual, however, to denote in augite the faces s as those of the primary pyramid — P , since on other crystals of this mineral other faces and edges are developed which give a more convenient set of axes.

Fig. 83 shows a monoclinic crystal of felspar (like that in plate 1, fig. 1, in which, however the faces a are absent). The face b is the clino-pinacoid parallel to the plane of symmetry; and we select the vertical axis parallel to the edge p/b , and the clino-axis parallel to the edge c/q . a is then the ortho-pinacoid, p the vertical prism, c the base, q a clino-dome, r and r' are positive ortho-domes, and o a positive hemi-pyramid. The Naumannian symbols of these forms are: —

$$b = \infty P \infty, a = \infty P \infty, p = \infty P, c = 0P, \\ q = 2P \infty, r = P \infty, r' = 2P \infty, o = P.$$

Examples of monoclinic crystals are furnished by the minerals felspar (plate 60), augite (plate 65), hornblende (plate 66), and gypsum (plate 79).

Triclinic System.

On crystals of this system all the faces and all the edges intersect in oblique angles. The only element of symmetry present is the centre of symmetry; so that corresponding to each face there must be a parallel face on the opposite side of the crystal. It follows that the three crystallographic axes will be all dissimilar and of unequal lengths, and that they will be inclined to one another at oblique angles (α , β and γ). These axes are arbitrarily chosen parallel to any three edges (which are not parallel) of the crystal: it is usual to place one vertically and this is called the c or vertical axis; a second, placed from right to left is called the macro-axis b ; and the third, which is directed towards the observer, is called the brachy-axis a .

Each form consists only of a pair of parallel faces, but from analogy with monoclinic and rhombic crystals we may conveniently refer to them as pyramids, prisms and so on, according to their positions with respect to the crystallographic axes.

Pyramids, then, are pairs of faces which intersect all three axes; and from their positions they may be distinguished by the Naumannian symbols P' , $'P$, P'' , $''P$, according to the octant in which they lie, that is right and above, left and above, right and below, and left and below, respectively.

Prisms are pairs of faces which are parallel to one of the axes: vertical prisms, $\infty P'$, $\infty' P$, parallel to the vertical axis; brachy-prisms or brachy-domes, $P \infty$, parallel to the brachy-axis; and macro-prisms or macro-domes, $P \infty$, parallel to the macro-axis.

Pinacoids are those pairs of faces which are parallel to two axes: the brachy-pinacoid parallel to a and c ; the macro-pinacoid parallel to b and c ; and the basal pinacoid or base parallel to a and b . Their symbols are $\infty P \infty$, $\infty P \infty$ and $0P$ respectively, as in the monoclinic and rhombic systems.

These simple forms cannot exist alone, and all triclinic crystals must necessarily be combinations of forms. Fig. 84 represents a crystal of the variety of felspar known as albite. The a axis is taken parallel to the edge between the faces P/M , the b axis parallel to the edge between P and the larger face x at the back, and the vertical c

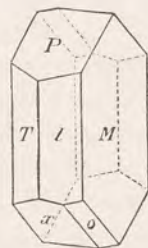


Fig. 84.
Triclinic crystal
(Felspar).

axis parallel to the edge T/l . T will then be a left vertical prism $\infty' P$, l a right vertical prism $\infty P'$, M the brachy-pinacoid $\infty P \infty$, P the base $0 P$, x a macrodome $P \infty$, and o a pyramid P_1 .

Examples of minerals which crystallize in this system are albite (plate 61), axinite (plate 51), and copper-vitriol (plate 14).

Forms of Growth of Crystals.

In the foregoing sections we have given a brief account of the more important forms of crystals, but have considered them to be ideally developed with all the similar faces of the same size. This scarcely ever happens to be the case in nature, and we find considerable variations in the forms even on crystals of the same kind. It would, in fact, be scarcely possible to find two crystals of a mineral which are exactly alike: they all show greater or smaller differences, depending on the manner in which they have grown.

The regularity of the growth of crystals will be greater if the material for their growth is supplied to an equal extent on all sides, if the growth has taken place more slowly, and if there are no adverse conditions to hinder the growth. Under the most favourable conditions the crystal may perhaps assume an almost perfect form. But under less favourable conditions, when the material is supplied in unequal amounts on different sides, or when the growth has taken place rapidly, the crystals which result are distorted in form (compare p. 13). These distorted forms may have the appearance of unfinished crystals; or they may be delicate and branching, with a striking resemblance to the forms of plants, looking, indeed, so little like crystals that we are not disposed at first to recognize them as crystals. Such forms are familiar to all of us in the frost-flowers which grow on a window-pane in the winter, or the snow-flakes with their beautiful and extremely varied star-shaped forms. These forms are but the result of the rapid crystallization of water when lowered in temperature to the freezing point. Similar forms, due to peculiarities in the conditions of growth, are also frequently met with amongst minerals. Illustrations of irregularities in the forms of growth of minerals are given on plate 2, and examples may also be found on several other plates, more particularly those representing gold, silver and copper.

Figs. 1—4 (plate 2) show the common mineral iron-pyrites exhibiting different forms of growth, the first being an ideally developed octahedron. In fig. 2 we still see distinctly the octahedral form of the crystal at its summit, but round the sides the form is less regular and broken up with interspaces: in this instance the growth of the crystal has taken place mainly in the direction of the vertical axis, more material having been supplied to the top of the growing crystal than to its sides. This is still more emphasized in fig. 3, where material has been supplied only along the upper edges and not on the faces themselves, and the crystal has grown upwards like a column. In the extreme case, illustrated in fig. 4, the growth of the iron-pyrites has been confined between the layers of a slaty rock, and the result is the delicate branching forms like frost-flowers.

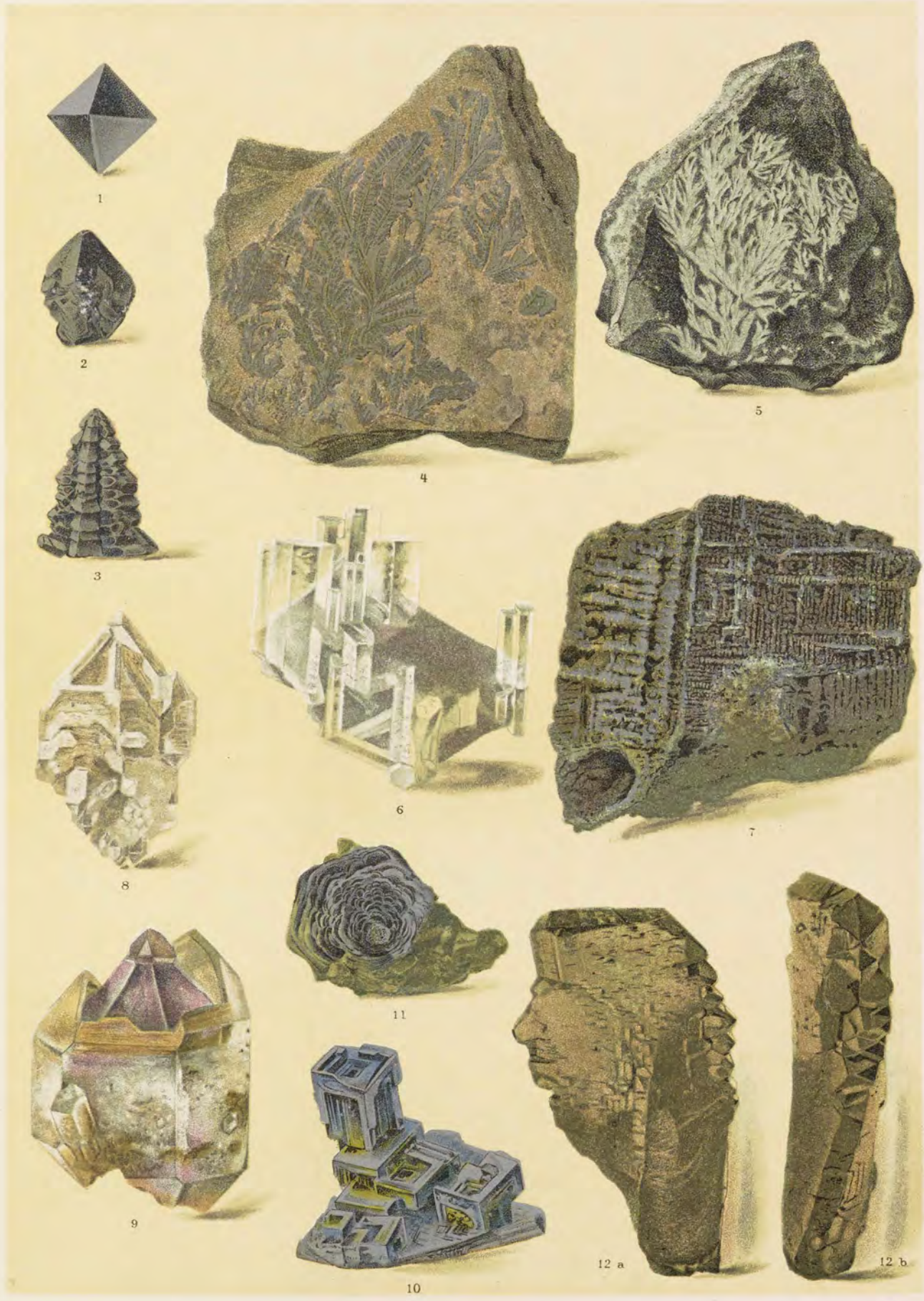
Branching forms of this kind are called dendritic forms, from the Greek, *dendron*, a tree. Another example of this form of growth is shown in fig. 5, representing the mineral wollastonite which has grown in a rock crevice.

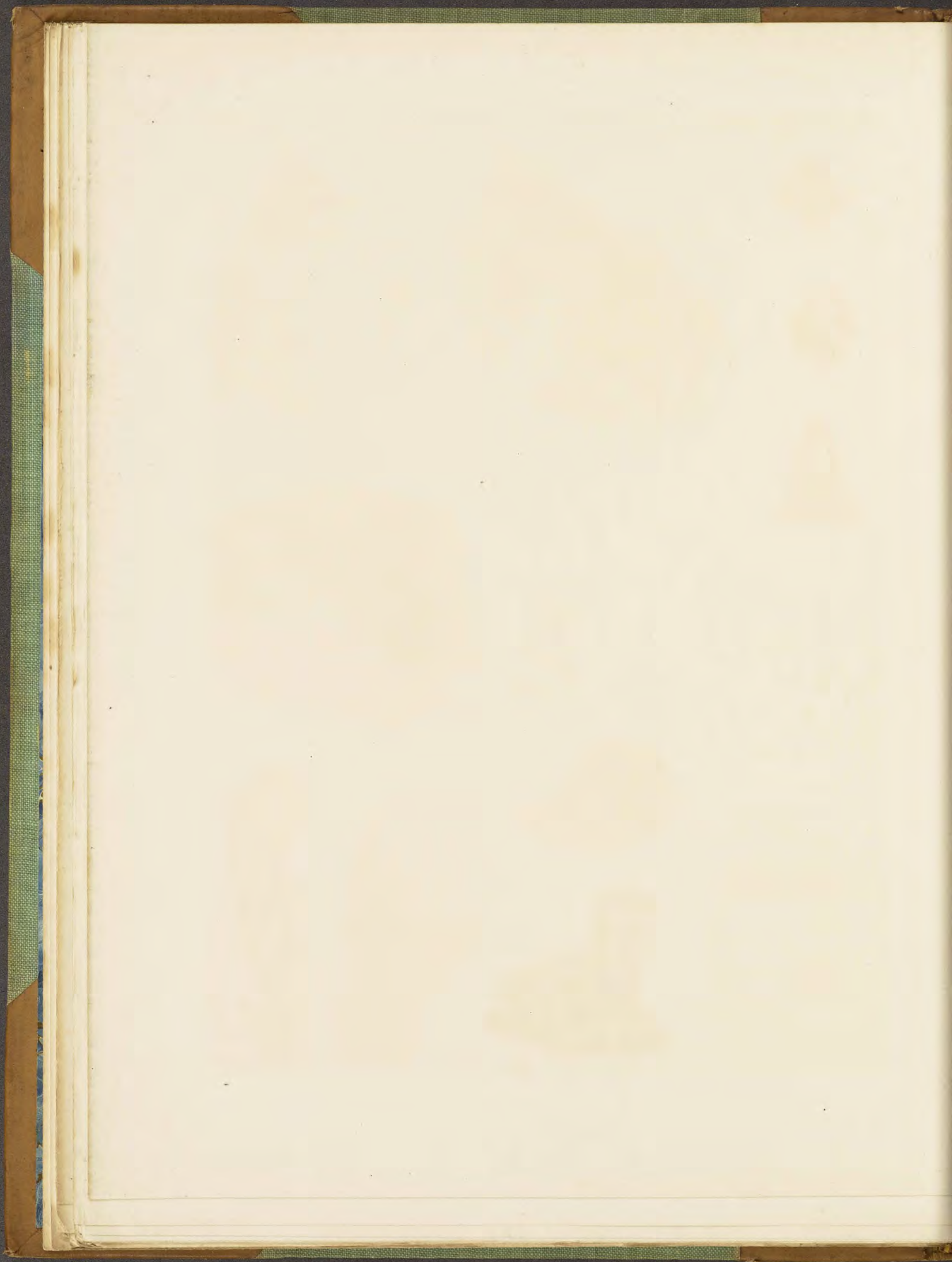


Forms of Growth of Crystals.

Fig.

1. **Regularly developed octahedron** of iron-pyrites.
French Creek mines, Pennsylvania, U. S. A.
2. **Distorted octahedron** of iron-pyrites. Growth has taken place more rapidly in the direction of the axes than on the faces.
Rinkenkuhl, near Gross-Almerode, Hesse-Nassau.
3. **Distorted octahedron** of iron-pyrites. Growth has taken place mainly in the direction of one axis.
Rinkenkuhl, near Gross-Almerode, Hesse-Nassau.
4. **Dendritic** iron-pyrites on clay-slate.
Münsterappel, near Kreuznach, Rhenish Prussia.
5. **Dendritic** wollastonite on black limestone.
Berggiesshübel, near Pirna, Saxony.
6. **Parallel growth** of calcite crystals. Several colourless prismatic crystals of calcite are grown in parallel position on a violet coloured rhombohedron of the same mineral.
Andreasberg, Harz Mountains, Germany.
7. **Reticulated growth** of galena. The growth has taken place along three directions at right angles, that is, parallel to the edges of the cube.
St. Paul mine, near Welkenraedt, Belgium.
8. **Skeletal growth** of rock-crystal. Hopper-shaped depressions take the place of the faces at the end of the crystal.
Poretta, near Bologna, Italy.
9. **Parallel growth** of rock-crystal and amethyst.
Ilmen Mountains, southern Urals, Russia.
10. **Hopper-shaped crystals** of bismuth. Artificially prepared from a fused mass.
11. **"Iron roses."** Rosette-like grouping of tabular crystals of haematite.
Fibbia, St. Gotthard, Switzerland.
- 12a and b. **Twisted crystals** of smoky-quartz. The crystals were attached to the matrix at their lower ends.
St. Gotthard, Switzerland.





The artificially prepared crystals of metallic bismuth shown in fig. 10, illustrate, as in the crystal of iron-pyrites, the growth of crystals along their edges, leaving vacant spaces or hopper-shaped depressions in place of the faces. That this is a result of a rapid and hurried crystallization we can only conjecture in the case of the natural crystals of iron-pyrites; but in the case of these artificial crystals we know that the material has crystallized rapidly from a molten condition. Similar hopper-shaped depressions are often shown on the faces of quartz crystals from Poretta near Bologna (fig. 8); but whether this also is a result of rapid growth it would be difficult to say. Sometimes it may happen that these cavities on the faces may become partly filled up by a later growth of material; and in this way we may explain the presence of cavities enclosing liquid in crystals, representing, in fact, some of the mother liquor in which the crystal has grown.

An incompletely finished crystal is shown in fig. 9, where we see a crystal of violet quartz (amethyst) partly surrounded by a later growth of colourless quartz (rock-crystal). This later growth has taken place mainly at the sides, but it will be seen that the amethyst has made an attempt to grow at its summit. Had the crystal remained in its home embedded in the rock and had the conditions necessary for its growth been uninterrupted, it would perhaps have continued to grow until the pyramid was completed.

In the colourless shell of rock-crystal surrounding a nucleus of amethyst, we have an example of shelly growth. Still more pronounced cases of shelly growth are sometimes shown by common quartz, see for example, fig. 11, plate 52. Sometimes, when the shells are arranged closely together and are differently coloured, the banding of the crystal is especially conspicuous (fig. 4, plate 42; fig. 3, plate 47; fig. 6, plate 70; fig. 2, plate 76). In such cases it is obvious that the growth of the crystal has taken place by the addition of layers of material on its faces, and that at different stages of the growth there have been slightly different conditions and different colouring matters present. The successively larger layers piled on a face in this manner form together a pyramid, the base of which lies in the face of the crystal and the apex is at the centre of the crystal; these are known as "pyramids of growth". They are shown, for example in fig. 8 of plate 56, which represents a cross-section of a crystal of amethyst, with three colourless sectors alternating with three violet-coloured sectors. In the accompanying figure (fig. 85) of a gypsum crystal two "pyramids of growth" on opposite sides of the centre are transparent, while the two others are clouded by enclosed impurities.

Another form of growth is shown in fig. 7 of plate 2, representing reticulated galena from the St. Paul mine at Welkenraedt in Belgium. The thin rods or branches of galena interlace at angles of 90° in three directions parallel to the edges of the cube. The interspaces between this network are finely encrusted with yellow zinc-blende. A somewhat similar form of growth is often seen in magnetite (fig 1, plate 59), in which a number of minute octahedral crystals are arranged in rows parallel to the axes. In fig. 2 of the same plate are shown cauliflower-like growths of a mineral which is probably augite.



Fig. 85.
Gypsum from Cornwall, with "pyramids of growth".

Several other forms of growth may be distinguished by names borrowed from objects whose shapes the forms assume. For instance, mossy, filiform or wiry, leafy, etc. Examples of these are often to be seen in the native metals gold, silver and copper. We shall see further on that in each of these forms of growth, and especially in the leafy forms, there is a regularity in the arrangement of the particles of which they are composed.

Quartz crystals showing various peculiarities of growth and distorted forms are represented on plate 2a. We have already seen from figs. 8 and 9, plate 1, that the typical form of a quartz crystal is that of a six-sided prism surmounted by a six-sided pyramid: we have further seen that the faces of the pyramid are of two kinds, and represent two rhombohedra in combination. All the crystals of quartz represented in plate 2a are set up in corresponding position to those in plate 1, the principal axis being vertical and a prism face to the front. Fig. 1 has already been referred to as an example of a distorted crystal (p. 14), being flattened in one direction owing to the large development of one pair of parallel prism faces. Fig. 2 shows a twisted crystal of quartz, like that of figs. 12*a* and *b*, plate 2; the latter is, however, placed with the principal axis horizontal. These have resulted by the growing together of several individual crystals not quite in parallel position, but each turned through a small angle with respect to the one next to it. The twisted crystal in fig. 3 does not show so distinctly this composite nature of smaller crystals, but it still shows the twisted form. The large triangular faces of the trapezohedron show that the crystal in fig. 2 is a left-handed crystal of quartz, and in fig. 3 a right-handed crystal: the twist of each crystal is also in the same direction, fig. 2 having a left-handed twist, and fig. 3 a right-handed twist.

The quartz crystal depicted in fig. 5 has a helical twist about its vertical or principal axis; those in fig. 2 and 3 are twisted about a horizontal axis. These crystals were attached to the rocky matrix at the ends of the axes about which they are twisted: in fig. 5 at the lower end of the vertical axis, and in fig. 2 and 3 at the right-hand and left-hand sides of the crystal respectively. The question may be asked, what is the cause of this twisting of the crystals? Since the crystals have grown freely in a cavity in the rock it is clearly not due to the influence of any external force, but must be due to a peculiarity of the growing material itself, whereby the small particles place themselves in positions not absolutely parallel to their neighbours. There is here a regularity of a certain kind in the growth, which we will consider further on when we come to consider twin intergrowths of crystals.

A remarkable instance of distortion is afforded by the bent crystal of quartz shown in fig. 4. Several suggestions may be made to account for this bending. Has the crystal, during its growth, reached an unyielding obstacle round which it has grown, as the root of a tree grows round a stone? Or has the crystal, during its growth, been subjected to a continued pressure from one side causing it to deviate from its proper direction, like the branches of a tree exposed to wind mainly from one quarter? Or again, has the crystal been bent by some pressure applied to it after the completion of its growth? This would be a difficult question to answer, but the explanation last suggested is perhaps the most plausible, and for the following reason. Consider a wax model of a quartz crystal with the prism faces marked with the horizontal striations. If we subject this to a pressure from one side it will be gradually bent; and the striations on the prism faces on the inner side of the bend will be pressed closer together, while those on the outer side will come to be wider apart: this is how the striations are actually arranged on the natural crystal.



Forms of Growth of Quartz.

Fig.

1. **Rock-crystal**, tabular parallel to a prism face.
St. Gotthard, Switzerland.
2. **Smoky-quartz**, a twisted, left-handed crystal. Several individual crystals have grown together in not quite parallel positions to form a larger crystal.
Canton Wallis, Switzerland.
3. **Smoky-quartz**, a twisted, right-handed crystal.
Canton Graubünden, Switzerland.
4. **Quartz**. One crystal is bent round another.
Ruines, Medelser-Thal, Switzerland.
5. **Quartz**. The crystal has a helical twist about the vertical axis.
Baveno, Piedmont, Italy.
6. **Smoky-quartz**. Skeletal growth.
Schattiger Wichel, Bristenstock, Switzerland.
7. **Quartz**. The crystal has been broken at its end and cemented together again by later growth.
Ruines, Medelser-Thal, Switzerland.
8. **Quartz**. The crystal shows an attached portion of later growth.
Ilmen Mountains, Urals (?)
9. **"Sceptre-quartz."** The crystal shows a later growth on its end.
Schemnitz, Hungary.

2a



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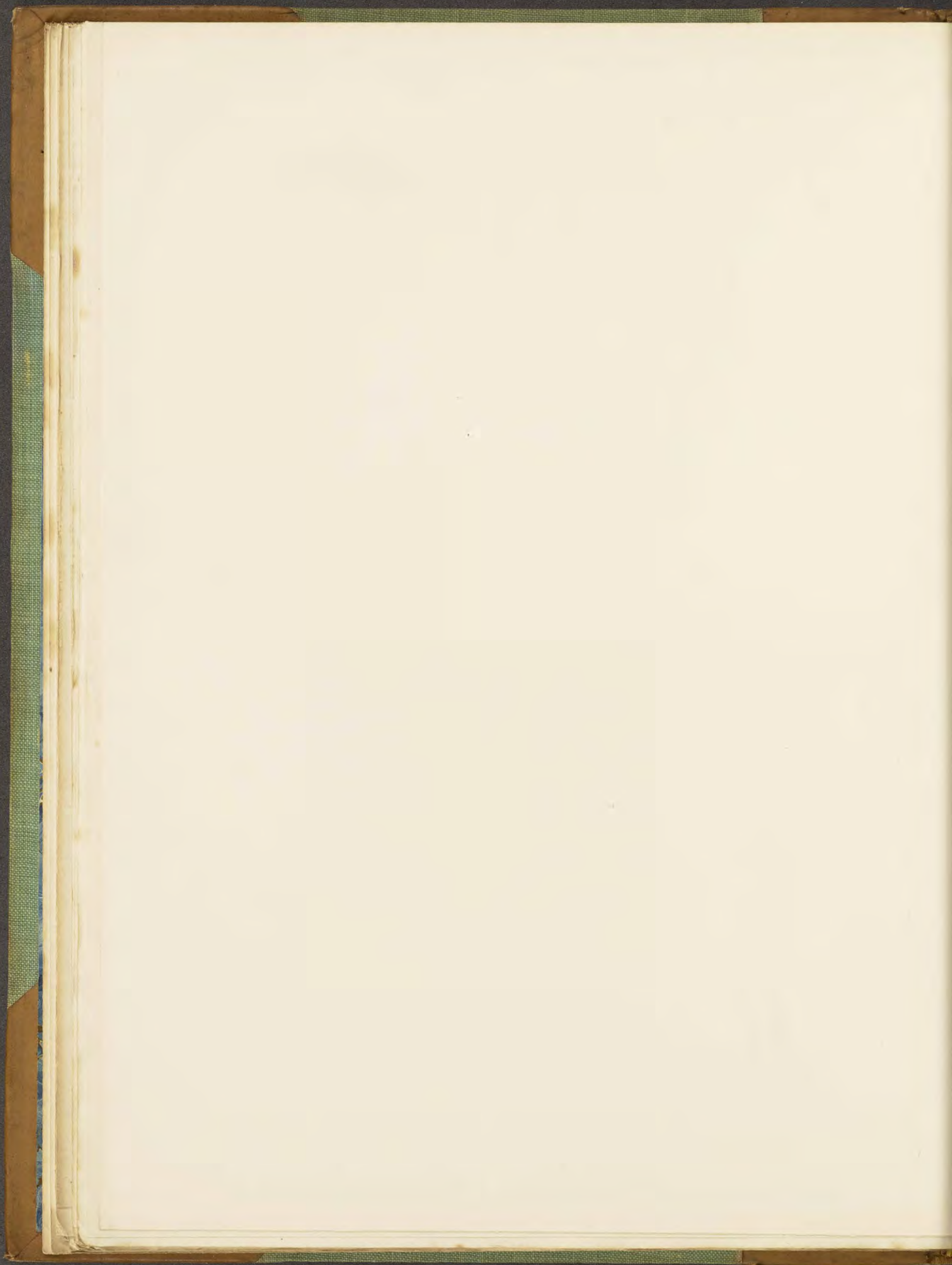
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The distortion shown by the crystal in fig. 7 is more readily explained. Here, clearly, the crystal has been actually broken by a sudden and violent movement of the rocks in which it was enclosed, possibly during an earthquake. Subsequent to the fracture, the growth of the crystal has continued, and the broken portions have been welded together by the accretion of new material. Broken crystals which have been healed in this way are by no means uncommon.

Instances proving a later period of growth in quartz crystals are shown in figs. 8 and 9 of plate 2a: in the former the growth has been continued in a small crystal attached to the side of the larger one. In fig. 9 the later growth has taken place at the apex of the crystal, and we have a columnar crystal surmounted by a shorter and thicker crystal: this is known as "sceptre-quartz". Fig. 9 of plate 2 also shows a later growth on quartz. And in fig. 6 of the same plate the dark violet rhombohedral crystal of calcite has continued its growth as colourless crystals of prismatic habit.

Intergrowths of Crystals of the same substance.

Crystals occur usually intergrown with others of the same kind, either as irregular groups or aggregations of crystals (plate 79, fig. 5), or grouped in parallel position, or in twinned position.

In cases of *parallel growth* the similar faces and edges of the several crystals are parallel to one another, and it will readily be seen that the faces which are parallel reflect light simultaneously. A good example of parallel growth is shown in plate 2, fig. 6, in which the several prismatic crystals of calcite are not only parallel to one another, but are also in parallel position with respect to the central rhombohedron of calcite around which they have grown. Since there are no similar faces on the prismatic and rhombohedral crystals, their faces will, of course, not be parallel, but their axes are parallel and so are the cleavages of the calcite in the two portions. In the large specimen of barytes represented in plate 77 the crystals have grown in parallel position.

In many cases there may be attempts at parallel growth with a greater or less deviation from the true position. Successive particles may be inclined to one another at only a small angle from the true position of parallelism, but between the first and last there may be quite an appreciable deviation in position. In this way we may have considerable variation in the forms of aggregation of crystals. An example of this is shown in fig. 11 of plate 2, representing a specimen of haematite from St. Gothard: here a number of small six-sided plates have grown together in nearly parallel position, but in such a manner that the composite crystal (which still shows the hexagonal outline) has a rosette-like form, and the specimen is called an "iron rose". Sheaf-shaped crystals of stilbite (plate 64, fig. 1) and the saddle-shaped crystals of dolomite (text-fig. 86) are also due to this sub-parallel aggregation of smaller crystals: so also are the twisted crystals of quartz already described.

Twinned crystals. — Some crystals may be seen to consist of two individual crystals of the same mineral grown together in a certain symmetrical manner, but not in parallel position. The two portions may interpenetrate, or one portion may have grown on the other.

In fig. 87 we have the interpenetration of two cubes, one of which is drawn in the normal position with four of its edges vertical. It will be noticed that at two

points the corners of the two cubes are coincident; and if we imagine the cube to be combined with the octahedron (as in fig. 25) the octahedral faces on these two corners will be common to the two crystals. If further, we imagine the crystal to be rotated about an axis perpendicular to these two octahedral faces, i. e. an axis joining the two coincident corners of both cubes, we can bring one cube into the position of the other by rotating it through 180° . Or again, we may imagine the compound crystal to be cut in two equal portions by a plane parallel to this octahedral face, and it will then be seen that the one half is the symmetrical repetition of the other half across this plane. The two cubes are therefore grown together in a perfectly definite and symmetrical manner.

In fig. 88 there are two octahedra (each apparently half of the whole form) grown together with an octahedral face on each in contact, and in such a manner that one portion may be brought into the position of the other by a rotation of 180° about an axis perpendicular to the face common to both. Further, the two portions are symmetrical with respect to this common plane, one portion being the mirror-reflection of the other across this plane.

Regular intergrowths of this kind of two crystals of the same mineral are known as twinned crystals or twins. The two individuals of the twin have one plane on each

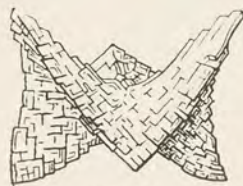


Fig. 86.
Saddle-shaped crystal of Dolomite
(After Tschermak).

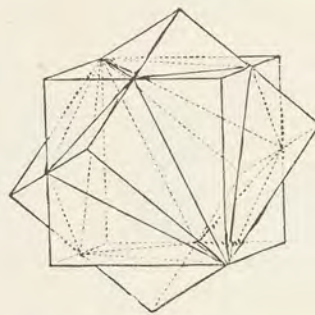


Fig. 87.
Interpenetration twin of two cubes
(Fluor-spar).

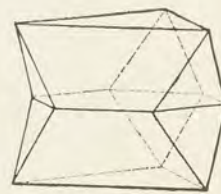


Fig. 88.
Contact twin of two octahedra
(Spinel).

in common, and across this plane one individual is the mirror-reflection of the other individual: this plane is called the twin-plane. When the two individuals interpenetrate one another, as in fig. 87, the intergrowth is called an interpenetration-twin; when they are in contact only, as in fig. 88, it is called a contact-twin.

A twinned crystal may be derived from two simple (i. e. untwinned) crystals by first placing them side by side in parallel position, and then turning one of them through 180° about an axis, called the twin-axis, which is perpendicular to the twin-plane. It may readily be seen that a plane of symmetry of a crystal cannot be a plane of twinning, since rotation about an axis perpendicular to such a plane would simply bring the crystal in a similar position again. Contact-twins are in many cases much flattened parallel to the plane of twinning, and the two portions look more like half crystals (fig. 88). The relations of twinned crystals may be very readily demonstrated by the aid of wooden models: the simple form is sawn through the middle and the two halves rotate one on the other about a peg, giving either the simple form or the twinned form according to their relative positions. Twinned crystals may usually be recognized by the re-entrant angles between their faces, as in all the figures here given of twins, but these are not invariably present. It should be remembered that an accidental and irregular intergrowth of two or more crystals will also show re-entrant

angles between the faces, but these will not be disposed in the same symmetrical manner as in twins.

In the *cubic* system the twin-plane is very often a face of the octahedron, as in the examples (figs. 87 and 88) already given. The twinned octahedron of fig. 88 is a common type, and, being especially well shown by the mineral spinel, it is called the spinel-twin. The same kind of twin is also often to be observed in the leafy forms of gold and silver, and will be described further on.

In the *tetragonal* system the twin-plane is most often a pyramid face, which is usually taken as a pyramid of the second order. The crystal of cassiterite (tin-stone) represented in fig. 89 is a combination of the primary pyramid $s = P$ and the vertical prism $m = \infty P$. The twin-plane is a face of the pyramid of the second order $P \infty$ which truncates the edge between two s faces at the top of the figure. Such twins are common in cassiterite (plate 38) and rutile (plate 39).

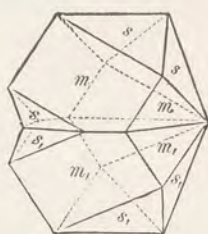


Fig. 89.
Tetragonal crystal twinned on a face of the pyramid of the second order (Cassiterite).

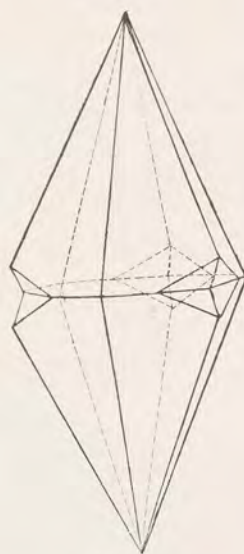


Fig. 90.
Scalenohedron of calcite twinned on the base.

In *rhombohedral* crystals of the hexagonal system the basal plane or a rhombohedral face are common twin-planes. The scalenohedron (compare fig. 68) twinned on the basal plane gives the twin represented in fig. 90; in which the lower half has been turned through an angle of 180° about the principal, vertical axis. In the twinned scalenohedron similar edges, over which the angle is either obtuse or acute, come opposite above and below, and the edges at the middle of the crystal are horizontal. A twinned scalenohedron of calcite is represented in plate 73, fig. 6.

In *rhombic* crystals the twin-plane is usually a prism face, less often a pyramid face. The crystal of aragonite in fig. 91 is bounded by the vertical prism $m = \infty P$, the brachy-pinacoid $b = \infty P \infty$, and the brachy-dome $k = P \infty$; and the second individual is so grown on the first that a face of the vertical prism is common to both, the two portions being symmetrical across this plane. A further description of these twins will be given under aragonite (plate 74) and cerussite (plate 17).

In *monoclinic* crystals the twin-plane is often the ortho-pinacoid, sometimes the base or a clino-dome. An augite crystal (fig. 82) when twinned on the ortho-pinacoid a gives the twin represented in fig. 92, where it is readily seen that the two portions are symmetrical about a plane parallel to a .

In *triclinic* crystals any face may be a twin-plane, but usually it is one of those chosen for a pinacoid.

Sometimes in the same crystal the twinning may be repeated several times on the same twin-plane: the first, third, fifth etc. portions will then be in parallel position with each other, and the second, fourth, sixth etc. will also be parallel, but adjacent portions will be in twinned position with respect to each other. Repeated twinning of this kind when the several portions are quite thin gives rise to a lamellar structure of the crystal; and in some instances the twinning is only rendered obvious by the striations produced by the lamellae on the faces. This is shown in the crystal of aragonite in fig. 93. The portion to the front is as in fig. 91. But the second

portion is quite thin; the twinning is repeated on the same prism face three more times, and the last (fifth) individual is parallel to the first. The crystal then looks like a simple crystal with fine striations on its faces (compare plate 74, fig. 3 and 4).

In other cases of repeated or multiple twinning the twinning may be repeated not on the same face but on other faces of the same form. For example, in the aragonite crystal in fig. 91, the twin-plane is the prism face m to the left, but the prism face m to the right is a similar face and may also be a plane of twinning. We may therefore have three aragonite crystals twinned together on both of the prism faces of one of them,

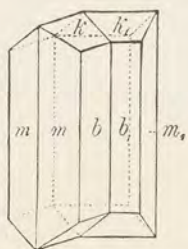


Fig. 91.
A rhombic crystal twinned on
a prism face (Aragonite).

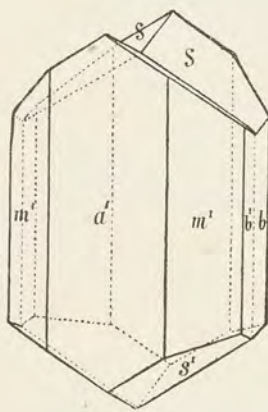


Fig. 92.
A monoclinic crystal twinned
on the ortho-pinacoid.
(Augite).

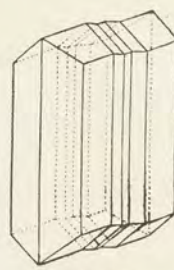


Fig. 93.
Repeated twinning in ara-
gonite.

and since in aragonite the angle between the faces m and m is 116° the result will be a compound crystal resembling a hexagonal crystal in appearance (figs. 5—7, plate 74). In some other minerals with a prism angle still nearer to 120° this kind of twinning may produce forms which by the unaided eye cannot be distinguished from hexagonal crystals.

There are several instances of this kind among minerals in which twinning has the effect of increasing the apparent symmetry of a crystal: and such twins are called mimetic or pseudo-symmetric twins.

Regular intergrowths of crystals of different minerals: Enclosures in crystals.

Sometimes we meet with regular intergrowths between the crystals of two totally different minerals. An example of this is shown in fig. 9 of plate 28 and in text-fig. 94; on the basal plane of the large tabular crystal of haematite are laid a number of small prismatic crystals of reddish rutile, arranged in three directions at 60° to one another and parallel to the three horizontal crystallographic axes of the haematite. In fig. 95 a rhombic crystal of brown staurolite is grown in a definite position on a triclinic crystal of blue cyanite. Fig. 3, plate 67 shows under the microscope a regular growth of the two minerals augite and hornblende. The light coloured augite in the upper half of the figure has two sets of cleavages intersecting at an angle of 87° , and the darker hornblende (below) has also two sets of cleavages but at an angle of $124\frac{1}{2}^\circ$:

both minerals are monoclinic and they are so placed in relation to one another that their ortho-pinacoids and vertical axes are parallel.

In cases of regular intergrowth of this kind it is clear that one mineral must have exerted an influence over the other and constrained its particles as they crystallised to assume a definite orientation.

Enclosures of foreign material are very frequently present in crystals, and these will of course be more conspicuous and easily detected the larger the particles and the more transparent the crystal. The enclosed materials may consist of other minerals, of glassy matter, liquids, or gas. They may be distributed through the crystal without any regularity, or

they may be arranged in bands or zones; or again, there may be a definite crystallographic orientation between the enclosing and enclosed minerals.

Enclosures of green actinolite in clear rock-crystal are shown in fig. 9, plate 54; of rutile needles in rock-crystal in fig. 4, plate 55; of glass in leucite in a microscope section of Vesuvian lava in text-fig. 96. Regularly arranged enclosures of glass and

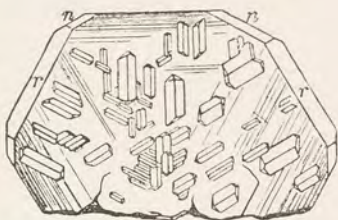


Fig. 94.
Regular growth of rutile on haematite. (After Tschermak).



Fig. 95.
Regular growth of staurolite on cyanite. (After Tschermak).



Fig. 96.
Glassy enclosures in leucite. Lava from Vesuvius.
Magnification 45.

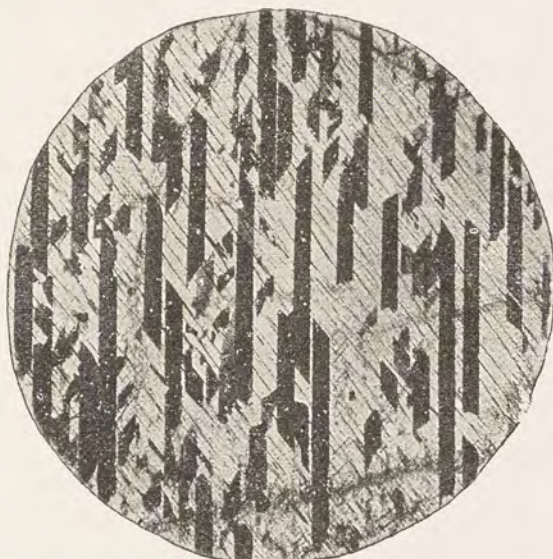


Fig. 97.
Dark mineral enclosures in (pale) hypersthene.
Magnification 45.

slag in a felspar crystal are shown in fig. 5, plate 59, and in leucite in fig. 4, plate 61a. Enclosures of liquid in a crystal may usually be recognized by the presence of a bubble of gas, which moves about as the crystal is moved. Cavities containing gases are usually only of microscopic size.

The presence of enclosures in crystals is of significance from several points of view. In some cases they give rise to peculiar colour phenomena which are not exhibited by minerals free from enclosures. The very thin brown plates, possibly of

ilmeneite, often enclosed in hypersthene (fig. 97) are the cause of the coppery sheen so characteristic of this mineral (plate 65, fig. 2). The brilliant colours of labrador-felspar and the spangled reflections of sun-stone are also due to the presence of enclosed minerals.

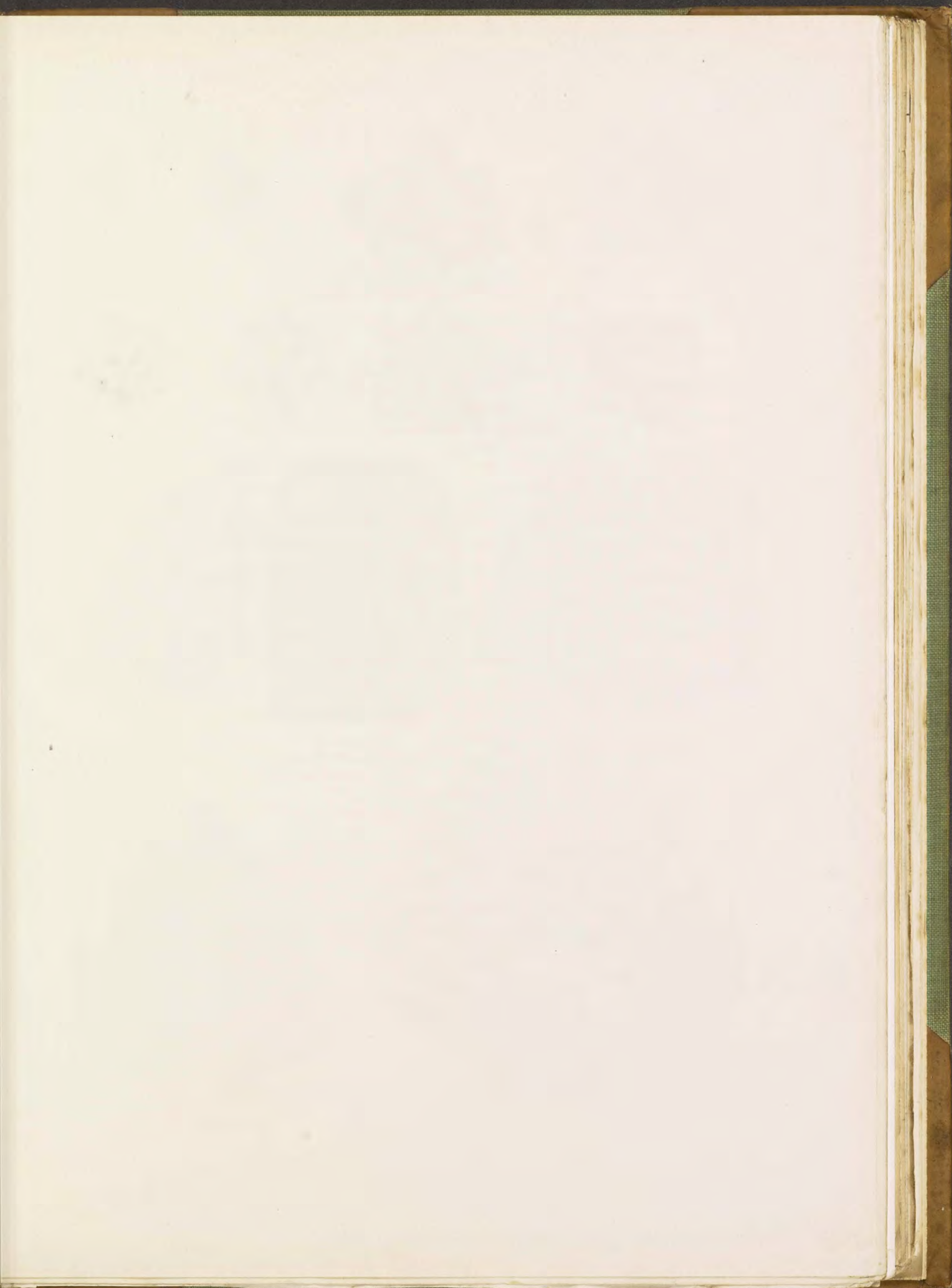
The enclosure of glass and slag in a crystal proves conclusively that the crystal has crystallized from a molten mass; whilst the presence of liquid enclosures proves that the crystal has grown from a solution. Enclosures of liquid carbonic acid indicate that the crystal was formed under considerable pressure; and the presence of cavities containing petroleum in rock-salt (plate 70, fig. 6) points to the presence of petroleum during the period of crystallization of the rock-salt.

Grouping and aggregation of crystals.

In describing the forms of crystals we have assumed that the crystals have been completely bounded on all sides by faces. This will, of course, only be the case when the crystals have been freely suspended in the medium in which they grew, and material for their growth supplied on all sides. Crystals of this kind are called *embedded* crystals, since they have grown embedded in the matrix in which they are found (see, for example, plate 41, figs. 1—6; plate 47, fig. 13). More often crystals occur attached to the matrix, and they are then called *attached* crystals (plate 1, figs. 2, 5, 7). This must happen whenever the crystals have grown on the walls of rock crevices or cavities. At the point of attachment faces are, of course, not developed; but the freely developed faces of attached crystals are usually much brighter and sharper than are the faces of embedded crystals; and for this reason they are preferred by the mineralogist, since they give better measurements of the angles between the faces on the reflecting goniometer. Also, as a rule, attached crystals are richer in crystal-faces of different forms than are embedded crystals. When several embedded crystals have grown together they may be referred to as a cluster of crystals (plate 79, figs. 4 and 5); and when several attached crystals are grown together they form a group of crystals (plate 23, and frontispiece).

Rock-cavities completely lined with attached crystals are known as *geodes* or *druses* (plate 1, fig. 1). Sometimes these are so large that they are practically caves lined with crystals; as for example the large cavities containing rock-crystals and smoky-quartz in the Alps. Cavities lined with large crystals of gypsum or of calcite are also sometimes of considerable size.

When a number of crystals have grown so close together that they have interfered with each other's development, there may be no faces formed, and the whole mass consists of a compact aggregate of imperfectly formed crystals, which may be called a *crystalline aggregate*. Certain minerals have a strong tendency to grow in such crystalline aggregates, which may be of various kinds depending on the shapes of the constituent crystalline particles. For instance the structure of a crystalline aggregate may be platy (plate 41, fig. 8), fibrous (plate 41, fig. 9), columnar (plate 15, fig. 10), radiating (plate 22, fig. 5), shelly (plate 13, fig. 6). A granular structure may be coarse, or fine to compact, according to the size of the grains. Sometimes two forms of aggregation are present in the same specimen; for example, in malachite (plate 13, fig. 7), where alternate layers show a radially fibrous structure and a concentric shelly structure; and in kidney-iron-ore (plate 28, fig. 11) and limonite (plate 30, fig. 3).



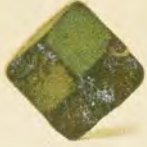
Pseudomorphs.

Fig.

1. **Cuprite**, fresh, but with a dull surface. A cube, which has continued its growth as rhombic-dodecahedron.
Chessy, Lyons, France.
2. **Cuprite** partly altered on the surface to malachite. A large rhombic-dodecahedron.
Chessy, Lyons, France.
3. **Cuprite** altered to malachite: a pseudomorph of malachite after cuprite.
Chessy, Lyons, France.
4. **Cuprite** altered to malachite. An octahedron with rhombic-dodecahedron: the octahedral faces are depressed.
Chessy, Lyons, France.
5. **Cuprite** altered to native copper: a pseudomorph of native copper after cuprite. In the interior (shown in fig. 5b) some unaltered cuprite remains.
Old Dominion mine, Globe, Gila Co., Arizona, U. S. A.
6. **Iron-pyrites**, a fresh, unaltered cube. The faces are striated parallel to one of the edges of the cube.
Brosso, near Ivrea, Piedmont, Italy.
7. **Iron-pyrites** altered to limonite: pseudomorph of limonite after iron-pyrites. The striations on the cube-faces are still recognizable, proving that the crystal was originally iron-pyrites.
Brosso, Piedmont, Italy.
8. **Iron-pyrites**, a striated cube (as in fig. 6) altered to iron hydroxide (limonite or goethite).
Tavistock, Devonshire (?)
9. **Iron-pyrites**, a pseudomorphous crystal broken through, to show the interior of unaltered iron-pyrites and the exterior altered to limonite.
Beresovsk, Ural Mountains, Russia.
10. **Calcite**, a fresh (unaltered) scalenohedral crystal.
Iserlohn, Westphalia.
11. **Calcite**, crystals coated on their surface with earthy haematite, but in the interior still consisting of unaltered calcite. An early stage in the pseudomorphism of haematite after calcite.
Amönau, near Wetter, Marburg, Hesse.
12. **Calcite** altered to haematite, and filled in the interior with quartz.
Iserlohn, Westphalia.



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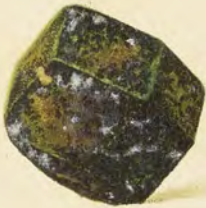
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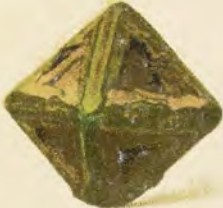
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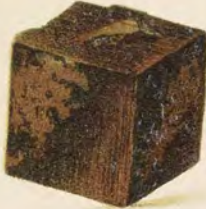
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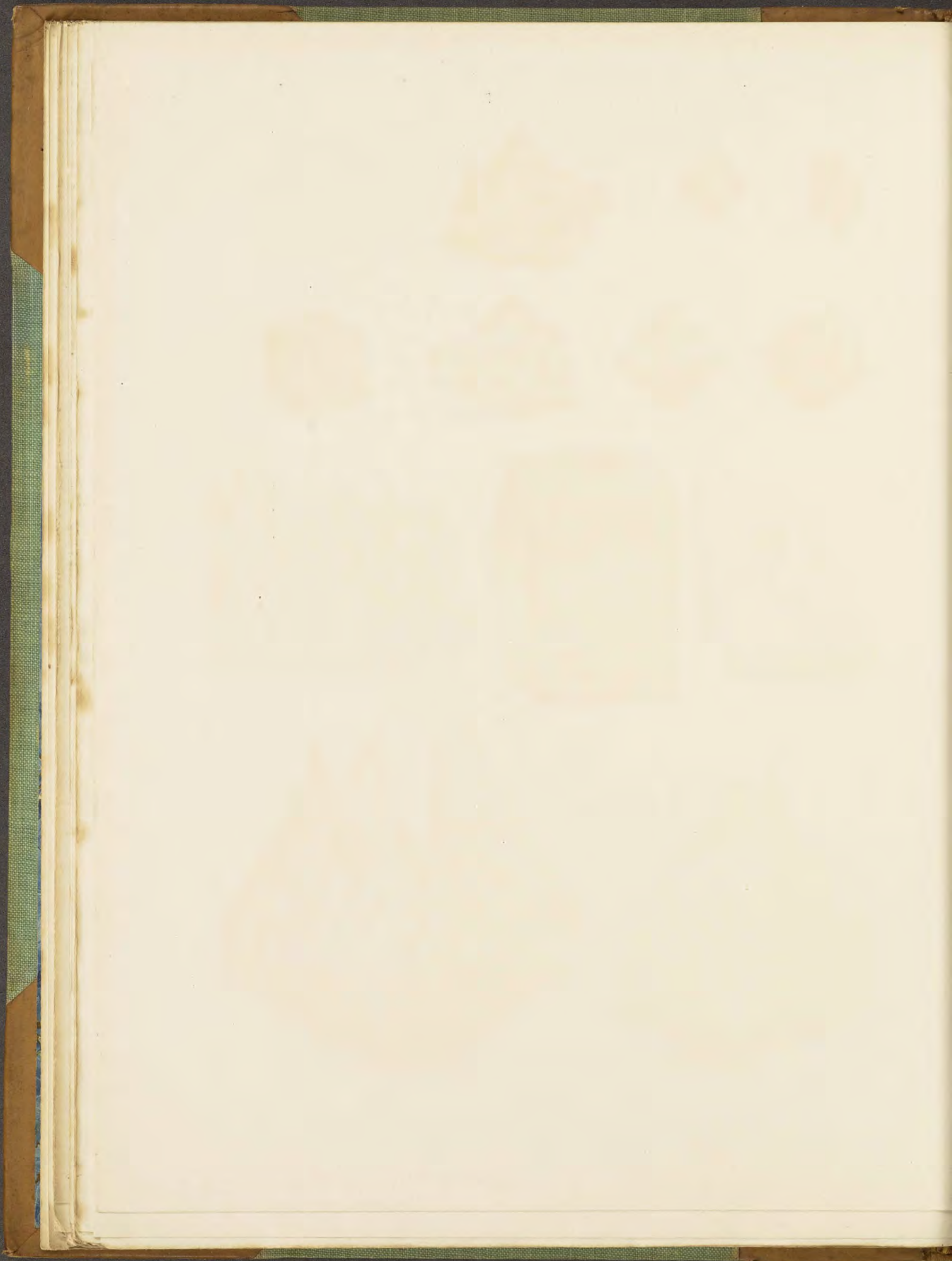
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Amorphous Substances.

Crystals, as we have seen, are bounded by plane faces and may be cleaved with greater readiness in certain directions than in others: their properties vary with the direction, and the ultimate particles of which they are built are disposed in regular order. Even when plane faces are absent, as in crystalline aggregates, the material possesses this regularity of internal structure. In contradistinction to this, there are a few minerals which possess no definite external form and no regularity in their internal structure: their particles are arranged according to no definite plan, and the properties of the mass are the same in every direction so that there is no particular direction in which the material may be more readily cleaved. Such substances are called amorphous. A good example is given by glass, and amongst minerals by opal. When an amorphous mineral exhibits an external form other than that of conchoidal fractured surfaces, this is rounded, being globular, botryoidal or reniform. This form has not been developed by the substance itself, as in crystals, but is the result of external influences, mainly of gravity, during the formation of the material.

Pseudomorphs.

Not infrequently we find minerals exhibiting a crystalline form which is characteristic not of that mineral but of some other mineral. The mineral which originally gave rise to the form has been destroyed and its place has been taken by some other mineral. This replacement of one mineral by another may be complete and the material of the crystal transformed throughout; or it may be only partial, the new mineral forming only the outer portion with the remains of the original mineral still forming the central portion of the crystal. Such altered crystals are called pseudomorphs. They have been formed when, in course of time, the conditions of environment have become different to those under which the crystal at first grew. The process of alteration is usually a purely chemical one, brought about by the aid of various solutions. Pseudomorphs are thus of particular interest and importance, for they tell us the chemical changes which minerals have undergone in the earth's crust. A few concrete examples will help to make the matter clearer.

The crystal represented in plate 3, fig. 3 has the form of the rhombic-dodecahedron, and its substance consists of the green mineral malachite. But malachite when it crystallizes freely takes the form of needle-shaped monoclinic prisms, and not cubic crystals as we have here. By examining and breaking open other crystals of the same kind we shall perhaps find some which consist on the outside only of green malachite and inside of a red transparent mineral. The crystal shown in fig. 2, which like the previous crystal is also from Chessy near Lyon in France, shows this clearly; the main part of this crystal consists of the red mineral, with the green malachite only in patches on the surface. In fig. 1 we have a crystal of the red mineral, cuprite, in its unaltered condition and exhibiting its own characteristic crystalline form. Cuprite is an oxide of copper, and when immersed in water containing carbonic acid it will slowly take up water, carbonic acid and oxygen, and be converted into malachite, a hydrated carbonate of copper. This alteration of cuprite to malachite has commenced in the crystal shown in fig. 2, and is completed in that of fig. 3. In the crystal shown in fig. 4 some of

the malachite appears to have been subsequently dissolved away, or perhaps the depressions on the octahedral faces were so in the original cuprite crystal (as in fig. 8, plate 2).

The example just described in detail may be briefly described as a pseudomorph of malachite after cuprite. Here the cuprite has been acted upon by a solution from which it could abstract carbonic acid, water and oxygen; but if the solution had been of another kind the result of the alteration would be quite different. If, for instance, the solution contains a substance having an affinity for oxygen, this element may be extracted from the cuprite and only the copper left. This has happened in the crystal represented in fig. 5, in which the exterior consists of native copper, though the interior still consists of cuprite, the alteration having been only partial. Here we have a pseudomorph of native copper after cuprite.

The crystals shown in figs. 7 and 8 of the same plate are regular cubes and their material consists of hydrated oxide of iron, a compound which never crystallizes in cubic forms. It will be noticed that the faces of these crystals are each striated parallel to only one of the cubic edges: and this feature we have already seen is especially characteristic of crystals of iron-pyrites (fig. 6), a mineral composed of iron and sulphur. That iron readily combines with oxygen and water with the formation of rust is a fact well known to everybody, and the same is also true in the case of the iron of iron-pyrites. When then, crystals of iron-pyrites are exposed to the action of underground waters containing oxygen their iron is converted into a hydrated oxide and their sulphur is removed in solution as free acid or as sulphates. If the alteration has been only superficial, the crystal when broken open will show an interior of still fresh iron-pyrites (fig. 9).

In the three examples of pseudomorphs so far given, the original substance of the crystal has undergone a chemical alteration of such a kind that the new material still contains one of the elements (copper or iron) that before were present: the other constituents have been exchanged. Pseudomorphs of this nature are called *alteration pseudomorphs*.

In other cases the new substance and the original substance of the pseudomorphous crystal have no constituent in common. Here the original substance has not been altered; it has been simply removed, and the space it occupied has been taken up by the new substance. A case of this kind is illustrated in figs. 10—12 of plate 3. The first figure represents fresh and unaltered crystals of calcite; in fig. 11 the calcite crystals are coated over with a deposit of red iron oxide; and in fig. 12 the calcite is entirely replaced by the iron oxide. The interaction of a solution containing iron on the calcium carbonate of the calcite produces a precipitation of iron oxide and a corresponding amount of calcium carbonate goes into solution. In the course of time the calcite will be in this way gradually removed and its place taken by the precipitated iron oxide. The interior of such pseudomorphs of red iron oxide (earthy haematite) after calcite are often, as in the specimen of fig. 12, filled with a deposit of massive quartz. That this iron was here deposited as oxide rather than as carbonate is readily explained by the readiness with which iron carbonate is oxidized. If, however, the solution had contained no oxygen available for oxidation then the new mineral might be deposited as a carbonate, providing, however, that this carbonate is more difficultly soluble than the calcium carbonate of the calcite. This is the case with dolomite and calamine, both of which minerals occur as pseudomorphs after calcite. Dolomite, which is a double carbonate of calcium and magnesium, often occurs only as a thin crust on calcite crystals, the interior of the crystal still consisting of calcite: but sometimes the

crystal may be entirely replaced by dolomite, or by calamine. Pseudomorphs of the kind described above (haematite after calcite), in which the whole of the original material is replaced, are called *replacement pseudomorphs*.

Less often do we find examples of pseudomorphs in which there has been no chemical change of the material, but only an alteration in the crystalline structure, and in the specific gravity and other physical characters. The crystal shown in fig. 13 of plate 19 has the form of a rhombic prism with pyramid, and is the form characteristic of the mineral brookite, which is a modification of titanium dioxide, TiO_2 , possessing a specific gravity of about 4.0. The material of which this crystal now consists is likewise titanium dioxide; but it has a specific gravity of 4.2. Moreover its internal structure is not that of a single crystal, but we have an aggregate of numerous small prismatic crystals with no definite arrangement, which give a damask-like sheen to the surface of the crystal. These small needle-like crystals belong to the tetragonal system and have all the characters of the mineral rutile, which is another crystalline modification of titanium dioxide. Thus, without any alteration in chemical composition, the rhombic crystal of brookite has been transformed into a confused aggregate of tetragonal crystals of rutile. There has been a rearrangement of the minute particles of the substance, and the alteration may be said to be a molecular transformation. Changes of this kind can only take place with substances which occur in more than one crystalline modification, that is polymorphous substances; and their pseudomorphs are called *paramorphs*. The crystal described above is a paramorph of rutile after brookite. Other examples are given by the alteration of aragonite to calcite, both of which minerals consist of calcium carbonate (plate 74, fig. 9); and of tridymite to quartz. The crystal shown in fig. 14, plate 54, is a paramorph of quartz after tridymite; it has the form of tridymite, but the material of which it now consists is quartz; these two minerals are chemically identical, both consisting of silica (SiO_2), but different in their crystalline form and physical characters.

The Physical Characters of Minerals.

Of the physical characters of crystals those of hardness and cleavage first engage our attention.

By *hardness* is understood the resistance which a mineral offers to a point pressed against it: if the point be harder than the mineral, the mineral will be scratched. If we try the hardness of a number of minerals by pressing the point of a knife against them, we will find that some are readily scratched, others only with difficulty, whilst others will turn the point of the knife. We thus see that different minerals possess different degrees of hardness. For the convenience of being able to express in numbers the approximate degree of hardness of a mineral the following series of ten minerals, each one successively harder than the preceding, was selected by Professor F. Mohs to form a scale of hardness.

Mohs' Scale of Hardness.

- | | | |
|----------------|-------------|--------------|
| 1. Talc. | 5. Apatite. | 8. Topaz. |
| 2. Gypsum. | 6. Felspar. | 9. Corundum. |
| 3. Calcite. | 7. Quartz. | 10. Diamond. |
| 4. Fluor-spar. | | |

Talc, no. 1 on the scale, is the softest of minerals, and diamond, no. 10, is the hardest. Calcite, no. 3 on the scale, is harder than gypsum, no. 2, and a piece of gypsum is readily scratched by calcite. We have thus an easy means of determining the hardness of any mineral. For example, it will be found that rock-salt is capable of scratching gypsum, but that it can be scratched by calcite: rock-salt is therefore harder than gypsum, but less hard than calcite, and its degree of hardness is expressed as $2\frac{1}{2}$ on the scale. Again, garnet may be scratched by topaz, and it will itself scratch felspar; but it does not scratch quartz, nor does quartz scratch garnet. The hardness of garnet is therefore the same as that of quartz, and is expressed by 7.

Gypsum and other minerals with a hardness of less than 2 on the scale may be easily scratched with the finger-nail; and they are greasy to the touch (especially talc). Ordinary window-glass has about the same hardness as apatite, and it may be used as no. 5 of the scale. A good knife will scratch felspar with difficulty, but will not touch quartz.

The degree of hardness of a mineral differs on the faces of different crystal-forms, and in different directions on the same face. But usually these differences are so small that they can only be detected with the aid of specially constructed instruments. In a few instances, however, the difference is more pronounced, especially in certain minerals which possess a perfect cleavage. A cleavage face of calcite can be scratched by a crystal of calcite in the direction of the shorter diagonal of the rhomb-shaped face, but not in the direction of the longer diagonal.

In the scale of hardness given above, which is the one universally used by mineralogists, there are very wide differences in the actual degree of hardness between consecutive numbers. Taking the hardness of corundum as 1000, that of diamond = 140,000, topaz = 175, quartz = 120, felspar = 37, apatite $6\frac{1}{2}$, fluor-spar = 5, calcite = $4\frac{1}{2}$, gypsum = $1\frac{1}{4}$, and talc = $\frac{1}{33}$.

Cleavage. — Crystals of many minerals may be broken or split more readily in certain plane directions than in others. This important property of crystals is called cleavage. The direction of cleavage is always parallel to a possible face on the crystal, which is usually a prominently developed face of some simple form. Such a fractured surface is called the cleavage face, and a portion of a crystal entirely bounded by cleavage faces is called a cleavage form or cleavage fragment. The ease with which a crystal may be cleaved and the perfection of the resulting cleavage face vary widely in different minerals. In the same crystal there may be one or several directions of cleavage; if these are parallel to the faces of different forms, the character of the cleavages will be different; but if they are parallel to the several faces of the same form they will be similar in character. When a crystal possesses a cleavage parallel to one face of a simple form, it must also possess similar cleavages parallel to all the other faces of that form. Thus in fluor-spar, which readily cleaves parallel to the octahedron, there are four directions of perfect cleavage parallel to the four pairs of parallel octahedral faces (plate 1, fig. 6).

The best example of perfect cleavage is to be seen in mica, a mineral which cleaves in one direction parallel to the base. It can with ease be split into the thinnest of sheets, and these find an extensive application for the windows of stoves, for lamp chimneys, etc. Rock-salt has three directions of perfect cleavage parallel to the faces of the cube (fig. 3), and calcite also has three directions parallel to the faces of the primary rhombohedron (plate 73, fig. 8). When crystals of these minerals are broken, they almost invariably break along these directions. Zinc-blende has six directions of perfect

cleavage, parallel to the faces of the rhombic-dodecahedron (plate 20, fig. 9). Other minerals have less distinct cleavages; and in some, for example quartz, this property is almost or quite absent.

The presence or absence of cleavage can usually be made out from the inspection of the fractured surface of a crystal. Cleavage cracks may also be often seen inside a crystal, and on these coloured rings may frequently be observed.

The broken surfaces of minerals which do not possess any distinct cleavages are often quite characteristic in appearance. And according to the character of these surfaces, the *fracture* is distinguished as conchoidal, splintery, uneven, etc.

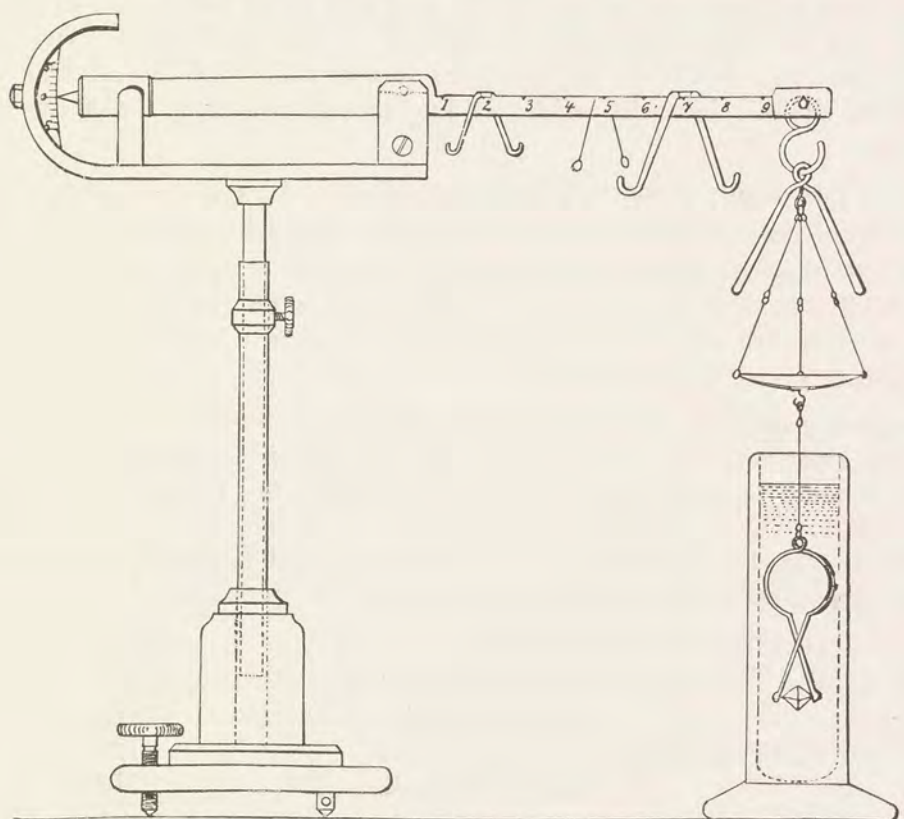


Fig. 98.

Westphal's balance for determining the specific gravity of small crystals.

Specific gravity. — The specific gravity of a body is a number which expresses how many times heavier that body is than an equal volume of water. When we know the weight and volume of any given body, we can calculate its specific gravity by dividing the weight of the body by the weight of an equal volume of water. The weight of the body is found by weighing, and its volume is determined by immersing it in water. The volume of the water displaced, which will be equal to the volume of the body, may be found by direct measurement. Usually, however, the volume is determined by weighing the body in water, when the difference between its weight in air and its weight in water will give the weight of the displaced water. These weighings may be conveniently made with a Westphal's balance (fig. 98), with which the specific gravity of specimens weighing from 0.2 to 2.0 grams may be determined. The instrument consists of a horizontal beam supported on knife edges. At the free end hangs a scale-pan, below which is a fine wire carrying a clip for holding the specimen.

The wire and clip are immersed in a vessel of water. The pointer on the left-hand end of the beam moves across the scale, and it is brought to the zero position by placing the weights or riders at suitable positions on the graduated beam.

When using the instrument, the clip must be first immersed in the water and the beam brought into the position of equilibrium with a rider, the position of which is noted. The mineral is then placed in the scale pan, and the rider or riders moved to the left until the beam is again in the position of equilibrium. The difference between the readings, given by the positions of the riders, is the weight of the mineral in air. The mineral must now be fixed in the clip and immersed in the water, care being taken that no fragments are broken off, and that no air bubbles are adhering. The riders must now be moved towards the right to restore equilibrium. The difference between the last two weighings will give the loss of weight of the mineral in water. This difference divided into the weight of the mineral will give the specific gravity of the mineral.

The series of operations will be perhaps clearer if we give a concrete example. The riders are of three sizes, the largest being the unit weight, and the others $\frac{1}{10}$ and $\frac{1}{100}$ of the unit. If they are hung on the hook at the end of the beam they have their full value, whilst if they are placed in the first notch on the beam they have only one-tenth of their full value. The positions of the four riders shown in the figure (fig. 98) indicate a weight of 1.725.

Supposing now, we wish to determine the specific gravity of a cut brown zircon such as that represented in plate 43, fig. 16, the clip is immersed in the vessel of water, and in order to bring the beam into equilibrium the reading of the weights is, let us say, 2.425. The stone is now placed on the scale pan, when the weights will be at, say, 1.614. Finally, the stone is fixed in the clip and immersed in water, and the weights re-adjusted to 1.786 to restore equilibrium. We then have: —

(1.) Tare without the stone	2.425
(2.) Tare with stone in scale-pan	1.614
Weight of stone	0.811
(3.) Tare with stone in water	1.786
Deduct the reading (2)	1.614
Loss of weight in water	0.172

$$\frac{\text{Weight of stone}}{\text{Loss of weight in water}} = \frac{0.811}{0.172} = 4.71.$$

This result, 4.71, is the specific gravity of the specimen of zircon.

A very convenient and rapid method of determining the specific gravity of minerals, and especially of small fragments of them, is with the help of heavy liquids. The method depends on the fact that a body will float on a liquid which is heavier than the body, while if the liquid is lighter than the body, the latter will sink. If both the body and the liquid have exactly the same specific gravity, the body will remain suspended at any part of the liquid. It is therefore possible, when starting with a liquid heavier than the mineral to be tested, to so dilute the liquid and thus reduce its specific gravity, that the mineral will remain exactly suspended. If then we determine the specific gravity of the liquid, we know that of the mineral also. The specific gravity of the liquid may be determined by means of the Westphal's balance and a float in the liquid, or more conveniently, as mentioned below, with a set of indicators.

There are several heavy liquids which may be used for this purpose. The most convenient is methylene iodide, which at the ordinary temperature has a specific gravity of 3.33. This specific gravity may be successively reduced to rather less than 1 by adding increasing amounts of benzole. If a small fragment of a mineral or a faceted gem-stone be dropped into this liquid we shall know at once whether its specific gravity is greater or less than 3.33. If it sinks, the determination of its exact specific gravity cannot be made with the help of this liquid; all we know is that it must be greater than 3.33. If, on the other hand, it floats, the methylene iodide must be diluted with benzole, added drop by drop, until the stone remains suspended in the liquid, neither floating to the surface nor sinking to the bottom.

For purposes of distinguishing different minerals it is often not necessary to make an exact determination of the specific gravity, but only to find out whether a given specimen is lighter or heavier than, or has the same specific gravity as, a known mineral. For example, supposing we have two colourless faceted stones, one a topaz and the other quartz, and we wish to distinguish one from the other. Topaz has a specific gravity of 3.35, and quartz that of 2.65. If we drop the two stones into methylene iodide, the topaz will, of course, sink and the quartz will float. If now, the methylene iodide be diluted with benzole until the cut quartz just remains suspended, we shall find that a quartz crystal, which we know by its crystalline form, dropped into the liquid will also remain suspended. We thus see that the cut stone has exactly the same specific gravity as quartz, and for this reason it may be pronounced to be quartz.

Or again, supposing we wish to determine whether a small splinter of a mineral (which we know to be a carbonate from the fact that it effervesces in a drop of hydrochloric acid) is calcite (sp. gr. 2.72) or aragonite (sp. gr. 2.93). The mixture of methylene iodide and benzole is brought to a specific gravity of about 2.8, when the fragment, if aragonite, will sink, or, if calcite, will float. By placing in the liquid, together with the fragment to be determined, fragments which are known to be aragonite and calcite, the specific gravity of the fragment can be determined exactly.

This method, with the use of indicators, is indeed the most convenient. We may have a set of tubes containing methylene iodide and benzole in different proportions, and in each tube have recognizable fragments of one or more minerals to act as indicators, for example, gypsum (sp. gr. 2.32), quartz (2.65), calcite (2.72), tourmaline (3.02), apatite (3.20) etc.

Methylene iodide, though the most convenient liquid to use for the determination of the specific gravity of minerals, has one drawback, namely that of expense; but it need be used in only small quantities and without any waste if care be taken. A much cheaper liquid is bromoform, but, since this has a specific gravity of only 2.8 its application is much more limited.

The specific gravity of each kind of mineral (except in those cases where there is isomorphous mixing, as explained below) has always a fixed and definite value, which is characteristic for that mineral. It is necessary, however, that the determination should be made on material that is quite pure, with no signs of alteration nor with any foreign enclosures. For purposes of determination and for discriminating different minerals the specific gravity is a character of the greatest value.

Optical Characters.

The optical characters of crystals, or their action on light, are of the utmost importance to the mineralogist. But, since this is a somewhat technical branch of the subject, and the observations require the use of special instruments, we shall here only briefly mention the main points, reserving some others of interest till when we come to treat of the individual minerals. Those who wish to study the subject must refer to the textbooks on mineralogy, such as Professor H. A. Miers' "Mineralogy" (London, 1902) and Professor J. P. Iddings' "Rock Minerals" (New York, 1906).

Minerals possess different degrees of transparency and opacity; some are perfectly transparent, and others are perfectly opaque, and between these two extremes there is every grade of transition, even in one and the same kind of mineral.

Colour is also an important, though often variable, characteristic of minerals. In some minerals the colour is an essential character and peculiar to the kind of substance, but in many others it is non-essential and quite accidental. Examples of minerals which possess a colour peculiar to themselves are: the native metals (e. g., gold, copper), a few non-metallic elements (sulphur), minerals with a metallic lustre (iron-pyrites), and several other minerals which contain a metal (malachite). But in some of these cases it must be borne in mind that the colour may be hidden or obscured by a surface tarnish (for example, on native silver); it is therefore sometimes necessary to observe the colour on a freshly fractured surface of the mineral. Most other minerals, however, owe their colours to the presence of foreign colouring matter enclosed in them. This may be present as visible particles, for example, the small platy enclosures which give a brown colour to hypersthene (text-fig. 97, p. 47); but more often it is extremely finely divided, like the colouring matter in a solution. For this reason the colours exhibited by different specimens of one and the same kind of mineral may often be very varied. A good example of this is afforded by fluor-spar, which when quite pure and free from colouring matter is perfectly colourless and transparent; some of the colours actually exhibited by this mineral are represented on plate 71.

Usually the colour of a mineral is not the same when seen in fine powder as when seen in the mass. The colour of the powder of a mineral may be readily obtained by rubbing a piece of the mineral on a piece of unglazed porcelain. For this reason the colour of the powder is called the *streak* of a mineral, and this is often a character of importance. The streak of iron-pyrites is black, whilst the mineral in the mass has a brassy yellow colour. All minerals which contain foreign colouring matter give a white or grey streak; whilst those which have a colour peculiar to themselves give a coloured streak.

The *lustre* of minerals is another character depending on light. The different kinds of lustre of minerals are distinguished, by comparison with common objects, as metallic, vitreous (or glassy), pearly, silky, or greasy.

Refraction of light. — It is well known that when a stick is placed in a slanting position into water it appears to be bent. The reason for this is that the rays of light which are reflected by the stick alter their course on passing out of the water into the air: only those rays which are perpendicular to the surface of the water pass out without any deviation of their path. In the same way, light is bent or refracted whenever it passes from air into a denser medium: the ray of light is said to be bent towards the normal. If, in fig. 99, the line *G* represents the surface between a crystal and the air, then the line *LL* is the normal to this surface. A ray of light passing

from the air into the crystal takes the path shown by the broken line $S S$, which makes in the air an angle i with the normal, and in the crystal an angle r . The former angle i is called the angle of incidence, and the angle r is called the angle of refraction. Now, there is a fixed relation between these

two angles, the ratio of the sines, $\frac{\sin i}{\sin r}$, being constant for the same kind of substance. This ratio can be expressed as a number, which is called the index of refraction or refractive index of the particular substance. When light passes from air into any crystal the value of the refractive index must be greater than unity (1), and it is always the same for crystals of the same mineral.

Another fact depending on the refraction of light, which is known to everyone, is that when ordinary day-light passes through a prism a coloured band or spectrum is formed. The explanation of this is that ordinary white light is composed of light of different colours, and that rays of differently coloured light are refracted to different amounts, red being refracted the least and blue the most. It is clear then, that the refractive index of a substance depends on the colour of the light, being less for red than for yellow, green and blue. The values of the refractive indices for light of different colours in some few minerals will be given further on. This breaking up of white light into its coloured constituents is known as *dispersion*. To the very high dispersive power of diamond are due the brilliant flashes of colour which are shown by the cut gem.

Rays of light in air falling onto the surface of a transparent crystal can in all cases enter the crystal. On the other hand, rays of light in a crystal are not always able to pass out of the crystal into air. When the ray does pass from the crystal into air it is bent away from the normal, as shown by the broken lines $S' S'$, $S^2 S^2$ in fig. 100. A ray making a rather greater angle with the normal (but less than the angle made by S^3) will also be able to pass out, but it will glance along the surface in the

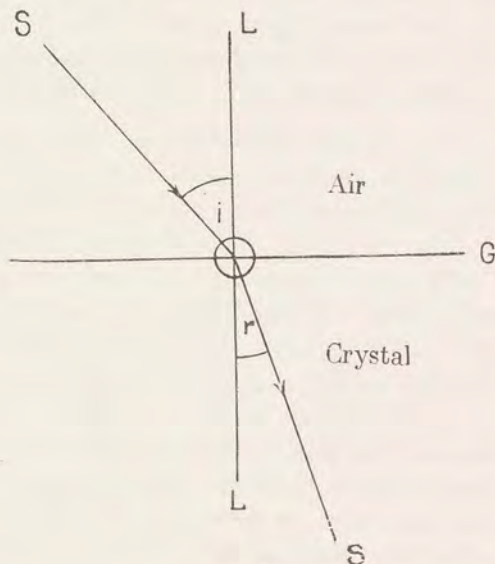


Fig. 99.
Refraction of light in passing from air into a crystal.

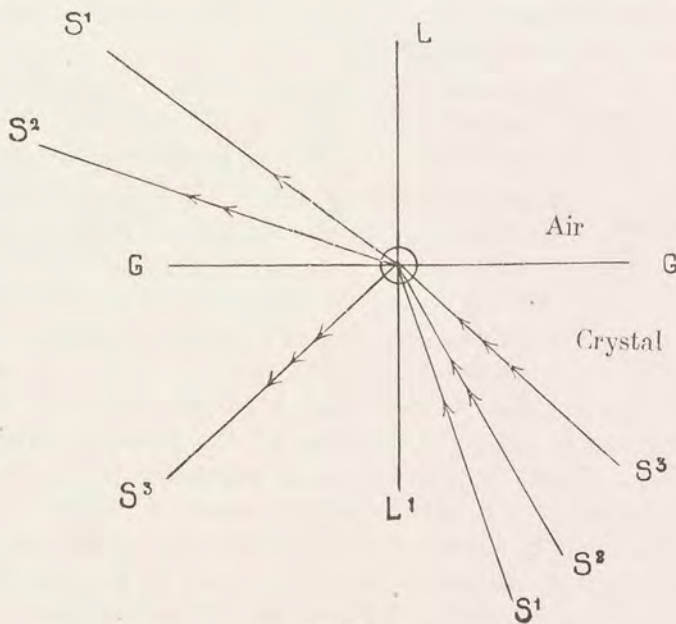


Fig. 100.
Refraction of light in passing from a crystal into air.
Total reflection in a crystal.

air. If the angle of incidence be increased slightly, to S^3 , the ray will no longer be able to pass out of the crystal, but will be totally reflected at the surface G along the path S^3S^3 back into the crystal. This *total reflection* of light inside a crystal is an important character in minerals. As we shall see later, it plays an important part in the faceted gem-stones. The silvery reflections sometimes seen in quartz crystals are due to the total reflection of light from enclosed minerals, which, though they have a bright metallic appearance, usually consist only of chlorite.

Double Refraction. — When an object is viewed through a clear cleavage rhombohedron of calcite, such as a piece of "Iceland-spar", the object will appear double. The calcite has the peculiar property of breaking a ray of light which passes through it into two rays. This property of calcite is illustrated in plate 3a (the German word "Kalkspath" meaning calc-spar or calcite, and "Doppelbrechung" meaning double refraction). If the piece of calcite be laid over a dot on a sheet of paper and we look straight down through the calcite we shall see two images of the dot (for example, the dot at the end of the word "Kalkspath" in plate 3a). If now we turn the piece of calcite round, while it still rests on the paper, we shall see that one of the dots remains stationary, but that the other moves round in a circle about the first. We can therefore conclude that the ray of light corresponding to the stationary dot has not been bent or refracted, but that the ray corresponding to the moving dot has been refracted, although we are looking along the normal to the surface. The first is called the ordinary ray o , and the second the extraordinary ray e , since it does not obey the ordinary laws of refraction of light. If the rays were to pass out of the calcite obliquely the ordinary rays and the extraordinary rays would be differently refracted, and, corresponding to each of these, calcite possesses two indices of refraction, the ordinary and the extraordinary.

The double refraction of calcite from Iceland ("Iceland-spar") was described in detail by Erasmus Bartholinus in 1669; and as this mineral exhibits the phenomenon more strikingly than any other it is sometimes called doubly-refracting spar.

All minerals, except those which crystallize in the cubic system, are, however, doubly refracting; but most of them so feebly that their double refraction can only be detected with aid of a special instrument. Cubic crystals do not possess this property of splitting a ray of light into two, and, like glass and water and other uncrystallized substances, they are singly refracting. There are, however, in all doubly refracting crystals certain directions in which the refraction is single and not double. If, for instance, we cut from a calcite crystal a plate parallel to the base and look through it along the direction of the principal axis, only one image of a dot will be seen. Calcite is therefore singly refracting in the direction of the principal axis. Such a direction in a doubly refracting crystal is called an *optic axis*. Crystals of the tetragonal and hexagonal systems possess one optic axis, which coincides with the principal or vertical axis: such crystals are said to be *optically uniaxial*. We thus see that there is a close connection between the optical characters of a crystal and its crystalline form; those crystals with a single principal axis being optically uniaxial.

In crystals of the three other systems (rhombic, monoclinic and triclinic) there are two directions along which light is only singly refracted, and such crystals are consequently said to be *optically biaxial*. In the rhombic system the plane in which these two axes lie, or the optic axial plane, is parallel to one or other of the three planes of symmetry; in monoclinic crystals it is either parallel to or perpendicular to the single plane of symmetry; and in triclinic crystals there is no definite relation

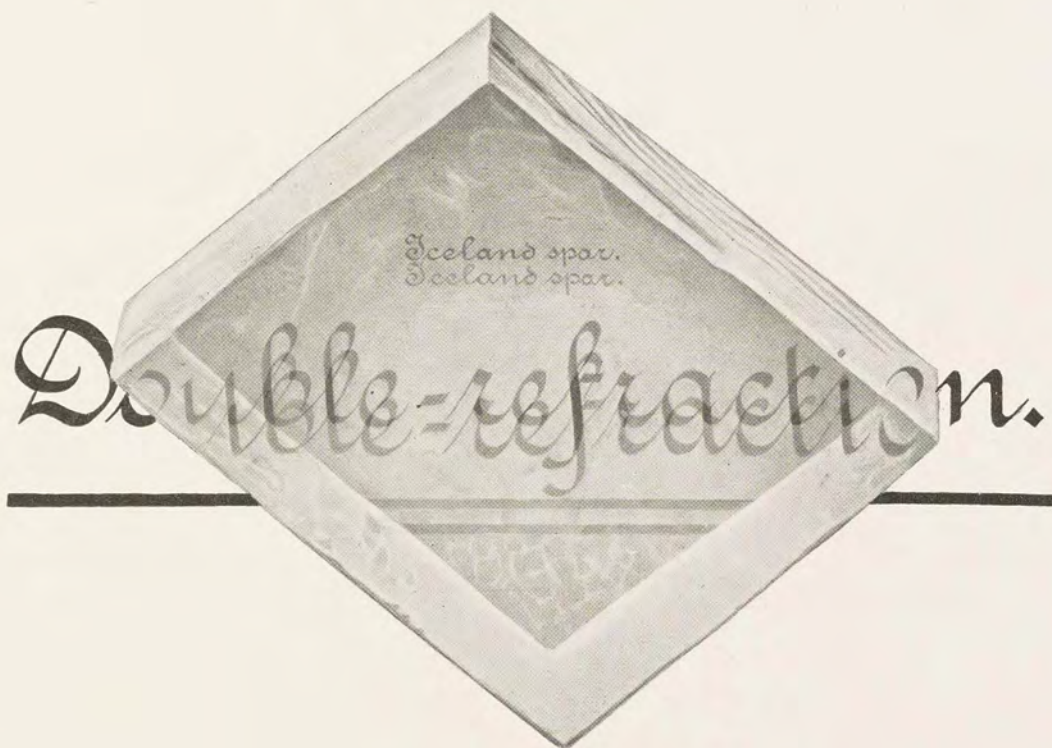
PLATE 3a.

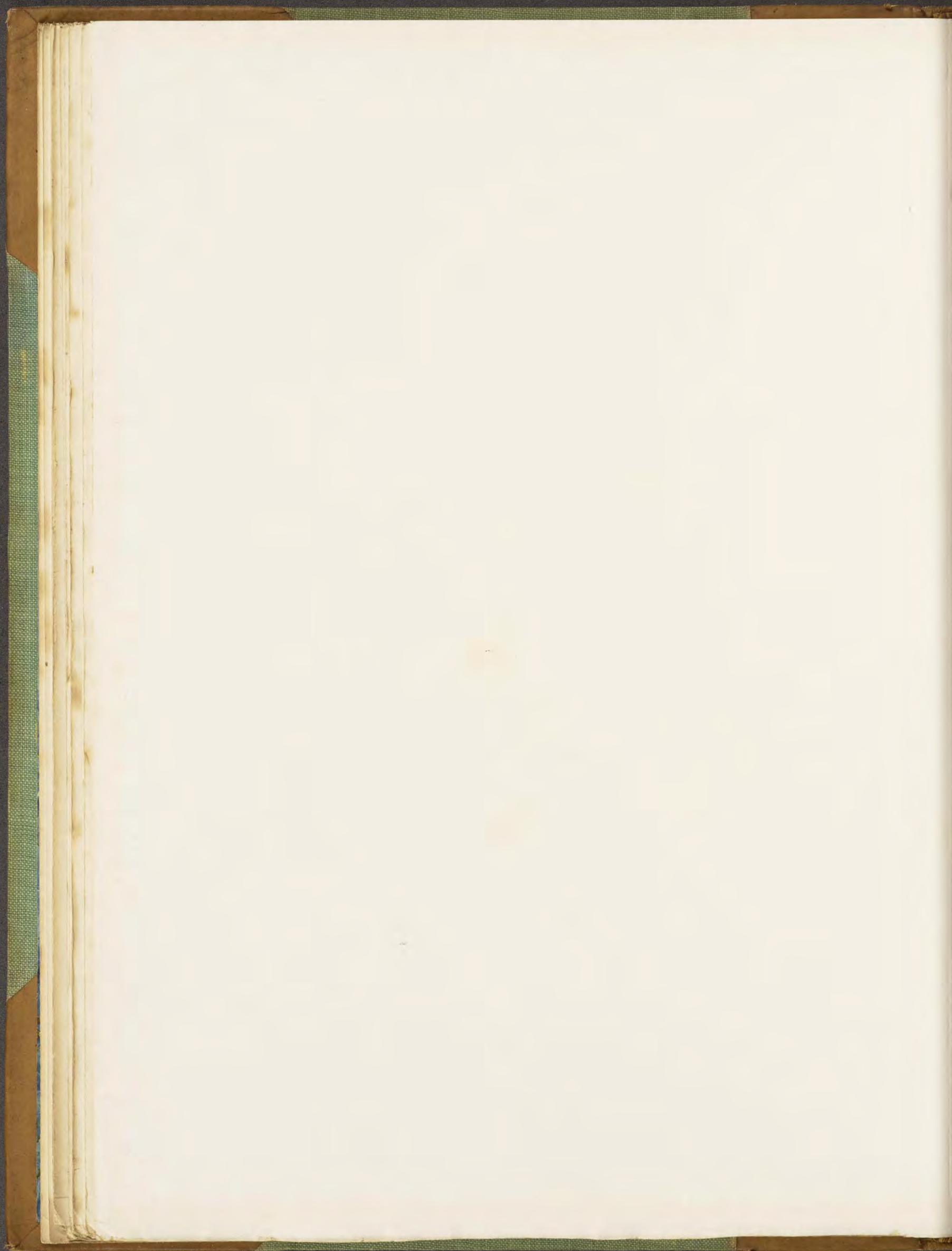
Double-refraction of light.

In calcite ("Iceland-spar").



PLATE 3a.





between the position of the optic axial plane and the faces of the crystal. The discovery of these important relations between the optical properties of crystals and their external crystalline form is largely due to the patient labours of Sir David Brewster.

Recognition of Double Refraction.

The phenomenon of double refraction in crystals can be recognized by the unaided eye in but few minerals besides calcite, since in most cases the double refraction is only feeble, or the minerals are too cloudy. It can, however, be easily and readily recognized with the help of special instruments in which light is endowed with peculiar properties.



Fig. 101.
Nicol prism.

Light which has been reflected from a bright non-metallic surface, such as a sheet of glass blackened at the back, has no longer the same properties that it possessed before reflection, although to the unaided eye no difference can be detected. If the reflected light be allowed to fall on a second reflecting surface of the same kind, it will be found that in certain positions of the second surface the light will be again reflected, but that in other positions only a portion will be reflected. Light possessing this and other peculiar properties is said to be polarized: the vibrations in the ether here take place all in the same plane,

whereas with ordinary light the vibrations take place in different planes.

In a polarizing apparatus the reflecting mirror which gives rise to the polarization of the light is called the polarizer; and the second mirror is called the analyser. Usually, however, in place of a second mirror a more convenient and efficient form of analyser is used. This is a nicol prism (fig. 101); and in the better instruments a nicol prism is also used for the polarizer. A nicol prism is constructed from a long cleavage rhombohedron of calcite ("Iceland-spar") which is sawn diagonally into two pieces, and the two pieces cemented together again with Canada-balsam. A ray of light L entering the calcite will be split into two polarized rays e and o for which the indices of refraction are different; one of these rays (o) will be totally reflected at the surface of the Canada-balsam, whilst the other (e) passes through the prism along the path E . The light which passes through a nicol prism is therefore like that reflected from a non-metallic mirror, but here the light is completely polarized; *all* the vibrations take place in one plane, which is the plane parallel to the shorter diagonal of the nicol.

A simple form of polarizing apparatus or *polariscope* is shown in fig. 102. The light from a window is reflected by the mirror Sp onto the sheet of glass P which acts as the polarizer. This reflects polarized light vertically upwards through the instrument to the analyser, which consists of a nicol prism in the tube A . Between the polarizer P and the analyser A is a rotating table on which is carried the crystal under examination.

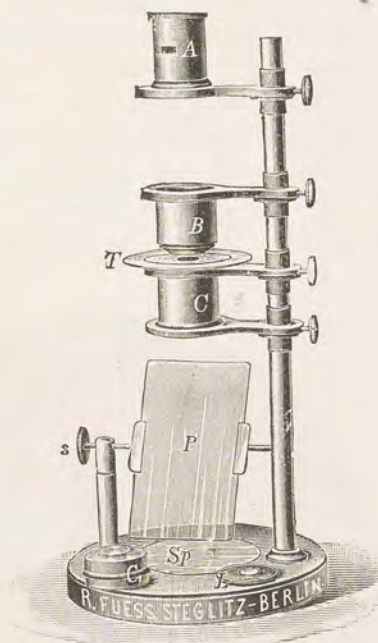


Fig. 102.
Polarizing apparatus or polariscope.

Use of the Polariscope.

This instrument requires a little adjustment before being used. After setting the instrument before a window, the analyser *A* should be removed and the light reflected by the mirrors upwards through the instrument. The analyser is now replaced, and as it is turned round in its collar it will be seen that the light is alternately cut out and allowed to pass through: the analyser has to be so placed that the light is cut out. The polarizer and analyser are then in crossed positions, that is their planes of vibration are at right angles. If now we place upon the table *T* a singly refracting cubic crystal, such as a cleavage fragment of rock-salt or one of the alum crystals which we have grown artificially (p. 9), we shall, on looking through the instrument, observe that the crystal still remains dark and has no effect on the polarized light. If, however, we place on the table a doubly refracting crystal or a fragment of one, such as a cleavage flake of mica or of gypsum, we shall see that the crystal not only causes light to pass through the instrument but that, as a rule, it appears brilliantly coloured. The colour actually seen will depend on the strength of the double refraction of the crystal, and also on the thickness of the crystal. With flakes of gypsum of varying thickness a range of vivid polarization colours may be obtained. The polariscope thus gives us an easy and ready means of recognizing the presence of double refraction in a crystal, or of distinguishing a singly refracting mineral from one that is doubly refracting.

If now we slowly rotate the table of the polariscope on which the flake of gypsum is placed, we shall see that the light gradually becomes fainter, until finally it is completely cut out and the gypsum will appear dark like the piece of rock-salt. On turning the table a little farther the light will gradually re-appear; and during a complete revolution of 360° , the light will be in this way cut out four times and re-appear four times.

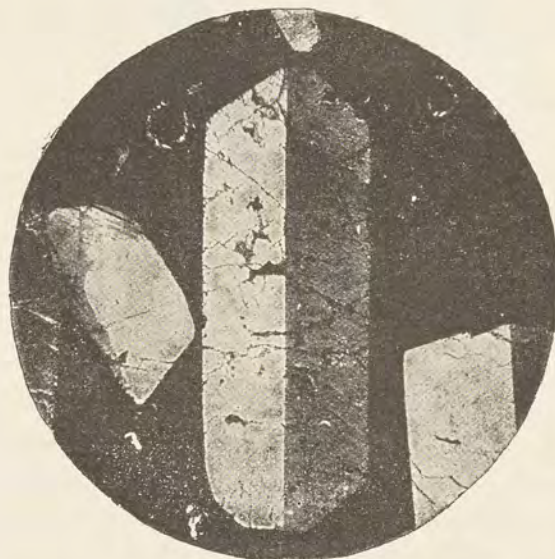
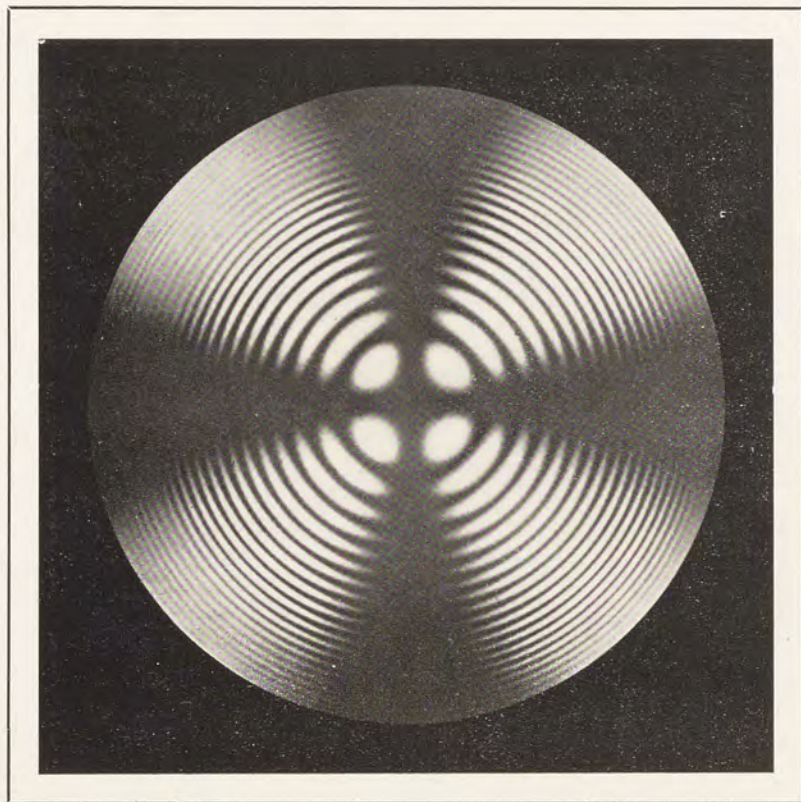


Fig. 103.
Twinned crystal of augite in polarized light. Kaiserstuhl,
Baden. Magnification 20 diameters.

Where the doubly refracting crystal under observation consists of a single individual it will be equally illuminated in all portions, but if the crystal be a twin, the two individuals will be differently illuminated, one portion being dark while the other is light, and vice versa (fig. 103). This gives us an easy means of recognizing twinned crystals, especially when we are examining the crystals in a thin section of a rock. The repeated twinning of a cleavage flake of labradorite felspar as seen in polarized light is represented in fig. 1 of plate 61a. The bands are alternately light and dark; and as the flake is turned round on the table of the polariscope the light bands become dark and the dark bands become light. A similar, but finer, laminated structure due to twinning is shown in figs. 2 and 3 of the same plate. In cases of this kind the twinning would never be recognized by the naked eye, and it only becomes obvious when thin sections of the mineral are examined in polarized light.

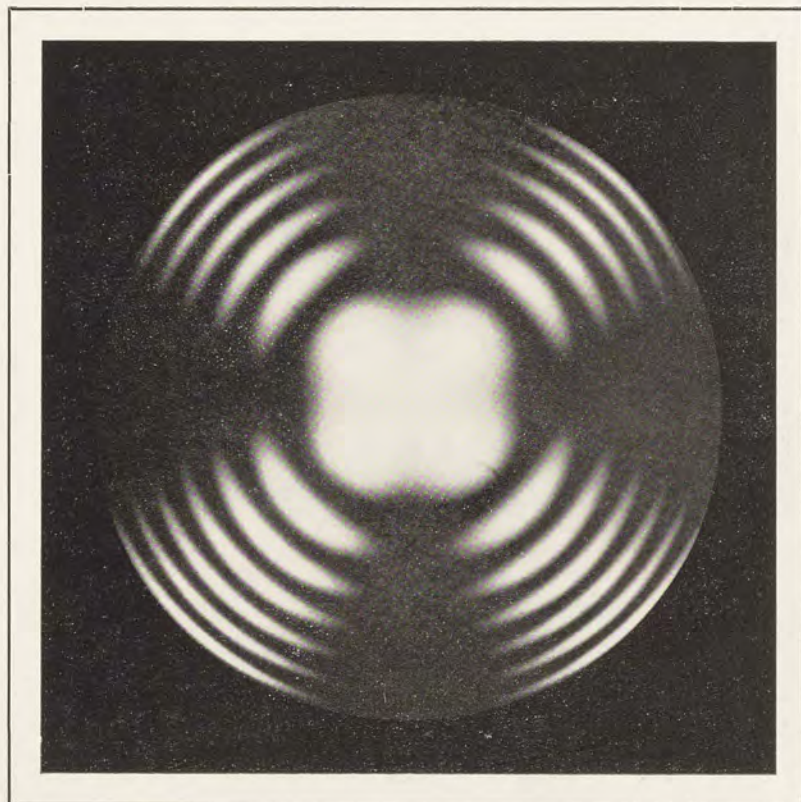


1.



1. Interference-figure of an optically uniaxial crystal (calcite) in convergent polarized light.

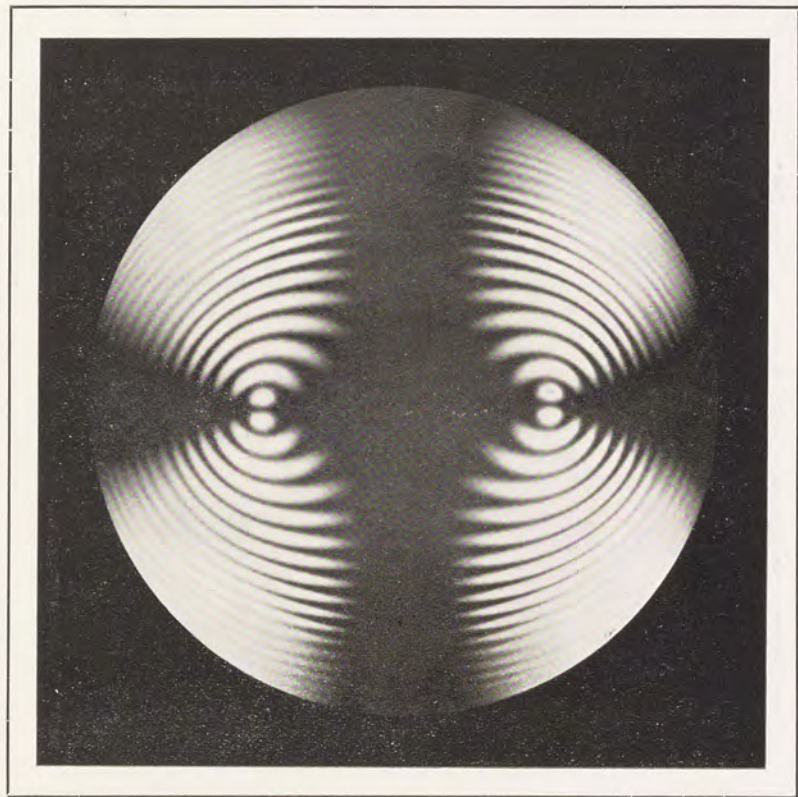
2.



2. Interference-figure of an optically uniaxial crystal with circular polarization (quartz) in convergent polarized light.

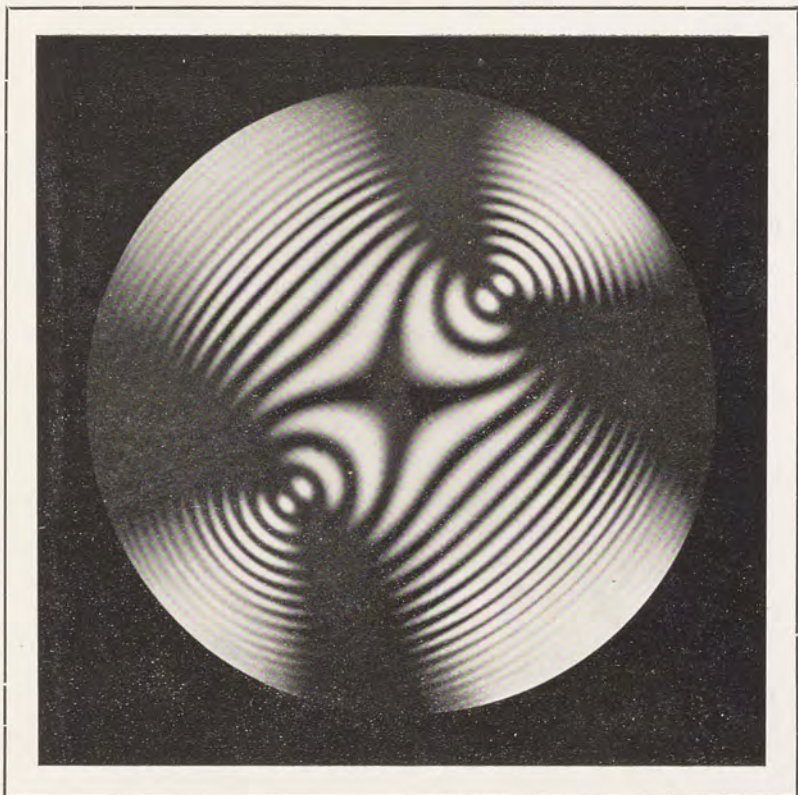
Interference-figure.

3.



3. Interference-figure of an optically biaxial crystal (aragonite) in convergent polarized light: with the crystal plate in the normal position of extinction.

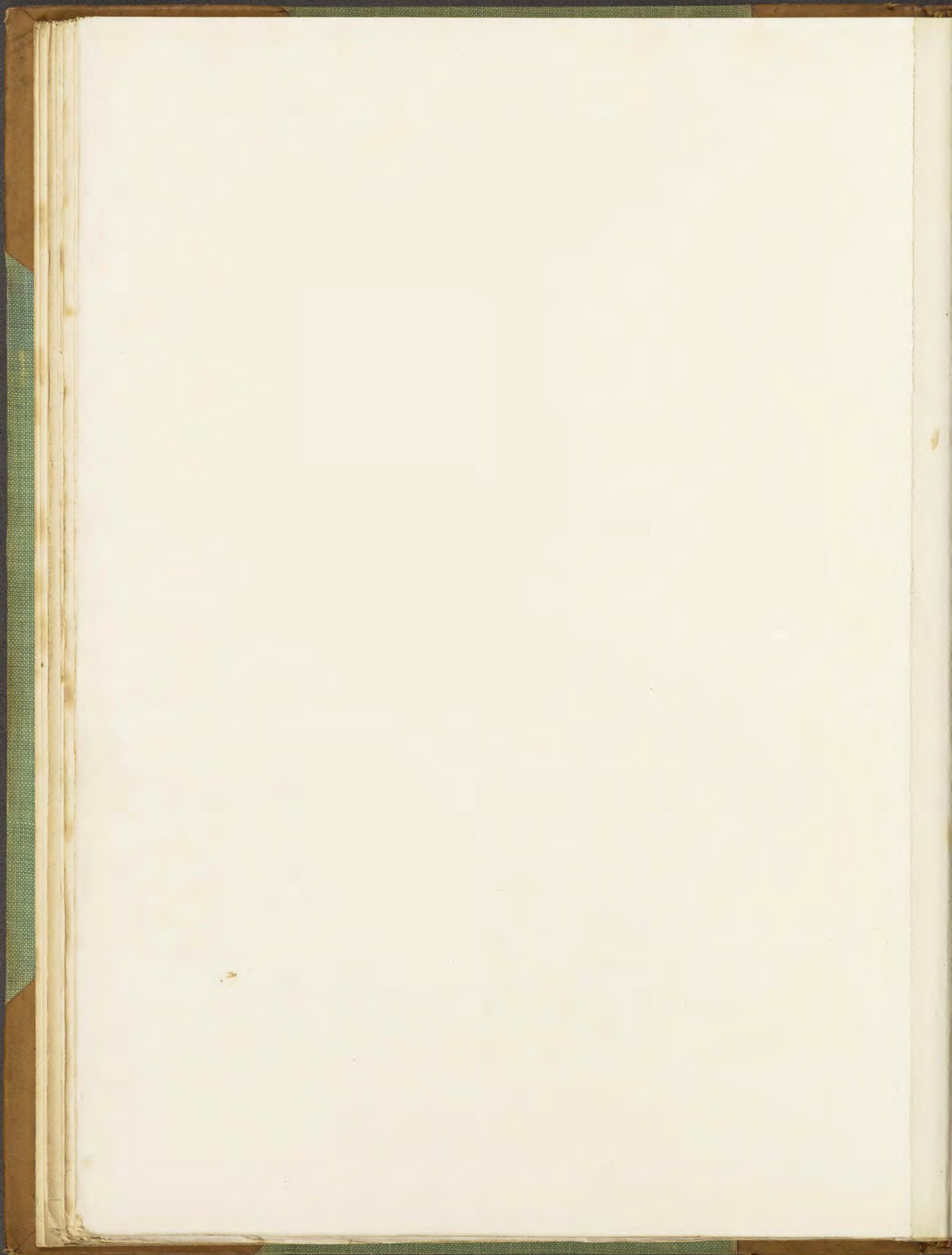
4.



4. Same as fig. 3, with the crystal plate in the diagonal position.

(Figs. 1—4, photographed in sodium-light.)

Stuttgart (Fritz Lehmann).



If we examine in the polariscope a cube of sodium chlorate (which may be obtained by crystallizing the salt from an aqueous solution) or a slice of a quartz crystal cut perpendicular to the edges of the prism, we shall see that they allow light to pass through and that they appear coloured; and furthermore, as the crystal is turned round with the table the light is not cut out, as was the case with the doubly refracting crystals above considered. If now we rotate the analyser it will be seen that the crystal changes in colour; and if we use red light (by placing a sheet of red glass before the eye) we shall see that the light fades or becomes brighter, and that at a certain position of the analyser it is cut out altogether. Crystals which behave in this peculiar manner are rather exceptional and are said to be *circularly polarizing*: they have the property of rotating the plane of polarization of plane polarized light. The right-handed and left-handed characters shown by different crystals of quartz (p. 36) may be distinguished by their circular polarization. If we take two plates of quartz of equal thickness, one cut from a right-handed crystal (fig. 76) and the other from a left-handed crystal (fig. 75) we shall find that in the polariscope they will both give the same colours, but that the order in which these colours (red, yellow, green, blue) appear depends on whether the analyser is rotated to the right or to the left.

When a doubly refracting crystal is turned round in the polariscope into the position of darkness, it is said to be in the position of extinction, the light being then extinguished. The principal directions of vibration for light in the crystal are then parallel to the vibration directions of the polarizer and analyser. The latter are fixed directions in the instrument, and are usually marked by cross-wires in the eye-piece. If, when the crystal is in the position of extinction, these directions coincide with some prominent edge on the crystal, for example the prism edges of a quartz crystal, then the extinction is said to be straight, and the crystal is said to give *straight extinction*. If, on the other hand, these directions do not coincide with an edge of the crystal, the extinction is said to be oblique. This distinction between straight and *oblique extinction* is of importance, since it is of great assistance in determining the symmetry of crystals. On all faces of a crystal perpendicular to which there is a plane of symmetry the extinction will be straight.

In tetragonal and hexagonal crystals the principal axis is, as already pointed out, a direction in which the refraction is single and not double. If, therefore, we cut from one of these crystals (except quartz, which is circularly polarizing) a plate parallel to the base, that is perpendicular to the principal axis, and examine it in the polariscope, we shall find that it behaves exactly like a cubic crystal. This will, however, only be true when the light travels parallel to the axis of the crystal. In the polariscope as so far described we have considered all the rays of light to be parallel to the axis of the instrument, and thus our examinations have been made in *parallel polarized light*.

The polariscope can also be arranged so that the rays of light passing through the crystal are not parallel but convergent. And when crystals are examined in *convergent polarized light* they present phenomena of quite a different kind. For this purpose two systems of converging lenses are placed in the holders *B* and *C* (fig. 102) above and below the table *T* carrying the crystal. When an optically uniaxial crystal, cut as a plate perpendicular to the optic axis, is observed in the polariscope in convergent light we see what is called an *interference figure*. With white light (i. e. ordinary daylight) this consists of a set of concentric circular coloured rings intersected by a black cross. If light of one colour be employed, for instance that given by the sodium flame, the rings will be alternately light and dark (plate 4, fig. 1). No change takes place in this interference figure when the crystal is rotated with the table of the polariscope.

Such an interference figure is typical of tetragonal and hexagonal crystals. The number and sharpness of the rings will depend on the strength of the double refraction and on the thickness of the plate.

A section cut from a quartz crystal, although also uniaxial, shows a slight difference in the interference figure (plate 4, fig. 2). Here the coloured rings are circular and concentric as before, but the black cross extends only towards the centre as far as the innermost ring. This difference is characteristic of circularly polarizing crystals.

A plate cut in a certain definite direction from an optically biaxial crystal (belonging to the rhombic, monoclinic or triclinic systems) shows in convergent polarized light the kind of interference figure represented in plate 4, figs. 3 and 4. As the crystal plate is turned with the table of the instrument the figure alternately changes in form from one of these shapes to the other. In the normal position of the plate, when the vibration directions in the crystal coincide with those of the polarizer and analyser the figure is as in fig. 3, with a narrower arm and a broader arm intersecting the two systems of rings. When the crystal is turned through an angle of 45° into the diagonal position the black cross breaks up into the two branches of a hyperbola (fig. 4). Interference figures of this kind are shown by cleavage flakes of muscovite mica.

It is thus possible from an examination in convergent polarized light to distinguish in a uniaxial crystal whether it is circularly polarizing, but it is not possible to distinguish a tetragonal crystal from a hexagonal. By noting the distribution of colours in a biaxial interference figure it is possible to distinguish between rhombic, monoclinic and triclinic crystals, but it would be out of place in this book to enter into this interesting branch of crystal optics.

Dichroism. — Some doubly refracting crystals which are transparent and coloured show different colours when viewed through in different directions. This phenomenon

is called pleochroism or dichroism. Some minerals show this very strikingly even to the unaided eye, especially so with the mineral cordierite, which for this reason is also known as dichroite. Usually, however, the presence of dichroism can only be detected with a special instrument, called a dichroscope. This consists essentially of a cleavage rhombohedron p of Iceland-spar with the ends squared off. At one end T of the

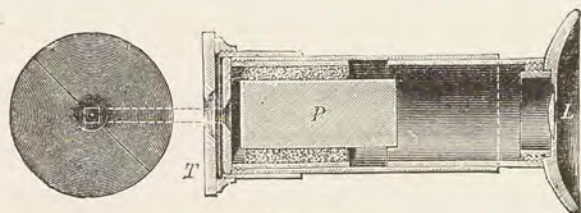


Fig. 104.
Dichroscope.

tube carrying the calcite is a small square aperture (shown in the end view of the instrument), and at the other end is a lens L . Rays of light admitted into the instrument through the square aperture are split up by the calcite into two rays, and on looking through the lens a double image of the aperture is seen. If now a dichroic crystal be placed in front of the aperture the two images will be differently coloured. A yellowish green crystal of aquamarine (plate 44, fig. 12) placed with one of its prism faces against the aperture will give a pair of images which are coloured yellowish-green and sky-blue these colours corresponding to the ordinary ray and to the extraordinary ray respectively. If an optically uniaxial crystal be placed with its basal plane against the aperture of the dichroscope the two images will be coloured alike. It is therefore necessary when examining a crystal for dichroism to turn it about in front of the aperture of the dichroscope: in certain positions the two images will be coloured alike, while in certain

other positions of the crystal they will show a maximum difference in colour. The dichroscope is especially useful for the examination of faceted gem-stones.

Some other physical properties which are especially characteristic of certain minerals will be considered when we come to a detailed description of those minerals: for instance the magnetism of magnetite, and the pyro-electricity of tourmaline.

The Chemical Characters of Minerals.

The Constituents of Minerals.

The substance of minerals consists of chemical elements, which may be present either singly or two or more combined together to form a chemical compound. Minerals consisting of a single chemical element represent a native condition of these elements, for example, native gold, native silver, native sulphur, etc. The composition of a mineral is determined by the ordinary methods of chemical analysis: the methods of qualitative analysis being employed to determine what chemical elements are present, and the methods of quantitative analysis to determine their relative amounts.

Many of the common minerals may be recognized by the help of their external characters alone, such as hardness, colour, lustre, streak, cleavage and crystalline form. But it is often necessary also to perform some chemical tests, if only by way of confirmation. A few simple tests which are useful in this direction will be briefly mentioned, but for fuller details the reader must be referred to the text-books on analytical chemistry: a particularly useful book is G. J. Brush and S. L. Penfield's "Determinative Mineralogy."

We may test whether the mineral is soluble in water or in acids. If it dissolves in acid with the liberation of carbon dioxide, we know that it is a carbonate. By heating in a flame the fusibility may be determined. Or if a fragment of the mineral be heated in a glass bulb-tube we may find that it gives off water or a solid sublimate, or that it changes in colour. Many other simple tests may be made with the blowpipe, by means of which a small, oxidizing or reducing flame may be directed against a fragment of the mineral placed on charcoal: the mineral may thereby be fused or volatilized and we may obtain fumes with a characteristic odour, or there may be a coloured sublimate formed on the charcoal. Minerals containing a heavy metal when mixed in a powdered form with sodium carbonate and heated on charcoal before the blowpipe will in many cases yield globules or spangles of the metals which they contain. If the mineral contains sulphur in combination with the metal, this will combine with the sodium of the sodium carbonate and on placing the fused mass on a silver coin and adding water a black stain will be formed on the coin: this is a very simple and reliable test for determining the presence of sulphur in a mineral. Many metallic compounds when fused in a borax bead on a loop of platinum wire give a characteristic colour to the bead. Other substances impart a characteristic colour to the non-luminous flame of the Bunsen burner or of a spirit lamp: several minerals will give this coloration if a fragment be moistened with hydrochloric acid and held in the flame on a platinum wire. It is unnecessary in this place to enter into further detail of this kind: but certain tests which may be applied for the recognition of particular minerals will be mentioned under the minerals themselves.

Chemical formulae. — When the composition of a mineral has been completely determined by quantitative analysis, it is convenient to be able to express this composition

simply and shortly by means of a formula. The results of a quantitative analysis are expressed in percentages of the weights of each constituent: and from these figures the formula can be calculated. The formula states what elements are present, and how many atoms of each go to form the chemical molecule. Each element is represented by a symbol, which is the first or first two letters of the common or the Latin name of the element: thus N stands for nitrogen and Na for sodium (natrium). The smallest particle, or atom, of each element which is capable of entering into chemical combination possesses a definite weight which is characteristic of that element. The absolute weights of the atoms are of course unknown, but we can express their relative weights. The following is a list of the more important elements, with their symbols and atomic weights, that of hydrogen being taken as unity.

	Symbol	Atomic weight		Symbol	Atomic weight
Aluminium	Al	26.9	Molybdenum	Mo	95.3
Antimony	Sb	119.3	Nickel	Ni	58.3
Argon	A	39.6	Niobium	Nb	93.3
Arsenic	As	74.4	Nitrogen	N	13.93
Barium	Ba	136.4	Osmium	Os	189.6
Beryllium	Be	9.03	Oxygen	O	15.88
Bismuth	Bi	206.9	Palladium	Pd	105.7
Boron	B	10.9	Phosphorus	P	30.77
Bromine	Br	79.36	Platinum	Pt	193.3
Cadmium	Cd	111.6	Potassium	K	38.86
Caesium	Cs	131.9	Radium	Rd	223.3
Calcium	Ca	39.8	Rhodium	Rh	102.2
Carbon	C	11.91	Rubidium	R	84.8
Cerium	Ce	139.2	Ruthenium	Ru	100.9
Chlorine	Cl	35.48	Samarium	Sm	148.9
Chromium	Cr	51.7	Selenium	Se	78.6
Cobalt	Co	58.56	Silicon	Si	28.2
Copper	Cu	63.1	Silver	Ag	107.12
Fluorine	F	18.9	Sodium	Na	22.88
Gallium	Ga	69.5	Strontium	Sr	86.94
Germanium	Ge	71.9	Sulphur	S	31.83
Gold	Au	195.7	Tantalum	Ta	181.6
Helium	He	4	Tellurium	Te	126.6
Hydrogen	H	1.000	Thallium	Tl	202.6
Indium	In	113.1	Thorium	Th	230.8
Iodine	I	125.90	Tin	Sn	118.1
Iridium	Ir	191.5	Titanium	Ti	47.7
Iron	Fe	55.5	Tungsten	W	182.6
Lanthanum	La	137.9	Uranium	U	236.7
Lead	Pb	205.35	Vanadium	V	50.8
Lithium	Li	6.98	Ytterbium	Yb	171.7
Magnesium	Mg	24.18	Yttrium	Yt	88.3
Manganese	Mn	54.6	Zinc	Zn	64.9
Mercury	Hg	198.5	Zirconium	Zr	89.9

The formula of the mineral rock-salt, which consists of the chemical compound sodium chloride, may be expressed as NaCl, indicating that each molecule of this substance consists of one atom of sodium and one atom of chlorine in chemical combination; or in other words rock-salt consists of 22.88 parts by weight of sodium and 35.18 parts by weight of chlorine. In the same way the formula of iron-pyrites may be written FeS₂, that is one atom of iron combined with two of sulphur: the mineral therefore consists of 55.5 parts by weight of iron and 63.66 of sulphur.

In order to calculate the formula of a mineral we must therefore first know the amounts by weight of each element present, these amounts are usually expressed as percentages of the weight of the whole substance. Thus 100 grams of perfectly pure iron-pyrites will on analysis be found to contain 46.58 grams of iron and 53.42 grams of sulphur. By dividing these numbers by the atomic weights of the respective elements, we obtain the atomic ratios, that is the ratio of the number of atoms present of each element in the compound. Thus for iron-pyrites $\frac{46.58}{55.5} = 0.84$, and $\frac{53.42}{31.83} = 1.68$.

Now the values 0.84 and 1.68 are in the ratio of 1 to 2, so that the molecule of iron-pyrites consists of one atom of iron in combination with two atoms of sulphur, as expressed shortly by the formula FeS₂.

Dimorphism and Isomorphism.

Dimorphism. — Sometimes we find one and the same chemical element or compound in crystals exhibiting different forms and with different physical properties. The chemical composition of the material is the same, but its crystallographic and physical characters differ. Thus, calcium carbonate is most frequently found as crystals belonging to the rhombohedral division of the hexagonal system, but it also occurs as rhombic crystals. These, then, are two distinct minerals, which are known as calcite (plates 72 and 73) and aragonite (plate 74) respectively. Calcite cleaves with ease in three directions parallel to the faces of a rhombohedron, it is optically uniaxial (plate 4, fig. 1), and has a specific gravity of 2.72. Aragonite, on the other hand, has no distinct cleavage, it is optically biaxial (plate 4, figs. 3 and 4), and its specific gravity is 2.93. These two minerals thus differ widely in character although they are identical in their percentage chemical composition, and they are therefore said to be dimorphous. Another good example of dimorphism is afforded by the element carbon, which occurs in nature as two crystallized minerals, diamond and graphite (plate 41). Here there is a very striking and marked difference in the appearance and physical characters of two minerals which are chemically identical. Diamond crystallizes in the cubic system, is transparent and heavy, and is the hardest of minerals; while graphite crystallizes in the hexagonal system, is opaque and less heavy, and is one of the softest of minerals. Cases are also known in which the same chemical substance crystallizes in three distinct forms: such substances are said to be trimorphous or polymorphous. A good example of this is given by the minerals rutile, anatase and brookite, all of which consist of titanium dioxide.

Isomorphism. — Many instances are known of minerals which are analogous in chemical composition and which at the same time exhibit similarity in crystalline form. Such minerals are said to be isomorphous. For example, the two minerals magnesite (MgCO₃) and chalybite (FeCO₃) are chemically analogous and both crystallize in

rhombohedra with nearly the same angles between the faces. Furthermore, they possess the peculiarity, which is a characteristic of isomorphous substances in general, that the substance of one may be replaced in the same crystal by an equivalent amount of the substance of the other: the same crystal may contain both magnesium carbonate and iron carbonate and still exhibit the characteristic rhombohedral form of magnesite or chalybite. Such intimate isomorphous mixing of two substances to form one and the same crystal is of extremely frequent occurrence amongst minerals. Less frequently are the two substances each collected in bands or zones in the same crystal, as would result if first one substance crystallized, and then a layer of the other substance was deposited on the crystal. Such zoned crystals of two substances may, however, be readily grown artificially: an octahedron of colourless potash alum if placed in a solution of chromium alum will continue its growth as a violet coloured octahedron.

When two or more minerals are isomorphous with one another they may be included in the same isomorphous group. If the substances are also dimorphous, there will be two parallel isomorphous series, thus giving an isodimorphous group. An example of this is seen in the calcite and the aragonite groups of carbonates.

Origin of Minerals.

We are apt to look upon minerals as permanent and unalterable; but, like animals and plants, they have a period of birth and growth, and later they may be altered and decomposed, their material giving rise to a new generation of other minerals. Minerals are formed in many different ways, and it is only rarely that we are able to trace out completely their mode of formation. Some have crystallized out from a molten rock mass, others have been deposited by vapours, but the majority have grown from aqueous solutions. The molten rock poured out as lava streams from volcanoes gives rise on its consolidation to minerals of various kinds, such as felspar, leucite, olivine, augite, magnetite, and others. The vapours and gases emitted by a volcano deposit solid materials near the crater of the volcano; for example, sulphur, rock-salt, haematite, etc. The water which is abundant everywhere on the surface and in the crust of the earth is capable of dissolving solid materials and depositing them again in other forms. From the largest of all solutions, the sea, immense deposits of rock-salt with associated beds of abraum-salts, gypsum and anhydrite have been formed. In the earth's crust water circulates in the cracks and crevices of the rocks, and in some cases is heavily charged with mineral matter, as is shown, for instance, by the springs of mineral water of various qualities. The mineral matter held in solution by these underground waters may under suitable conditions be deposited as crystallized minerals. For instance, on the evaporation of the water, gypsum crystals may be deposited in cavities. Or again, if two solutions containing different materials become mixed new compounds may be formed, and if these are only slightly soluble in water they will be deposited. The insoluble barytes (BaSO_4) may be deposited when, in a rock crevice, a water containing in solution a small amount of barium carbonate or barium chloride meets another solution containing calcium sulphate: by the interaction of the materials in the two solutions barium sulphate is formed, and being insoluble in water it is deposited on the walls of the crevice.

Weathering. — Water which falls as rain on the earth's surface takes into solution from the air and from the surface soil small amounts of oxygen, carbon dioxide and other

substances: and the water so charged will, on sinking into the rocks of the earth's crust, be able to react on various minerals. Pure water has very little action on most minerals, but when gases are present in solution most minerals, even the most resistant, will be slowly decomposed and dissolved. Crystals will commence to lose their brilliancy and lustre, becoming dull and rough on their surface: and finally they may be completely dissolved and carried away in solution; or certain constituents only may be dissolved and removed, leaving others in a powdery form. In weathering processes of this kind, it is only exceptionally that the form of the original mineral is retained, as in the pseudomorphs described above (p. 49). The water which has been the cause of this weathering and decomposition of the minerals has thereby gained mineral matter in solution, from which under other conditions new minerals may be deposited, and these in their turn will be subjected to weathering processes.

There are thus going on in the earth's crust slow but continual processes resulting in the formation and destruction of minerals. These changes in the inorganic world are in a way analogous to those in the organic world, but they are much slower. Further, they are essential to the existence of the organic world, for it is by the weathering of minerals that inorganic salts pass into solution and are then capable of being taken up by plants. Were it not for the weathering of minerals there would be no possibility of organic life, and the material of the earth's crust would belong solely to the mineral kingdom.

Special part.

The Ores and their Associates.

By the miner the term *ore* is applied to any mineral or mixture of minerals which can be profitably worked for the metal it contains. Mineralogists, however, would restrict the word to those minerals having a metallic appearance and containing a heavy metal. Quartz containing one ounce of gold to the ton is considered by the miner to be a rich gold ore; but as the gold is not visible to the unaided eye, the material looks exactly like ordinary massive quartz. On the other hand, the beautifully developed octahedral crystals of magnetite (plate 29 a) such as are found by mineral collectors in the Binnenthal in Switzerland, would be called an ore by the mineralogist, but not by the miner, since at this locality the mineral occurs too sparingly to be profitably worked for iron. When, however, magnetite occurs in large masses it is an important ore of iron.

For the miner to become thoroughly acquainted with the minerals present in his ore he must, like the mineralogist, study the minerals themselves. He would, for instance, be able to learn very little about the characters of native gold from an examination of a gold-quartz containing only one ounce of gold to the ton. In our description of the minerals which are of importance as ores we shall therefore select the most characteristic specimens, and draw attention to their prominent features, mentioning also their modes of occurrence and where they are found. In addition to details of importance to the miner, points of mineralogical and of general interest will be mentioned.

By the decomposition of metallic minerals in nature's laboratory various new minerals have been formed; these are often brightly coloured, and consist of the metal in combination with various mineral acids, such as carbonic or sulphuric acid. These secondary minerals occur in association with the metallic minerals from which they have been derived, and they may be considered as belonging to the same group or family. Some of them are included under the miner's term *ore*, whilst others are not. In this section dealing with the ores and their associates, we shall therefore describe these secondary or associated minerals immediately after the metallic ores from which they have been derived.

This method of grouping minerals, according to the metals which they contain, differs from the classification usually adopted by mineralogists, in which minerals containing the same acid radicle are grouped together. Thus in the text-books on mineralogy, cuprite is placed amongst the oxides and malachite amongst the carbonates: but in this book these minerals will be considered in connection with the ores of

copper from which they have been derived, and they are represented all together on the same plate (plate 13).

In this division of our classification we may also conveniently place sulphur, since this is used for the same purposes as are the sulphur-containing metallic minerals iron-pyrites and marcasite, and further it is sometimes spoken of as an ore.

As an appendix to the ores of iron we shall treat of meteoric iron and meteorites. These bodies represent extra-terrestrial rock masses and their consideration strictly belongs to the subject of petrology, but since many points of interest are presented by their origin and their characters they may find a place in this volume.

The minerals with which we shall deal in this section are then, with the exception of sulphur, the heavy metals and their more important compounds.

Ore-deposits. — The minerals which are of value to the miner as ores occur in the earth's crust under almost the same conditions as most other minerals: but on account of their economic importance their modes of occurrence have been much more extensively studied and numerous theories to explain their origin have been propounded. It would be out of place here to give a detailed account of the important subject of ore-deposits, and we shall only briefly note the more important types and indicate how they may have been formed.

Some ores are found in connection with eruptive rock masses, which have consolidated from molten material erupted from unknown depths of the earth; others are found interbedded in sedimentary rocks, which have been deposited in water; others again, are found filling crevices and cavities in the rocks of the earth's crust; and some occur as water-worn fragments with sand and pebbles in rivers gravels.

All eruptive rocks contain small amounts of heavy metals, and in general the amount is greater in those rocks containing less silica, that is, in the more basic rocks. As a rule, the heavy metals are here present in combination with oxygen or acids and are uniformly distributed throughout the whole rock mass. Of the minerals so present in igneous rocks, magnetite is the most prominent, small amounts of which are invariably present in such a rock as basalt. Sometimes these metalliferous constituents of the igneous magma have been collected together or concentrated in certain parts of the mass, by a process known as magmatic differentiation. Examples of this class of ore-deposit are furnished by the separation of magnetite in syenite, of titaniferous iron-ore in gabbro, and of pyrrhotite and other sulphides in gabbro (see under magnetite and pyrrhotite).

Ore-deposits occurring in sedimentary, or stratified, rocks are called bedded deposits. These ore-bearing sediments may be of considerable horizontal extent but of little thickness, as in the well-known copper-slate or "Kupferschiefer" of Thuringia; or they may be of limited extent horizontally and of considerable thickness, as in deposits of haematite iron-ore. In such cases as these the ore may have been deposited at the same time as the sediment forming the mass of the rock, the two being intimately intermixed. Or again, the ore may occur entirely in a separate bed or stratum with barren rock above and below.

The deposition of iron-ochre around a chalybeate spring is a process which can be observed any day, and it is probable that many important deposits of iron ore have had such an origin. In a bog-iron-ore the material presents much the same characters as when originally deposited; but in the course of time it may be considerably modified by the processes which take place in the earth's crust. For example, by heat and pressure, due to contact with a mass of igneous rock, the iron ore may become dehydrated and converted into magnetite. Ore-deposits which have been profoundly modified in

character by contact with igneous masses in this way are called contact metamorphic deposits. The alteration or metamorphism is not confined to the ore, but affects also the surrounding rocks. Thus, limestone is converted into marble; special minerals, called contact minerals, such as spinel, garnet, idocrase and wollastonite, are developed in clayey limestone; while in clay-slates, andalusite is formed as a new mineral.

The clay-iron-stone which is so abundant in the coal-measures is a sedimentary deposit, and was without doubt originally deposited as such (iron carbonate) with intermixed clay and coal. Certain deposits of limonite (e. g. the "minettes" of Luxemburg) and of red-iron-ore (haematite) are also probably true sedimentary deposits; and perhaps also the sandstone with grains of galena which occurs near Mechernich in Rhenish Prussia, although the density and the distribution of the grains appear to contradict this. The copper ores in the "Kupferschiefer" of Thuringia, have been considered by some authorities to be original sedimentary deposits, whilst others assert that the ore has been introduced into the beds at a later date. The pyrites deposits at Rio Tinto in Spain and at Goslar in the Harz Mountains have all the appearances of sedimentary deposits, being faulted and tilted in the same manner as are the sedimentary rocks with which they are interbedded.

In other sedimentary rocks, which in most cases have been deposited in the open sea, the ores have been introduced at a date subsequent to that at which the rocks were deposited; and we find the ore taking the place of the rock. This is especially the case with limestones, which are often replaced by ores of iron or of zinc. Calcium carbonate is capable of precipitating heavy metals from their solutions, an equivalent amount of calcium at the same time passing into solution. When, therefore, an underground water containing metallic salts in solution comes into contact with a bed of limestone, the metal is deposited and the limestone is removed. The state in which the metal is deposited, or the compound of the metal actually formed, will depend on the nature of the metal: in general, it is the carbonate of the metal that will be deposited and will remain in the deposit, providing that it is not readily oxidizable. Under such conditions zinc would be deposited as carbonate, but with iron and manganese, carbonates would only be formed in the absence of oxidizing agents; more often iron and manganese would be deposited as oxides or hydroxides, such as haematite, limonite, pyrolusite, psilomelane, etc. The solutions which have produced these changes in beds of limestone may have derived their metallic salts from a bedded ore-deposit included in strata overlying the limestone (an example of which is mentioned under calamine) or from some other neighbouring and preexisting ore-deposit which had been subjected to the action of percolating waters; or the solution of the metallic salts may have arisen from unknown depths in the earth's crust.

In some instances the metallic constituents may have been originally present in the limestone itself, but uniformly distributed through the whole mass in relatively very small quantity. By the action of carbonated waters the calcium carbonate of the limestone may be dissolved and removed, leaving the oxidized metallic compounds behind in a concentrated form, that is as a deposit of ore. Deposits of iron ore and of manganese ore may in some instances have been formed in this manner. The weathering of some other rocks may give rise to a concentration of ores in the manner just described for limestones.

The concentration of gold, platinum, tin ore, and precious stones in alluvial deposits is also a result of the processes of weathering. The mother-rock which contained these valuable minerals in only relatively small amounts became disintegrated by chemical and mechanical means, and a large portion of the lighter material carried away by

running water. In this way the heavier minerals come to be collected in the gravels of the streams in the immediate neighbourhood of the mother-rock. Deposits of this kind are known as placers when they contain gold, tin-stone and other valuable minerals, and as gem-gravels when they contain precious stones.

Of special importance are those deposits of ores and minerals known as *mineral-veins* or *lodes*. These are fissures, usually steeply inclined, in the rocks of the earth's crust, which have been filled with mineral matter. Whilst the minerals in bedded and other deposits are usually granular and massive, those found in veins are often well crystallized; and indeed most of the finest crystals and specimens to be seen in mineral collections have been taken from veins or other cavities. Several different types of veins may be distinguished. Some contain only minerals which are of no value to the miner, whilst others may be composed largely of valuable ore. Sometimes the whole vein may be filled by a mineral of one kind, but more often several minerals occur together in the same vein. In the latter case there is usually a symmetrical arrangement of the material, the layers of material on one wall of the vein being repeated in the same order on the other wall.

The mode of formation of mineral-veins and the origin of the heavy metals contained in the ores have been the subject of much study and controversy, and even at the present day such questions are far from being completely and satisfactorily settled. In very many cases mineral-veins occur in direct connection with masses of eruptive rock or at least in the immediate vicinity of such masses. There can thus be little doubt but that there is some essential connection between the formation of mineral-veins and the eruption of molten magmas into the rocks of the earth's crust. In some instances it is clear that the metals must have been brought up from great depths by solutions or vapours, either during or shortly after the eruption of the igneous magma, and further that the solutions or vapours contained certain elements (chlorine, fluorine and boron) which played an important part in the formation of the minerals. The solutions or vapours would penetrate, not only into the open fissures, but also to a certain extent into the surrounding rocks, and chemical changes would be brought about and some new mineral matter deposited. Examples of an action of this kind are to be seen in the veins of gold ore in the southern slopes of the Carpathians (see under gold) and in the copper veins of Lake Superior in North America. In some other instances we are driven to the conclusion that the heavy metals must have been brought up from the earth's interior by the igneous material itself: and that by the subsequent weathering of the rock they have been leached out and re-deposited in crevices in the rock. The metals may have been present as traces in the silicates (olivine, mica, augite, etc.) composing the rock, and have been set free when these minerals were decomposed. An example of this is perhaps afforded by the veins of manganese ore which penetrate a porphyritic rock at Ilfeld in the Harz Mountains; it having been determined that manganese is present in small amount in the porphyritic rock itself. Whether any particular mineral-vein has originated in either of these or in some other way would be difficult to determine. In any case the processes are obscure and complex. Solutions heavily charged with mineral matter arising from great depths may become mixed with surface waters which have obtained their soluble constituents by the weathering of superficial rocks; and by the interaction of these solutions in the fissures or by the presence of each alternately it is possible that different types of deposits may be formed in the same vein.

Mineral-veins are, however, not invariably found in association with igneous rocks: they also occur, quite independently of these, in sedimentary rocks. As an

example may be mentioned the veins of cobalt ore in the "Kupferschiefer" (see under bornite).

When the overlying rocks have been removed by denudation, a mineral-vein will become exposed to the action of weathering processes, and several secondary minerals, which are not present in the deeper portions of the vein, will be formed. By the action of water containing oxygen and carbonic acid in solution the original minerals of the vein will be decomposed, a portion of their material being removed in solution, and another portion giving rise to compounds which are stable under the new conditions nearer the surface. Thus with iron compounds, such as iron-pyrites, the decomposition will result in the formation of limonite: metallic ores of copper will be altered to malachite, chesylite, cuprite and native copper; lead ores to cerussite and anglesite. These secondary minerals are those mentioned at the commencement of this section as the associates of the metallic ores. They are especially characteristic of the upper or oxidized portions of mineral-veins; and, as iron is often a common constituent, they are usually much mixed with limonite (brown iron-ore). For this reason the outcrop of a lode at the earth's surface has usually a rusty and cellular appearance, and this ferruginous capping of the lode is known to the German miners as the "eiserner Hut" (iron hat) and to Cornish miners as the gossan. In this connection may be quoted an English equivalent of an old German saying:

"A lode that wears no iron hat
is never likely to be fat".

Gold.

From the earliest times gold has been used for personal ornaments, and it has long been employed as a standard of exchange. In the tombs of the Egyptian kings, dating back two or three thousand years before Christ, valuable gold ornaments and objects of various kinds have been found; these include armlets, clasps, weapons, chains with golden bees and scarabs for wearing as amulets, and small boats made of gold and silver.

That extensive use was made of gold in bygone ages is especially seen from the results of the excavations made by Heinrich Schliemann on the site of the ancient city of Troy. At the time of the second settlement, about 4000 B. C. and long before the Troy of Homer, the "great treasure" was hidden away in a silver vase and remained lost to sight for thousands of years. In this vase alone were found two gold cups, two large gold diadems, a frontlet, six armlets, four ear-pendants, fifty-six ear-rings and 8750 beads of gold. Belonging to the same period there were also found many other gold ornaments, needles, cups, goblets and vases, as well as bars of gold notched on one side which had perhaps been used as money. These ornaments and utensils are of beaten gold, and the handles of the cups are in some cases riveted and in others soldered. Even at this very early date the art of working gold had reached an advanced stage, though the later ornaments from Mycenae show a still greater advance. The large gold diadem carries a horizontal chain twenty inches (52 cm.) in length from which hang ninety chains of varying lengths, and on these scale-shaped plates are arranged, the whole design being simple but very effective. The gold of these articles has a fineness of 23, 20 or 18 carats; of the 18 carat gold, or electrum, cups were made. It is certain

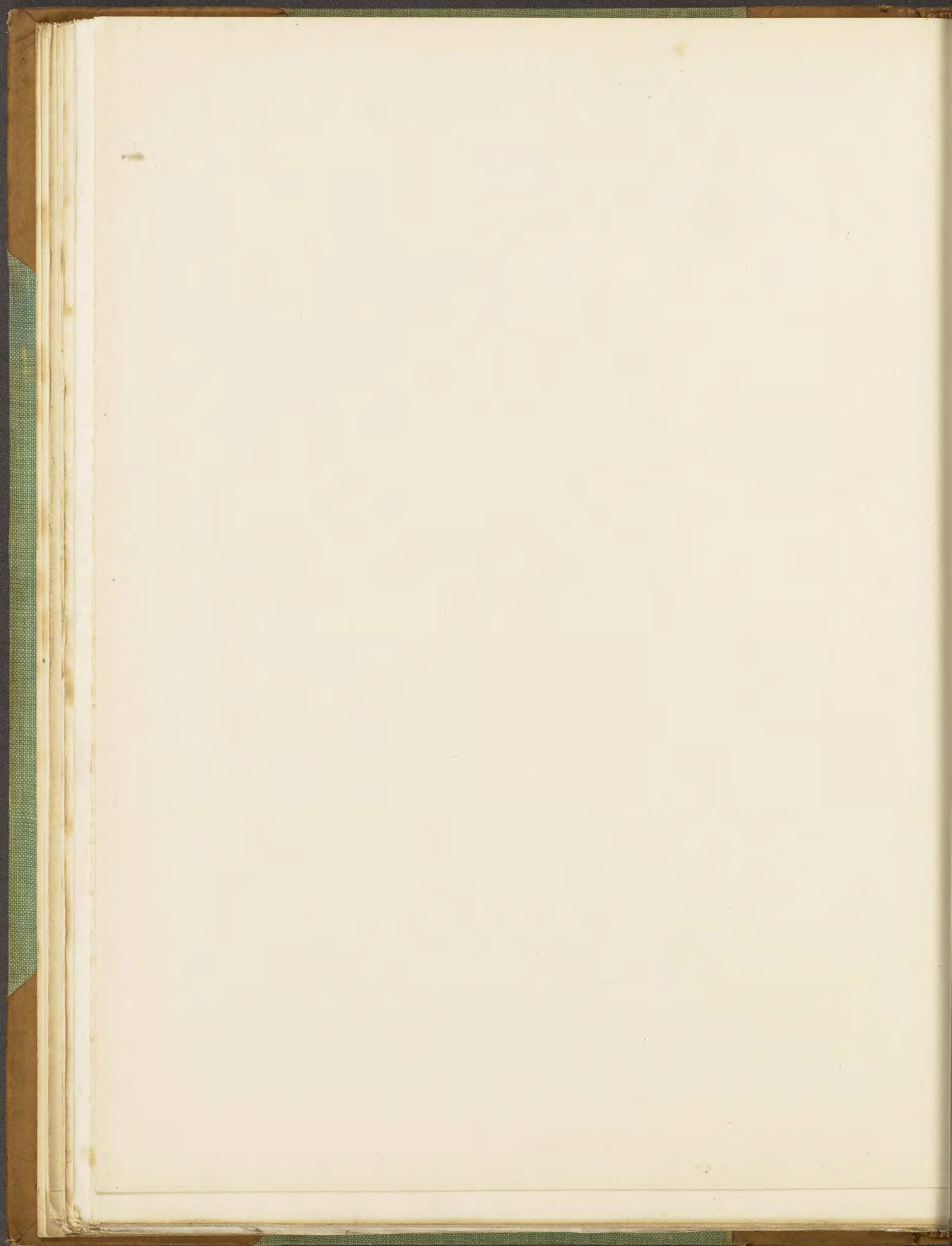


Native Gold and Platinum.

Fig.

1. **Gold crystal**, cube with small faces of the octahedron.
Vöröspatak, Transylvania, Hungary.
2. **Gold crystal**, cube with octahedron.
Mount Ararat, Cathcart, Victoria, Australia.
3. **Gold crystal**, rhombic-dodecahedron.
Ballarat, Victoria.
4. **Leaf-Gold**, with hexagonal outlines and minute triangular markings on the surface.
The same specimen is shown enlarged in plate 7, figs. 1*a* and *b*.
Vöröspatak, Transylvania.
5. **Leaf-Gold**, curved and without sharp outlines, but otherwise like fig. 4.
Vöröspatak, Transylvania.
6. **Alluvial gold**, with indications of triangular markings as on the leaf-gold. Weight,
14.82 grams.
California, U. S. A.
7. **Alluvial gold**. Weight, 10 grams.
California.
8. **Alluvial gold** with quartz. The gold holds together the quartz grains (or fragments
of fractured quartz). The particles of quartz are traversed by very fine veins
or strings of gold. The white spots are holes through the specimen. Weight
40 grams.
Mexico (California?).
9. **Gold**, blistery, with a very thin brown coating. 63 grams.
St. Antoine, Moravine, Dutch Guiana.
10. **Gold** with fractured quartz.
Sandhurst gold-fields, Victoria.
11. **Gold** with vein of iron-pyrites in quartz-trachyte.
Vöröspatak, Transylvania.
12. **Gold** in quartz. 330 grams.
Gold-washings in the Ural Mountains, Russia. (Bequeathed by Queen Olga
to the Stuttgart Mineral Collection.)
13. **Gold**, forming a vein in quartz. Gold-quartz.
Big Oak mine, Tuolumne Co., California.
14. **Gold**, wiry on limonite.
Copiapó, Chile.
15. **Platinum**. Weight, 54.3 grams.
Ural Mountains, Russia.
16. **Platinum**. Weight, 621 grams.
Mt. Bjelaia, Nizhne-Tagilsk, Urals.





that the gold was not alloyed with silver, but was used in the condition in which it had been found.

In the tombs of the ancient Grecian city of Mycenae, dating back two thousand years before Christ, Schliemann's excavations resulted in the discovery of a number of discs of gold impressed with patterns, large gold diadems, gold goblets and cups ornamented with the figures of animals (fig. 105), finger-rings, hair-pins, ear-pendants, armlets, buckles, and masks of sheet gold (fig. 106). In one tomb was found a child's body completely encased in sheet gold.

The kings of Assyria, Babylonia and Persia are said to have accumulated vast treasures of gold in their palaces; their temples were richly decorated with gold,



Fig. 105.
Gold cups from a tomb near Amyclae, Greece.



Fig. 106.
Gold mask from Mycenae, Greece.

and contained images of their gods wrought in pure gold. It is related that at the sacking of Nineveh such was the amount of gold and silver taken that a thousand camels were needed to convey the treasure to Babylon and Egbatana.

It is also said that Abraham had much gold, and that Solomon's ships brought large quantities of gold from the land of Ophir; but it would seem that later additions to the ancient writings have largely exaggerated the amount of gold which Solomon possessed and the richness of his temples. Ophir was probably an important trade centre in Arabia through which valuable goods, not necessarily gold, largely passed. In ancient times gold was compared with the sun, and the Hebrew name "sahab" for gold signifies "to shine as the sun"; to the Assyrians gold signified the colour of the sun, and the alchemists of later times gave to gold the symbol of the sun.

Other peoples of less cultured nations have also used gold for purposes of personal ornament. In the prehistoric graves of the Tchudi armlets ornamented with lizard's heads have been found, and the aborigines of the new world wore gold plates in holes bored through the nose.

That gold has been so generally used for ornaments since the earliest times is readily accounted for by its mode of occurrence and its characters. It is found widely distributed in the free state in the beds of streams and rivers, it retains untarnished its colour and lustre, and it can be readily worked; being the most malleable of metals, it can be readily hammered out into scales or drawn into fine wire.

Gold as it occurs in nature is never quite pure, but is always alloyed with variable amounts of silver. This fact was mentioned long ago by Pliny, who gave the proportion of gold to silver as being commonly 10:1 or as 8:1; the most valuable metal contained only a thirty-sixth part by weight of silver, whilst the least valuable contained four parts of gold with one of silver. The latter was distinguished by him as electrum, on account of its pale yellow colour, resembling that of amber which was known to the Greeks as electron. This has been completely confirmed by more recent investigations.

It has been shown that the purest of native gold always contains at least 1—2 per cent. of silver, and that in most cases 5—10 per cent. of silver is present, whilst for certain occurrences, for example in Transylvania, it reaches 25—30 per cent.

Correlated with the variation in the amount of silver present in the native metal there is a corresponding variation in the colour and specific gravity. Gold with little silver shows the deeper shade of gold-yellow characteristic of pure gold (as in figs. 6 and 7 of plate 5, representing gold from California, containing 7—10 per cent. of silver). On the other hand, when much silver is present the gold-yellow colour is much paler (as in figs. 4 and 5 of the same plate, representing gold from Transylvania, containing about 30 per cent. of silver). The specific gravity of the purest native gold is 19, that is to say, the native metal is nineteen times as heavy as an equal volume of water: as the silver increases in amount the specific gravity correspondingly decreases, and may be as low as 15.6. Pure gold melts at a temperature of 1035° Centigrade.

The hardness of pure gold is quite low, lying between that of gypsum and calcite, that is $H. = 2\frac{1}{2}$ —3 on the scale. The pure metal is thus too soft to be used for coins and for those ornamental articles, such as watch-chains, which are exposed to wear and tear. In order to increase the hardness of the gold it is melted with copper or less often with silver, the process of alloying with copper being known as "red caratizing" and with silver as "white caratizing". The "fineness" of this alloy is measured by the amount of gold present, and on this depends its value. In England this is expressed as so many carats, but this is not to be confused with a carat-weight, which unfortunately is a variable quantity. Taking pure gold as being of a fineness of twenty-four carats, an alloy containing half its weight of gold is said to have a fineness of twelve carats, and so on according to the number of the twenty-four parts which consist of pure gold. The English gold coinage has a fineness of twenty-two carats, that is, it consists of $\frac{22}{24}$ or eleven-twelfths of fine gold. A sovereign piece weighs 123.274 grains, of which 113 grains are gold. In Germany the fineness is expressed far more simply and rationally by stating how many parts of gold are present in 1000 parts of the mixture of metals. The German gold coinage has a fineness of 900, that is, 1000 parts of the alloy contain 900 parts of gold (90 per cent.) and 100 parts of copper. A ten-mark piece weighs 3.982 grams and therefore contains 3.585 grams of gold and 0.397 grams of copper; its specific gravity is 17.2.

For the purpose of testing the fineness of gold alloys the jeweller uses a test-stone, which is a compact, black variety of quartz known as lydian-stone. By rubbing the metal on the stone the streak of the former is obtained on the latter, and from the depth of colour of this, either before or after treating with acids, he is able to judge approximately the fineness of the gold, though of course only on the surface of the article so tested.

Gold is unattacked by any single acid, but is readily dissolved by aqua regia, a mixture of nitric and hydrochloric acids; other mixtures of acids which liberate chlorine also dissolve the metal, and it is soluble to a very slight extent in a solution of common salt. It is present as a minute trace in the salt water of the ocean, and recent determinations made with sea-water from the Australian coast show that a cubic mile of sea-water contains in solution 130—260 tons of gold. Attempts have been made to extract gold from sea-water on a large scale, but so far without any results of commercial importance.

Another important solvent of gold is a dilute solution of potassium cyanide, which is now extensively used for extracting metallic gold from its ores. From the solution so obtained the gold is separated by electrolysis. This is known as the cyanide

process, and it has now practically replaced other processes formerly employed for the extraction of gold.

Gold readily unites with mercury to form an amalgam, and this is also a property of the metal which has been extensively used for its extraction from the crushed ore or from auriferous sands. This method was used by the Romans and is still employed in the treatment of the finest gold-bearing sands. On heating the amalgam so obtained, the mercury is volatilized and the gold remains behind.

Although gold usually occurs in nature in the metallic or native state, yet it is often so finely divided that it cannot be separated from other minerals by purely mechanical means. It has therefore been necessary to resort to either the cyanide or amalgamation process in order to win the more finely divided metal. The coarser particles in a river gravel can be collected by a simple process of washing, by which the lighter minerals are carried away by a current of water, while the heavier gold remains behind.

When gold occurs embedded in the solid rock, it may be distinguished as rock-gold or *vein-gold* (plate 5, figs. 11, 13); but when it occurs as loose fragments with pebbles and sand in the beds of rivers and streams or in other alluvial deposits, it is distinguished as *alluvial gold* (plate 5, figs. 6, 7), or as gold-sand or washed gold. In all gold-yielding countries the deposits of alluvial gold, being more easily worked, are first exhausted before the solid rocks themselves are attacked.

In most cases rock-gold occurs in the quartz of veins which penetrate the ancient crystalline rocks (gneiss and mica-schist), deep-seated igneous rocks (granite, etc.), or volcanic rocks (especially trachyte). The quartz of such veins is called gold-quartz or auriferous quartz, and the gold it contains is in most cases not uniformly distributed throughout the mass, but collected in veins and strings (plate 5, fig. 13). Only rarely does the gold occur in relatively large masses, as in the specimen represented in the figure; more often it is present only as minute scales or as mere dust and is not visible to the unaided eye. In rare instances, however, large masses of gold have been found embedded in the solid rock; the largest on record is a mass weighing 43.08 kilograms (95 pounds avoirdupois) raised from the Monumental mine in Sierra County, California. Another unusually rich mass of native gold taken from the solid rock was one containing 57.7 kilograms (according to other accounts, 67.7 kilograms) of fine gold, which was found in the Muszari mine at Brad on the western side of the Csetras Mountains in Transylvania: the gold had the form of small platy crystals aggregated in mossy groups, and was associated with crystals of zinc-blende and marcasite on quartz.

The mineral most frequently associated with gold in quartz is iron-pyrites, which itself contains small amounts of gold. With the weathering of the iron-pyrites and the formation of limonite the gold it contained is liberated (plate 5, fig. 14). In this way free gold occurs in the oxidized ferruginous gossan in the upper part of mineral lodes, since in most cases iron-pyrites contains small amounts of gold. In such cases, however, the gold is usually so finely divided that it can only be extracted by amalgamation or by special metallurgical processes.

Distinctly developed crystalline forms are rarely exhibited by the gold which occurs embedded in quartz. Crystals may be sometimes found in cavities in the quartz or in the adjacent rock, but these crystals of gold are usually much distorted and their form obscured by twinning.

Three crystals of gold are represented in plate 5 (figs. 1—3); they are not large and finely developed as are the crystals of many other minerals, but they are quite good crystals for gold, which indeed only exceptionally occurs as distinct crystals. Fig. 1

shows a small sharp crystal, a cube with small faces of the octahedron, from Vöröspatak in Transylvania. Crystals from this Hungarian locality rarely exceed 3 mm. across. Fig. 2 shows a group of cubo-octahedra from Mount Ararat in Victoria; and fig. 3 a rhombic-dodecahedron from Ballarat, Victoria: the last two crystals from Australia are probably from alluvial deposits and not from a quartz-vein.

A pretty specimen of crystallized leaf-gold, belonging to the collection of Mr. Gustav Seligmann of Coblenz, is represented in its natural size in plate 5, fig. 4, and enlarged in plate 7, figs. 1 *a* and *b*. Its glittering lustre and the delicate patterns on its surface immediately attract attention, but unfortunately the beauty of the markings is not adequately brought out in the figures. It may, however, be seen that both surfaces of the plate carry numerous small, triangular pyramidal elevations, which are truncated by triangular facets parallel to the plane of the plate, and that these are all arranged in parallel position. The triangular facets are the faces of the octahedron, and the faces forming the sides of the small pyramids are those of an icositetrahedron. The hexagonal outlines of the plate are bounded by other narrow faces of the icositetrahedron. The whole plate is thus built up of a number of small crystals arranged in parallel position, but these crystals present a distorted or flattened form owing to their greater extension in the surface of the plate than perpendicular thereto. It may be further noticed (as more clearly seen in fig. 1 *b*) that the triangular markings on one portion of the plate are placed in a reverse direction with respect to the triangles on the other portion: this reversal in direction is due to twinning on the octahedral face parallel to the plate, the two twinned portions being combined along a plane perpendicular to the twin-plane.

Another, but less perfect, specimen of crystallized leaf-gold is represented in fig. 5 of the same plate. Other specimens of the same kind exhibit six-rayed patterns of golden stars, or delicate networks of various forms, which at first sight might be thought to be artificial gold brocade. Such specimens of gold afford excellent examples of the regularity and complexity of crystalline growth. They were exhaustively studied crystallographically by the late Professor G. vom Rath and the specimens he described are exhibited in the mineralogical museum at Bonn.

Besides the more regularly formed crystals and the crystallized plates already described, gold is also, but less frequently, found in wiry forms (plate 5, fig. 14); these also are built up of small crystals with perfect regularity of arrangement, but they are not so easy to decipher.

The gold-bearing rocks when exposed to the action of weathering agents become broken down and their materials carried away and sorted by running water. The gold being much heavier is not carried far from its source, whilst the lighter quartz is removed as sand and pebbles. In this way, during the course of ages, the gold set free from the mother-rock by weathering becomes accumulated in the beds of streams and in river gravels, and these secondary deposits are thus far richer in gold than are the rocks from which they have been derived. Not only are these deposits relatively richer in gold, but being incoherent they are more easily worked and the gold is readily won from them by a simple process of washing. It is therefore natural that in all gold-yielding countries these alluvial deposits were the first to be worked, leaving until later the more laborious and costly work involved in extracting gold from the mother-rock. At the present day the amount of gold extracted from the solid rock is far in excess of that won from alluvial deposits.

The free gold found in alluvial deposits is very variable in the external form of its particles; it does not present the rounded forms of the pebbles of quartz and

rocks with which it is associated. This is readily accounted for by the toughness and malleability of the material, which will yield more to blows and to pressure than to a rubbing and rolling action; there will thus be a tendency for the particles of water-worn gold to assume the form of scales rather than of rounded grains and pebbles. In most cases, by the battering of the pebbles in the running water, the gold has become completely isolated from the quartz, and it is not often that the two minerals are found intimately mixed together in the same pebble or fragment. An instance of this kind is seen in the magnificent specimen represented in plate 5, fig. 12, a specimen from the gold-washings in the Ural Mountains which was bequeathed by Queen Olga to the Natural History Museum at Stuttgart. The quartz, though much fractured, has here been held together by the large amount of gold which penetrates the whole mass as a coherent network. More often the brittle quartz would be shattered and broken away, while the films and strings of malleable gold would be more closely pressed together. In this way small fragments of quartz may still remain embedded in the mass of gold, as seen in fig. 8, representing a piece of alluvial gold from Mexico (or perhaps from California, which until 1848 formed a part of Mexico). It is, however, quite possible, that in this specimen the single grains of quartz, which appear to be water-worn, may have later become embedded in the mass of gold: the clear spaces in the figure are holes through the mass from which quartz grains have disappeared.

Figs. 6, 7 and 9 of the same plate represent specimens of alluvial gold entirely free from quartz: the two first are from California, and the last with a blistered surface and a thin brown coating is from Dutch Guiana. The specimens here figured are of relatively large size, and such larger pieces are called "nuggets". More often the pieces of gold found in alluvial deposits are much smaller, being only scales or grains. The largest nugget, or mass of alluvial gold, that has been found was one weighing 70.9 kilograms (156 pounds avoirdupois) from Victoria; and the largest from the Ural Mountains was one of 36 kilograms, found near Miask in 1842.

No other precious metal is so widely distributed as gold, and at the same time no other has been so eagerly sought. For long ages the more accessible and easily worked alluvial deposits of gold occurring in civilized countries have been exploited, with the result that such deposits are now practically exhausted. For this reason the largest production of alluvial gold at the present day is from districts bordering on unexplored regions, as for example in Alaska and British Columbia. The greater part of the gold now obtained is, however, extracted by new methods from solid rocks in which it is present in only relatively small amounts, as for example in the Transvaal.

In the following paragraphs we shall give an account of the occurrences of gold at the various localities where it has been found. Here, as throughout the whole volume, particulars concerning the localities of different minerals are largely taken from Professor C. Hintze's "Handbuch der Mineralogie", though use has also been made of some other sources of information. This branch of the subject is exhaustively treated by Professor Hintze, and in his treatise he has collected together all the available information of scientific value: to this work, then, the student is referred for further details, especially with respect to the localities of lesser importance, which are not mentioned in the present volume. In the statement of the localities of the specimens figured on the accompanying plates special efforts have been made to give these as accurately as possible.

In *Germany*, the principal gold-bearing river is the Rhine, from its confluence with the Aar (itself a gold-bearing river in Switzerland) downwards. Most of the Rhine gold has long ago been won, and the old washings were often at spots where the river

was breaking down its banks. The principal washings were between Kehl and Daxlanden, and especially near Helmlingen, in Baden. In 1838 the number of gold-washings in Baden still numbered four hundred; during the thirty years from 1804 to 1834 the total yield was rather over three hundredweights and of a value of 209,075 gulden. It was estimated by the French geologist Daubr e that the Rhine between Basel and Mannheim had yielded gold to the value of 170 million francs. The largest nugget known from Germany weighed 66 grams, and was found in 1826 in the Grossbach, a stream running into the Moselle (a tributary of the Rhine) near Enkirch.

From the Eder, a tributary of the Fulda, gold is said to have been washed in the time of Charles the Great. The first ducats of Eder gold were coined in 1677 by the landgrave Charles and bore the inscription "Moneta prima aurea Aederæ Aurifluæ":



Fig. 107.
Ducats made of gold from the river
Eder, Germany.



Fig. 108.

on the reverse side was a view of the Eder with the Guldensberg and Felsberg and a figure of the river-god. In 1731 ducats of Eder gold were coined under the landgrave Friedrich I, King of Sweden, which were inscribed "Eddergold" (fig. 107); and those coined in 1775 under landgrave Friedrich II bore on the reverse side the inscription "Sic. Fulg. Litora. Adranae. Auri. Fluae." (fig. 108). In the year 1832 a Hessian and Waldeck company with a capital of 400,000 thalers

was formed for the purpose of winning gold from the Eder, the work being carried on under the direction of L. von Eschwege, who had gained considerable experience in the Brazilian gold-fields. The production in 1833 amounted to 18 lot $1\frac{1}{4}$ quent, equal to 300 grams; and two years later all the capital had been expended. The peasants, however, continued washing for gold until the middle of the nineteenth century, but with no very profitable results.

Washing for gold has also been carried on in several rivers in Bavaria (the Donau, Salznach, Alz, Inn, Isar and Ammer, and several streams in the Fichtelgebirge), in Thuringia, and in Silesia. Of greater importance were the arsenic ores of Reichenstein in Silesia, which contained 3—4 grams of gold to the ton of ore: from this gold was made the font of the Royal House of Germany. Most of the gold now won in Germany is extracted from metallic ores, such as galena, copper-pyrites, iron-pyrites and zinc-blende, which usually contain traces of the precious metal: some of these ores are however imported, and are not of German origin.

In the *British Isles*, gold has been found at several localities, and has been worked on a small scale ever since the time of the Romans and no doubt also before them, since gold ornaments were worn by the Ancient Britons. Small quantities were formerly collected in the washings for stream-tin in Cornwall, especially in the Carnon Valley in Feock parish, near Falmouth; here several small nuggets have been found, the largest weighing 2 ozs. 3 dwts. (67 grams). In Wales, more particularly in the neighbourhood of Dolgelly in Merionethshire, gold occurs, sometimes in considerable quantity, in quartz-veins together with galena, copper-pyrites, iron-pyrites and zinc-blende. In 1904 the output of Welsh gold was valued at £73,925. In Scotland, gold was formerly found in considerable amount in the Leadhills district, and quite extensive workings were carried on there in the sixteenth century; a nugget weighing as much as 30 ounces has been recorded. Sutherland and Perthshire have also yielded alluvial gold. In Ireland, alluvial gold was discovered in 1795 in the neighbourhood of Croghan Kinshela in County Wicklow, and for a short time a considerable amount was collected: the largest nugget found weighed about 22 ounces.

In the eastern *Alps* of Salzburg and Carinthia considerable amounts of gold were formerly won, but at the present time workings on a small scale are carried on only at the Goldberg near Rauris and at the Rathausberg near Gastein. In the western Alps, Dauphiné is a district which has formerly yielded gold. The Romans obtained large quantities of gold from *Spain*, but the supply is now exhausted. Pliny refers to Asturia as the richest gold-field in the world, and he placed the value of the gold annually exported to Rome at £20,000.

Hungary is the only European country which, at the present day, is comparatively rich in gold, and the portion of this country in which it occurs is along the inner side of the great arc of the Carpathians, especially the eastern portion in Transylvania. The veins of gold-bearing quartz here intersect trachytic volcanic rocks of Tertiary age, or other rocks in the immediate neighbourhood of these volcanic rocks. At Schemnitz in Hungary, where mining is said to have been carried on before the Christian era, the ore in the veins consists largely of auriferous and argentiferous galena, zinc-blende, copper-pyrites and iron-pyrites with very little free gold. The same is also the case at Kremnitz in Hungary. On the other hand, the mines in the neighbourhood of Brad in Transylvania are unusually rich in free and visible gold. This small mining town is situated on the western borders of the Csetras Mountains, and the richest mine in the district is, at the present time, the Muszari mine. The veins are richer in gold at those points where they are crossed by other veins. The gold occurs in the form of plates and scales and is associated with auriferous iron-pyrites, black zinc-blende and other ores as well as the ubiquitous quartz. On an average, the ore contains 1000 grams of gold to the ton, while in places it yields five times this amount. It was the Muszari mine that yielded the exceptionally rich mass of gold mentioned above. In the year 1895 the production of this mine amounted to 732 kilograms of bar gold (i. e. gold containing some silver). Rich gold ores have also been obtained from the mines near the village of Boicza; and in the spring of 1897 the ore yielded 2050 grams of bar gold per ton, this consisting of 668 parts of fine gold with 310 parts of silver. The total production for the year 1895 amounted to 294 kilograms of gold and 166.7 kilograms of silver.

The best known of the Transylvanian gold localities is that of Vöröspatak, it being here that the best crystals are found, a few examples of which are represented in plate 5, figs. 1, 4, 5 and 11. The crystals are found either attached to the walls of drusy cavities, or they are embedded in the clayey material filling these cavities; in the latter case, the crystals or aggregates of crystals are freely developed on all sides, and they then sometimes exhibit more regular cubic forms. Usually, however, the crystals are much distorted and twinned, the delicately crystallized leaf-gold described above being especially characteristic of this locality. The leaf-gold found embedded in the clay is sometimes rolled up like paper or in concentric shells like an onion. Again, some of the distorted crystals are elongated like wire with a square cross-section, bearing on the free end a platy crystal. The distorted crystals of gold contained in the drusy cavities have often been considered to be of secondary origin, the finely divided gold contained in the rock and in the accompanying iron-pyrites being taken up in solution and re-crystallized in the cavities. The production at Vöröspatak is small compared with that of the other Transylvanian localities mentioned above: yet in this district there are 172 small workings, and the water from five reservoirs drives over 6000 stamps used for crushing the ore. The gold is so finely divided in the rock that it is not visible to the naked eye.

Bosnia is another of the countries from which the Romans obtained gold. Rich gold-washings were worked in the district lying to the north-west of Sarajevo, namely

in the upper courses of the Vrbas, in the valley of the Lasva, and in the neighbourhood of Fojnica.

In the *Russian Empire*, gold occurs in the Urals, the Altai, Transbaikalia, in governments Olonets and Yeniseisk, in Kamchatka, and on the east coast of Siberia opposite Alaska. Native gold is found embedded in the solid rock at several places in the Ural Mountains, and indeed vein-gold was here discovered (in 1745) before the alluvial gold. For instance, in the district around Beresovsk, near Ekaterinburg on the eastern side of the Urals, gold occurs with auriferous iron-pyrites and copper-pyrites in quartz-veins which penetrate or are closely associated with a granitic rock called beresite. These veins of gold-quartz yield about 13 grams of gold per ton of ore. Of much greater importance are the widely distributed alluvial deposits on the eastern slopes of the Urals, especially around Bogoslovsk, Nizhne-Tagilsk, Beresovsk, Miask and Orenburg. The gold-bearing gravel rests directly on the ancient crystalline rocks, and is overlain by gravel, sand and turf of varying thickness up to twenty metres. The Uralian gold usually has the form of small grains and scales, sometimes of small rod-like particles, and rarely as crystals or large nuggets. A fine specimen is represented in plate 5, fig. 12, and mention has already been made (p. 77) of the largest mass found in the Urals. The content of silver is usually 6—8 per cent., though some grains contain as much as 16 per cent. and others as little as $\frac{1}{2}$ per cent. of silver. The gold-washings in the neighbourhood of Bissersk are of especial interest, since it was in these that diamonds were first discovered in the Urals. In some of the other washings, platinum occurs in association with the gold. The production of gold from the Urals in the year 1899 was 10,448 kilograms.

The gold of the Altai Mountains in Siberia contains much silver and is consequently of a pale brass-yellow colour; it is the variety known as electrum. At Zmeinogorsk (the German name for which is Schlangenberg) it occurs on the surface of the rock as thin plates or as a mossy aggregation of minute scales, and is also found in alluvial deposits. In the gold-fields of Eastern Siberia, alluvial deposits are worked, and these account for 60 per cent. of the production of the Russian Empire.

California is the most famous and richest of all gold-bearing countries. Alluvial deposits have been worked here since 1848, though before that date a few pieces of gold had been picked up on the surface. Since then fabulous amounts of gold have been obtained; during the last fifty years the total production is valued at 260 million pounds sterling, or a yearly average of $5\frac{1}{5}$ million pounds. The yield during the first thirty years was above this average, while at the present time it amounts to about three million pounds sterling per annum. This decrease in the production is explained by the fact that the richer alluvial deposits were first worked, and afterwards the gold-rock was exploited. The gold-bearing gravels of California occur on the western side of the Sierra Nevada for a distance of 700 miles; they lie in the valleys of the present rivers and also in old river valleys of Tertiary age, the latter having since been covered up by outpourings of volcanic lava (basalt) and their tuffs. The deposits in the present river valleys are now almost exhausted: those lying higher up the valleys were formerly worked by the process of hydraulic mining. The gravel was washed away by enormous jets of water which was conveyed under pressure from considerable distances. In this way, at a cost of two million dollars, almost 35 million cubic metres of débris was removed, and this enormous amount of material was carried by the water to the lower lying land, where if spread out uniformly to a depth of one metre it would have covered 35 square kilometres of country. Naturally the land owners objected to this, and since 1887 this method of working has been prohibited by law. Fairly large nuggets of gold were sometimes found in these alluvial deposits (plate 5, figs. 6 and 7), but usually

only very small grains and minute scales were present. The metal contains about 10 per cent. of silver.

At the present time most of the Californian gold is obtained by mining the quartz-veins in which the gold is embedded (plate 5, fig. 13) in association with auriferous iron-pyrites. Most of the gold is present in the quartz in a very finely divided state and is not visible to the naked eye; it also often occurs only in the iron-pyrites, so that in many mines there is no free gold. The average yield is 15 to 20 grams per ton of ore. The extensive system of veins of gold-quartz lies on the western slopes of the Sierra Nevada; they are associated with granitic rocks, which are widely distributed in this region, and to which the veins owe their origin. The main vein or "mother vein" is really a system of parallel veins extending unbroken for a distance of seventy-five miles; and it is along these that the richest mines are situated.

The regions further north on the west coast of North America are also rich in gold, especially in *British Columbia* and *Alaska*. Rich alluvial deposits were discovered here during the past decade, and doubtless still more remain to be found in these little-explored countries. The richest gold-field is on the Klondike river, a tributary of the Yukon river in British Columbia, situated not far from Fort Reliance in latitude 64° N. and longitude 139° W. The richest spot, in the Bonanza Creek, now called the El Dorado Creek, was discovered in the autumn of 1896, when thousands of searchers for gold from all lands rushed in and a new town, Dawson City, rapidly sprung up. Here, with a climate not of the best and a temperature in winter of -55° C., the population increased in two years to 20,000. The gold-bearing veins of quartz are here, as elsewhere, associated with granite, which breaks through the crystalline schists of the region; and the gold-bearing alluvial deposits lie directly on the crystalline rocks. The deposits of sand and pebbles attain a thickness of ten feet and stretch for miles along the valleys. On the average the yield of gold per cubic yard of gravel is of the value of £5 to £6, and a foot of ground along the valley will yield about £200. These gravels are the richest that have been met with anywhere. The gold is comparatively coarse grained, the grains being the size of those of a coarse sand; and it contains on the average 75 per cent. of fine gold.

In very nearly the same latitude are the rich gold-sands discovered in the summer of 1899 on the sea-shore at Cape Nome in Alaska. These find their continuation across the Bering Sea on the east coast of Siberia.

Other states of the *United States* besides California are also rich in gold, and at the present day the production of California is surpassed by that of Colorado. The famous Comstock lode in the state of Nevada is the richest lode that has been worked in any part of the world. The ore which it yields contains native gold and several rich silver minerals (argentite, stephanite and polybasite). During the years 1860—1892 gold to the value of £30,000,000 and silver to the value of £45,000,000 were extracted. The lode has been worked along its whole length to a depth of a thousand yards, when springs of water with a temperature of 77° C. stopped further progress. The ores, together with quartz, fill a crevice in volcanic rocks of the andesitic type, and their materials were without doubt brought up from some deep-seated source subsequent to the eruption of the volcanic rock; and it is probable that mineral matter is still being brought up and deposited by the hot water which rises in the crevice.

Further to the south, native gold is found in Mexico, Central America, and several parts of *South America* as far as the Straits of Magellan. In Colombia and the northern part of the western coast the gold occurs in connection with granitic rocks, while further south in the Andes of Peru and Chile the veins are in connection with

younger volcanic rocks, such as liparite and andesite. In Chile some of the veins contain much iron-pyrites and copper-pyrites together with quartz and tourmaline: a specimen of free gold with limonite from the upper oxidized portion of such a vein is represented in plate 5, fig. 14. Alluvial deposits rich in gold are well represented in Brazil and further to the north in British and Dutch Guiana and Venezuela. In Dutch Guiana in addition to crystalline schists and granite there are basic eruptive rocks (dolerite) which are said to be auriferous. By the weathering of these rocks the gold is set free and collects in the rivers flowing northwards. The gold here has usually the form of small rods and grains, large nuggets being rare; one weighing 33 grams is represented in fig. 9 of plate 5. The production of Dutch Guiana reached a maximum in 1891 of 1237 kilograms.

The gold-fields of *Australia*, which were discovered at about the same time as those of California, have been extensively worked from the year 1851, and so continuous and abundant has been their yield that Australia (together with Tasmania and New Zealand) is one of the most important gold-producing countries of the world. All the states of the commonwealth are productive, and the gold occurs in the alluvial deposits of present or ancient rivers of Tertiary age (the latter being called "deep leads"), and in quartz-veins traversing archæan and palæozoic rocks. In plate 5 are represented three specimens of gold from Victoria; fig. 10 of gold in fissured quartz, and figs. 2 and 3 of two isolated crystals.

In *Africa* by far the most important gold-field is the Witwatersrand, or the "Rand", in the Transvaal. Gold was discovered here in the year 1884, but under conditions quite different from those known in other parts of the world, so that there was not at first the enormous production of gold such as followed the discovery of the Californian alluvial deposits. The gold-bearing rock, known as "banket", is a conglomerate consisting of pebbles of quartz, the size of a pigeon's or hen's egg, cemented together with siliceous material. Throughout the rock are scattered microscopically small crystals or irregular grains of native gold and of auriferous iron-pyrites: only very exceptionally are the particles of gold large enough to be visible to the unaided eye. The conglomerates rest on beds of sandstone and are themselves overlain by thick sheets of amygdaloidal dolerite. This mode of occurrence of the gold renders its extraction all the more difficult: water and wood are scarce, though there is a sufficiency of coal in the district. The sinking and working of a mine therefore require the expenditure of a considerable amount of capital. The rock contains on an average 23 to 30 grams of gold per ton. In 1893, less than ten years after the first discovery, there were seventy gold mines on the Rand producing 45,980 kilograms of gold per annum. In 1898 the annual production had increased to 110,860 kilograms with a value of about fourteen million pounds sterling. During the Boer war the production fell off, but increased again in 1905 to 152,324 kilograms.

In *Egypt*, veins of gold-quartz traverse granite, which is also intersected by veins of quartz-porphry and other eruptive rocks: when the latter are present in greater number, the neighbouring veins of quartz are richer in gold. The gold mines of Egypt were probably the earliest of any to be worked, and they must have supplied a large part of the gold used in ancient times.

Gold ores. — The only compounds of gold which occur in nature as minerals are various tellurides of gold usually with some other elements. The following are the more important.

Sylvanite (plate 8, fig. 1) is also known as "graphic tellurium" (German, Schrift-erz) for the reason that the small rod-like crystals are often grouped on the surface of the rocky matrix in patterns bearing a certain resemblance to written characters. This

particular grouping of the crystals is due to twinning. The crystals are monoclinic but their forms cannot, as a rule, be made out by mere inspection. There is a perfect cleavage in one direction parallel to the clino-pinacoid, and it is usually on this face that the crystals are attached to the matrix. The mineral is steel-grey in colour with a bright metallic lustre, and contains approximately 30 per cent. of gold, 10 per cent. of silver, and 60 per cent. of tellurium.

Calaverite is distinguished from sylvanite by the absence of cleavage and by its pale brass-yellow colour. In these characters, and also in the metallic lustre, calaverite often presents a striking likeness to iron-pyrites, from which it may be readily distinguished by heating a fragment of the mineral on charcoal before the blowpipe, when calaverite (which contains 44 per cent. of gold with 56 per cent. of tellurium) will yield a bead of gold.

Nagyagite (plate 8, fig. 2) occurs in platy forms and has hence been called "foliated tellurium". Its colour is blackish lead-grey and the lustre is metallic. The chemical composition is complex, the mineral containing 6—8 % gold, 54—61 % lead, 15—32 % tellurium and some silver, antimony and sulphur.

These minerals occur in veins which usually penetrate acid volcanic rocks, and they have as yet been found at only a few localities, namely Nagyag and Offenbanya in Transylvania, Cripple Creek in Boulder County, Colorado, and Kalgoorlie in Western Australia. More especially at the two last mentioned localities they are of great importance, since here they have yielded large quantities of gold. At Kalgoorlie, tellurides of gold were discovered in 1896, when it was found that some of the material which had been thrown away on the waste heaps as comparatively worthless iron-pyrites was in reality calaverite containing no less than 44 per cent of gold! Since that date large quantities of tellurides have been mined, and the Kalgoorlie district is now the richest of the Australian gold-fields, yielding in fact as much gold as all the remaining gold-fields of Western Australia taken together. Unfortunately, the tellurides of gold are rather obscure minerals with no striking characteristics and they are not readily recognized. If carefully and diligently searched for by prospectors they will doubtless be found at other localities.

Besides the minerals mentioned above, which contain gold as an essential chemical constituent, there are several other metallic minerals in which gold is often present in traces and from which it may be profitably extracted. Such minerals are iron-pyrites, galena, copper-pyrites, zinc-blende, mispickel, stibnite, etc. All the gold produced in Germany is extracted from ores of this kind, some of the ores being of German origin and others imported.

The *applications of gold* are so well known that they need scarcely be mentioned here. By far the largest amount is coined; considerable amounts are made into plate, jewellery, watches, etc., and used for gilding; and some is employed in photography and for colouring porcelain. Quartz with gold embedded in it is sometimes cut and polished for ornamental purposes.

Coins and jewellery become gradually reduced in weight by wear, or they may be lost, and the small amounts of the metal used in photography and for colouring porcelain are used up and not recovered. There is thus little loss of material, and one often wonders what becomes of the large amounts of gold produced year after year.

The *total production of gold* in the year 1883 was estimated to be of the value of twenty million pounds sterling, while the value of that produced in 1899 was sixty million, this large increase being a result of the discovery of the rich deposits of the Transvaal. There is a striking difference between such amounts and the production of former times. Thus, during the three and a half centuries which elapsed between the

discovery of America and the discovery of the Californian gold-fields, 1493—1850, it is estimated that the gold produced amounted to 4,750,000 kilograms, whereas in the eleven years 1885—1895 the total production was 6,050,000 kilograms. The continued increase during recent years is shown in the following table. There is not the slightest fear of the exhaustion of the world's gold resources, as was at one time suggested by the advocates of a silver standard of currency.

The details of production of the principal gold-producing countries given in the following table are taken with some modifications from "The Mineral Industry". For the year 1898 the percentages of the total amount yielded by the three principal countries are — the Transvaal 27 per cent., the United States 22½ per cent., Australia 21½ per cent., which together amount to 71 per cent. of the total. During 1905 the total production for the world amounted to 580,087 kilograms, and of this amount 342,005 was produced in the British Empire.

Countries	1898		1901		1905	
	Kilograms*)	Value in Dollars*)	Kilograms	Value in Dollars	Kilograms	Value in Dollars
North America:						
<i>United States</i>	97932·9	65802430	120691·0	80211545	132519·6	87948237
<i>Canada</i>	20613·9	13700000	36807·4	24462222	21800·0	14486833
<i>Mexico</i>	12393·5	8236720	15554·2	10329316	21860·0	14526855
<i>Central America</i>	790·0	525000	1549·8	1030000	1686·3	1120700
South America:						
<i>Brazil</i>	3809·3	2531687	4514·0	3000000	3651·5	2426575
<i>Colombia</i>	5567·3	3700000	3114·7	2070000	2970·8	1974400
<i>Chile</i>	2118·0	1407623	677·1	450000	958·4	636900
<i>Guiana</i> <i>(Brit., French and Dutch)</i>	5739·0	3814150	5567·9	3700441	6322·7	4201857
Africa:						
<i>Transvaal</i>	117470·3	78070761	7432·9	4939944	152324·1	101225558
<i>Rhodesia</i>	652·5	433682	4626·4	3074730	10840·4	7203865
Asia:						
<i>British India</i>	11684·9	7765807	14178·2	9422855	17943·7	11924308
<i>China</i>	9992·8	6641190	4514·0	3000000	6771·0	4500000
<i>Japan</i>	1073·3	713300	2300·0	1528580	6771·6	4500000
<i>Korea</i>	1646·1	1094000	3460·7	2300000	1805·7	1200000
Australia	93732·3	62294481	115947·8	77058938	129369·2	85970779
Europe:						
<i>Russia</i> <i>(including Siberia)</i>	37217·0	24734418	38988·5	25911744	33402·3	22197155
<i>Hungary</i>	3068·0	2038993	3270·1	2173308	3668·7	2438006
<i>Germany</i>	2847·0	1892116	112·0	74435	3933·0	2613639
<i>United Kingdom</i>	9·0	6321	161·2	107267	422·5	280781

*) To convert Dollars to £ divide by 5; to convert kilograms to ounces multiply by 31½.

Platinum.

This metal was discovered in the Choco district in Colombia, South America, and was first brought to Europe in the year 1735. It was called platina in Spanish, since it is a white metal somewhat resembling silver (Spanish, plata). Although the native metal has since been found at some other localities and has been much sought for, it is still one of the rarest of metals. It occurs also in very small quantities in some gold ores. Only one compound of the metal is found in nature; this is the mineral *sperrylite*, a compound of platinum with arsenic, with the formula $PtAs_2$, which occurs as small cubic crystals with a tin-white colour and metallic lustre in the province of Ontario in Canada.

Native platinum is found almost exclusively in alluvial deposits in the form of small isolated scales and grains, less frequently in large grains and nuggets. The largest piece on record was found in the Ural Mountains, and it weighed 10 kilograms. The grains have a smooth or a rough surface, and are often pitted. Crystals, which have the form of a regular cube, are extremely rare. Two pieces of native platinum are represented in plate 5; that in fig. 15 weighs 54.3 grams, and the other, fig. 16, 621 grams. Nuggets of the size here shown are of rare occurrence. Professor G. Rose counted only five which each weighed over 500 grams in a collection of 3384 platinum nuggets all of them over $4\frac{1}{2}$ grams in weight.

The colour of native platinum is steel-grey, while that of the pure metal is silver-white. It is malleable and ductile, and its hardness exceeds that of gold and silver. The specific gravity of the native metal varies between 14 and 19, that of pure platinum being 21.5; it is therefore the heaviest of metals, with the exception of iridium and osmium. The considerable variation in the specific gravity of native platinum is due to the presence of impurities, namely, 5—16 per cent. of iron, some iridium, rhodium, palladium, osmium and copper. The fact that some grains of native platinum are strongly magnetic with polarity is probably due to the presence of iron.

Platinum is very resistant to acids, being dissolved only by aqua regia. It is also very difficultly fusible, the melting point being about $1770^{\circ}C$. For these reasons the metal finds many applications in the chemical laboratory and in chemical industries, and its place could be taken by no other metal. It is easily attacked when heated with sulphur, arsenic, or easily fusible metals; these substances should therefore not be heated in a platinum crucible or on platinum wire.

The greater part of the platinum now found is of Russian origin, coming from a district about 5000 square kilometres in area on the upper Tura river, which is situated on the eastern side of the Urals in government Perm. The richest deposits are on the Iss, a tributary of the Tura, and were discovered in 1825. In the district of Nizhne-Tagilsk, some hundreds of kilometers to the south, large quantities have also been won; and the large nugget represented in plate 5, fig. 16, is from this locality. The mother-rock of platinum in the Urals is a serpentine, which has been formed by the weathering of an olivine-rock: the latter is an igneous rock, which was intruded as a molten magma, bringing with it the precious metal.

Platinum is also found in Colombia in South America (where it was first discovered), in Brazil, California and British Columbia, being associated in these countries with gold; in Borneo, where it is associated and intergrown with iridosmine; and in New South Wales and New Zealand.

Platinum has several important uses. In the chemical laboratory it is used in the form of wire and foil, and as a material for crucibles, dishes, retorts, etc. The chemical manufacturer uses platinum vessels for the concentration of sulphuric acid. The points of lightning conductors are made of platinum.



Fig. 109.
Russian platinum coin.
3 rouble piece.

Formerly the metal was used for coins in Russia, but owing to its rarity this is no longer the case. The nominal value of the three rouble piece (fig. 109) when coined was 9s. 7d., but at the present price of platinum it is worth double this amount: the coin weighs 10.3 grams. Altogether 14,250 kilograms of platinum were coined, and since then the value of this quantity has increased by £700,000. The ordinary commercial platinum always contains small amounts of iridium, about 0.1 to 1.5 per cent. Chemically pure platinum is almost as soft as pure gold, and like the latter it must be alloyed with some other metal to make it more resistant to wear. For many purposes alloys rich in iridium are more suitable than is ordinary platinum.

In addition to its use in the metallic state, salts of platinum also find useful application as chemical reagents and in photography. When ammonium platinum chloride is heated to redness, the platinum remains in a very finely divided state, and this "platinum-sponge" possesses some very remarkable properties: it condenses gases in its pores, and when brought into contact with hydrogen or coal-gas causes them to ignite. Use was made of this property of platinum in the Döbereiner lighter, which is now superseded by self-lighting arrangements attached to gas-burners.

Iridium is a heavy metal which occurs in nature alloyed with platinum or with osmium. Most native platinum contains it in small amount, but specimens in which iridium predominates are very rare. When alloyed with osmium it forms the mineral known as *iridosmine* or *osmiridium*, which is found as thin scales in alluvial deposits in Choco (Colombia), the Urals, and in California. Iridium is fusible only with great difficulty, the melting point being 600° C. higher than that of platinum, so that formerly this metal could not be worked. Now, however, it can be worked up into foil and wire. It is a very hard metal, and has a specific gravity of 22. Iridium finds an important application in the construction of the Chatelier pyrometer, which is a form of thermometer capable of measuring temperatures up to 1600° C. Wires of platinum and iridium are soldered together to form a thermo-electric couple: when the junction is heated an electric current is generated, the strength of which is dependent on the temperature and may be measured by means of a galvanometer. Still higher temperatures — 1600° to about 2200° C. — may be measured in this way by constructing the thermo-electric couple of pure iridium and of an alloy of iridium and ruthenium.

Osmium is another heavy metal which is won in small amounts as a by-product from platinum, the amount being about 32 kilograms from 5000 kilograms of platinum. This has been used for the mantles of incandescent gas-lights and for the filaments of electric lamps. Osmic acid, a compound of osmium and oxygen, is used in the preparation of microscopic sections of animal tissues. Chemically pure osmium has a specific gravity of 22.5, and is the heaviest known substance.

In the production of platinum Russia takes the first place, contributing over 90 per cent. of the total amount. In the year 1900 Russia produced 5100 kilograms (165,000 ounces troy), and in 1905, 5241.3 kilograms. Colombia in South America yields annually about 356 kilograms (11,500 ounces). In the United States about 6 kilograms per annum are separated from the gold coined at the mint in San Francisco. Appreciable amounts of platinum are known to occur in New South Wales, but, owing to want of



Native Silver.

Fig.

1. **Silver**, cubes (simple crystals, and twin-crystals twinned on an octahedral face); on calcite with some fluor-spar and quartz.
Kongsberg, Norway.
2. **Silver**, octahedra (simple crystals grouped in parallel position); on calcite with some fluor-spar and quartz.
Kongsberg, Norway.
3. **Silver**, octahedron with cube faces (an unusually large crystal at the top of the figure); with massive silver.
Kongsberg, Norway.
4. **Silver**, cube with octahedron, twinned on an octahedral face; on calcite.
Kongsberg, Norway.
5. **Silver**, octahedron with icositetrahedron $3O3$, twinned on the predominating octahedral face.
Kongsberg, Norway.
6. **Silver**, slightly tarnished. A platy group of branching crystals. The small triangular facets are those of the octahedron, and the narrow facets at their edges belong to the icositetrahedron $3O3$. The thicker crystals at the end of the branches are bounded by the faces of the icositetrahedron $3O3$. The structure of this specimen is more clearly shown in Figs. 2 a—c on Plate 7.
Kongsberg, Norway.
7. **Silver**, with a black tarnish. A branching aggregate of crystals, with the branches at right angles to the main stem.
Sophie mine, Wittichen, Black Forest, Baden.
8. **Silver**, grey and dull. A branching form with the branches at 60° to the main stem.
Himmelsfürst mine, Freiberg, Saxony.
9. **Silver**, a delicate branching form with the branches at 60° .
Kongsberg, Norway.
10. **Silver**, wiry, with a cork-screw twist.
Bolanitos mine, Guanajuato, Mexico.
11. **Silver**, mossy.
Bolanitos mine, Guanajuato, Mexico.
12. **Silver**, dentiform.
Kongsberg, Norway.
13. **Silver**, wiry and chippy, with a black tarnish; on calcite.
Freiberg, Saxony.
14. **Silver**, a thick wiry form, bent and angular, with indications of crystal-faces.
Kongsberg, Norway.





water, there are practical difficulties in winning the metal. The demand for platinum is greater than the supply, and hence the price has continually been increasing, though subject to great fluctuations, and at the present time exceeding that of gold. In 1903 the price of a kilogram of commercially pure platinum was £125, and in 1907 about £140.

Native Silver and Silver Ores.

Native Silver.

Native silver, like native gold, has been known from the earliest times. It is not, however, so readily won as is gold, for it never occurs as rolled fragments in the beds of streams, but is always found in the solid rock, though usually quite near to the earth's surface. Silver resembles gold in the ease with which it can be wrought, in its mode of occurrence, and in many of its characters. It has not, however, the unalterable lustre of gold, and in contact with the air it soon becomes tarnished and black: it is less permanent than gold and differs from it also in colour. For these reasons, and also because of its greater abundance, silver is less valuable than gold. Moreover, silver more readily forms compounds with other elements than does gold; several minerals containing silver as an essential constituent occur in nature, and indeed most of the silver which we use has been obtained from the metallic ores of this metal.

Native silver, when in a fresh and unaltered condition, is white with a metallic lustre; usually, however, owing to the formation of a film of sulphide of silver, it is dulled on the surface by a yellowish or blackish tarnish. It crystallizes in the cubic system, and is found as well-formed crystals, or more frequently as delicately branching forms, or as platy, wiry, dentiform, or mossy aggregates, which frequently present a certain resemblance to the forms of plants.

Some examples of well-formed crystals of native silver from Kongsberg in Norway are illustrated in plate 6, figs. 1—3: they are attached to calcite, with which is a little fluor-spar and quartz. In fig. 1 the form is the cube, and in fig. 2 the octahedron; while the unusually large crystal shown in fig. 3 (on a large piece of massive native silver) is a combination of the cube and the octahedron. The small crystals shown in fig. 4 are also bounded by faces of the cube and the octahedron. Very frequently the crystals are twinned on a face of the octahedron: the crystals represented in figs. 1, 2 and 4 are so twinned, though this is not evident in the figures. A twinned crystal is shown in the upper part of fig. 5; the triangular face is that of the octahedron, and the three faces bordering on it belong to the icositetrahedron $3O3$; the other side of the same crystal is also bounded by one octahedral face and three faces of the icositetrahedron; the whole form being thus bounded by only two faces of the octahedron and six of the icositetrahedron, with the omission of the remaining six octahedral faces and eighteen icositetrahedral faces. This peculiar development of the crystal is due to twinning on the octahedral face.

The plate of native silver represented in plate 6, fig. 6, and again in plate 7, figs. 2 *a—c*, consists of an aggregation of such twinned crystals arranged in rows parallel to the three sets of lines at 60° which bisect an octahedral face. The thicker crystals at the end of the branches show very distinctly the form of the icositetrahedron (plate 7, fig. 2 *c*). At several places (especially in fig. 2 *a*) the triangular outline of the individual

crystals is clearly visible; while in other parts (fig. 2*b*) these triangular faces are greatly elongated in one direction, giving rise to the network of branches intersecting at angles of 60° . This plate of silver with its delicate and beautiful regularity of crystalline structure has been described in detail from a purely crystallographical point of view by the late Professor G. vom Rath.

Another plate of native silver is represented in plate 7, fig. 3, and this exhibits a striking resemblance in its structure to the plate of gold (figs. 1*a*, 1*b*) already mentioned. The small triangular markings on its surface are in reversed positions with respect to one another in the upper and the lower parts of the figure; this reversal in position being due, as in the plate of gold, to twinning.

In the specimen of dendritic silver shown in plate 6, fig. 7, from the Sophie mine, at Wittichen in the Black Forest, the branches are at right angles to the main stem, and springing from these branches are still smaller branches again at right angles. This particular dendritic growth, which has a certain resemblance to a fir-tree, is due to the aggregation of numerous minute octahedra along the three rectangular cubic axes. Other tree-like or fern-like aggregates of silver crystals are represented in figs. 8 and 9; here the branches are at angles of 60° .

Fig. 4 of plate 7 shows a wiry form of native silver on calcite, and fig. 10 of plate 6 another wiry form twisted like a cork-screw. Fig. 11 of plate 6 shows a mossy form of native silver, due to the matted aggregation of numerous small wires. Such twisted wiry forms are especially characteristic of native silver. Sometimes these wires are rather thicker and curved like an elephant's tusk, so that they may be described as dentiform (fig. 12); or again they may be flattened, then resembling in form curved chips or shavings of wood (fig. 13); or they may be twisted in and out giving rise to a variety of shapes (fig. 14). It is usually possible to detect on the thicker portions of the wires some traces of crystal-forms, showing that the wires themselves are really distorted crystals. These wiry forms of native silver have usually grown out from a mass of silver sulphide (a grain of which may be seen in fig. 12), which has been acted upon by a reducing solution, whereby the sulphur is removed and the silver left free.

Silver is malleable and ductile to a high degree, and its hardness is not great, being rather less than that of calcite. The specific gravity of the native metal varies from 10 to 11; it does not range between such wide limits as does the specific gravity of native gold. The reason for this lesser variation is that native silver consists mostly of pure silver with usually only traces of gold or copper. Some specimens from Kongsberg in Norway contain, however, as much as 27 per cent. or even 50 per cent. of gold, but these auriferous silvers are quite exceptional, and they form a passage to amalgam. When the silver is dissolved in sulphuric acid the gold remains behind, and this is a means employed to separate the two metals. From the old German thalers much gold was obtained in this way. Pure silver fuses at a temperature of 945° C.

Native silver is usually found in veins in crystalline schists, granite and sedimentary rocks, and it is often associated with calcite, fluor-spar, barytes, quartz, and the sulphide silver ores which will be dealt with further on. These silver ores increase in amount in the deeper parts of the vein, whilst in the upper part of the vein their place is taken by native silver or sometimes by native silver and chloride of silver. It is thus clear that the native silver has been derived from the sulphide silver ores by their weathering in the upper parts of mineral lodes.

Well-known localities for native silver in Germany are the following. At Freiberg in Saxony, especially in the Himmelsfürst mine, where a mass weighing 4—5 hundredweights was found; the specimens shown in plate 6, figs. 8 and 13, are from

here. At Schneeberg and Johanngeorgenstadt, also in Saxony: in the fifteenth century it is said that a mass of silver and silver sulphide weighing 400 hundredweights was found at Schneeberg. At Wittichen in Baden (fig. 7), and at Andreasberg in the Harz Mountains.

In the Bohemian Erzgebirge, silver is won at Joachimsthal, and it is said that the name of the German thaler is derived from the fact that these coins were made of Joachimsthal silver. The silver mines at Kongsberg in Norway have long been famous for the large amounts of native silver which they have yielded, and for the exceptionally fine specimens of this mineral which have been there found: the best specimens represented in plates 6 (figs. 1—6, 9, 12, and 14) and 7 (figs. 2, 3 and 4) are all from this locality. These richer deposits have now been worked out, and at the present time the mines only yield an ore poor in silver, their annual production amounting to about 5000 kilograms of silver. Native silver has been found in many of the Cornish mines, though usually only in small amounts, and in the form of very fine twisted wires.

Larger quantities of native silver are found in North and South America than in Europe. Mexico is especially rich, and so are Chile and Peru. Two specimens of native silver from the neighbourhood of Guanajuato in Mexico are shown in plate 6, figs. 10 and 11. It is also found at several places in the United States: and of especial interest is the occurrence of native silver in close association with native copper in the amygdaloidal melaphyre rocks of the Lake Superior district in Michigan.

On the whole, native silver is much less widely distributed than is native gold, and most of the silver which we obtain is won from the ores of silver, which contain this element in chemical combination with sulphur, antimony and arsenic. At all the localities mentioned (except Lake Superior) these sulphide compounds of silver occur with the native silver, and from them the bulk of the metal is obtained. Since the native silver occurs in the upper parts of the mineral-veins, it is naturally the first to be found, while the richer silver ores are won when the mining is carried on deeper.

The applications of silver and the amount of its production will be mentioned after we have described the more important silver minerals.

Silver Ores.

The ores of silver consist of one or more elements in chemical combination with silver; these elements may be sulphur, antimony or arsenic, and less frequently chlorine, bromine or iodine. The more important silver minerals which we shall describe here are argentite, dyscrasite, the red silvers, stephanite and horn-silver; the rare mineral argyrodite will also be briefly described, being of interest as the source of the recently-discovered element germanium. Among other silver minerals one of the more important is polybasite, which somewhat resembles stephanite in appearance and consists of the same elements, but combined in different proportions. Silver also is often present in galena in small amounts, and in tetrahedrite sometimes in large amounts; these two minerals, which are frequently of importance as silver ores, will be considered with the lead and copper ores respectively.

Argentite, or silver-glance, contains a larger proportion of silver than any other ore and is therefore of first importance. It consists of 87.1 per cent. of silver and 12.9 per cent. of sulphur, this composition being expressed by the formula Ag_2S . Other elements are only exceptionally present, and the mineral is usually pure silver sulphide:

for instance, the analysis of a crystal, from Freiberg in Saxony, showed the presence of 87.09 per cent. of silver. These constituents can be readily detected by heating a fragment of the mineral before the blowpipe together with sodium carbonate on charcoal, when a bright bead of metallic silver is obtained. The fused yellowish mass on the charcoal if placed on a silver coin and moistened with water produces a black stain, thus proving the presence of sulphur.

The colour of argentite is dark lead-grey to black, and the lustre is metallic. A bright metallic lustre is, however, only to be seen on specimens which have not been exposed to the light for any length of time, or on a freshly cut surface of the mineral: on exposure to light the surface soon becomes dull and acquires a sooty coating. Argentite is highly sectile and malleable, and can be cut and hammered out like metallic lead. Masses of larger size, such as are found at Freiberg in Saxony, are sometimes carved by the miners; and King August of Poland caused some medals bearing his portrait to be struck in argentite. The hardness of the mineral is low, being a little over 2 on the scale; and the specific gravity is 7.35.

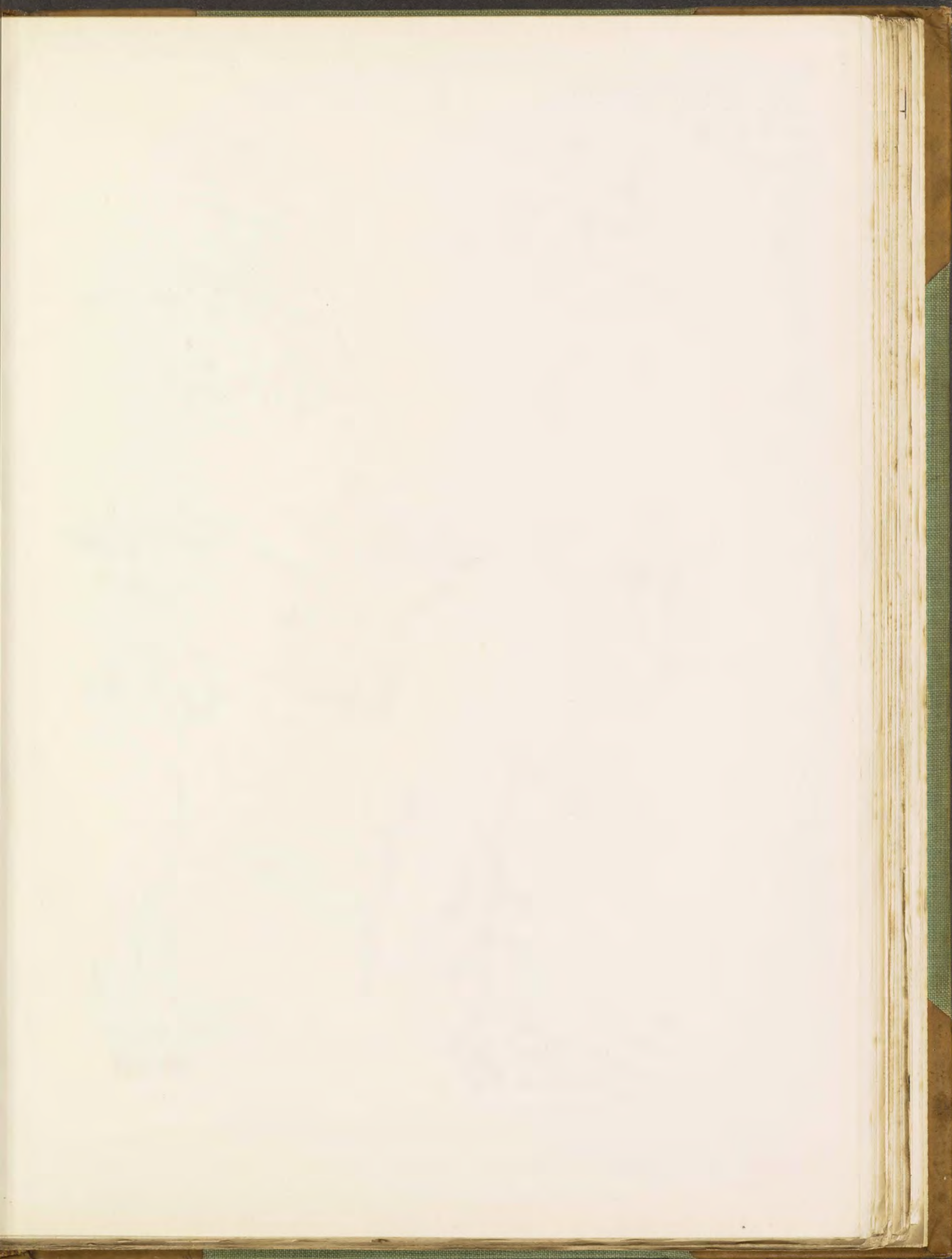
On account of its softness and malleability, the mineral is called "soft ore" by the Hungarian miners. The old German name "glass-ore" (Glaserz), used as far back as 1546 by Agricola for this and some other similar minerals, is singularly inappropriate, for the mineral possesses neither the transparency nor the brittleness of glass. Another old name, glance-ore (German, Glanzerz), is more in agreement with the characters of the mineral, but it could be equally well applied to several other minerals. The name argentite, given by W. von Haidinger in 1845, is from the Latin *argentum*, silver.

Argentite crystallizes in the cubic system, the most frequent form being the cube combined with the octahedron (plate 8, figs. 3, 4, 6), or the octahedron with the cube (fig. 5); less frequently, the octahedron occurs as a simple form (fig. 7) or in combination with the icositetrahedron. The crystals are not sharply developed, the faces being curved and drusy (figs. 5 and 7). Peculiar forms of growth, due to the aggregation of crystals, also occur (figs. 8 and 9), but these are not so delicate as in native silver.

Native silver is a common associate of argentite, and the two minerals often pass one into the other. Silver by the addition of sulphur becomes changed to argentite, and argentite when deprived of its sulphur is converted into native silver; wires of native silver may often be seen to have grown from a nucleus of argentite (plate 6, fig. 12). Argentite occurs only in mineral-veins traversing granite or crystalline schists, and is associated with other ores of silver and with quartz.

Amongst the localities where argentite is found, several places in Saxony are noted for producing crystallized specimens; namely, Freiberg (plate 8, figs. 3, 6, 8, 9), Annaberg (fig. 7), Schneeberg, and Johanngeorgenstadt; in the silver mines at these places lumps of pure argentite weighing several kilograms have been found. Other well-known German localities are Andreasberg in the Harz, and Wolfach in the Black Forest. At Kongsberg in Norway large masses were formerly found in association with native silver. The mineral has been found in several Cornish mines, but only in small quantities. Large quantities of massive argentite have been taken from the Comstock lode in Nevada, a locality which has already been mentioned under gold. The silver mines at Zacatecas and Guanajuato in Mexico are also rich in argentite, and specially fine crystallized specimens have been yielded by the silver mines at Chañarcillo in Chile (fig. 5).

Dyscrasite, or antimonial silver, when in a fresh condition is silver-white with a brilliant metallic lustre, but on exposure to light and air it soon becomes grey or yellowish and dull. It is found as small masses or grains embedded in native arsenic (plate 8, fig. 12), or as crystals embedded in limestone (fig. 13). The crystals are orthorhombic,





1a



1b



2a



2b



2c



3



5



4

PLATE 7.

Native Gold, Silver and Copper.

Fig.

1*a* and *b*. **Gold.** The specimen of plate 5, fig. 4, enlarged two diameters. A description of the surface markings is given in the text (p. 76).

Vöröspatak, Transylvania, Hungary.

2*a*, *b*, *c*. **Silver.** Three views, in natural size, of the specimen shown in plate 6, fig. 6. *a* and *b* show opposite sides, and *c* is the upper portion of the side *a*. A detailed description is given in the text (p. 87).

Kongsberg, Norway.

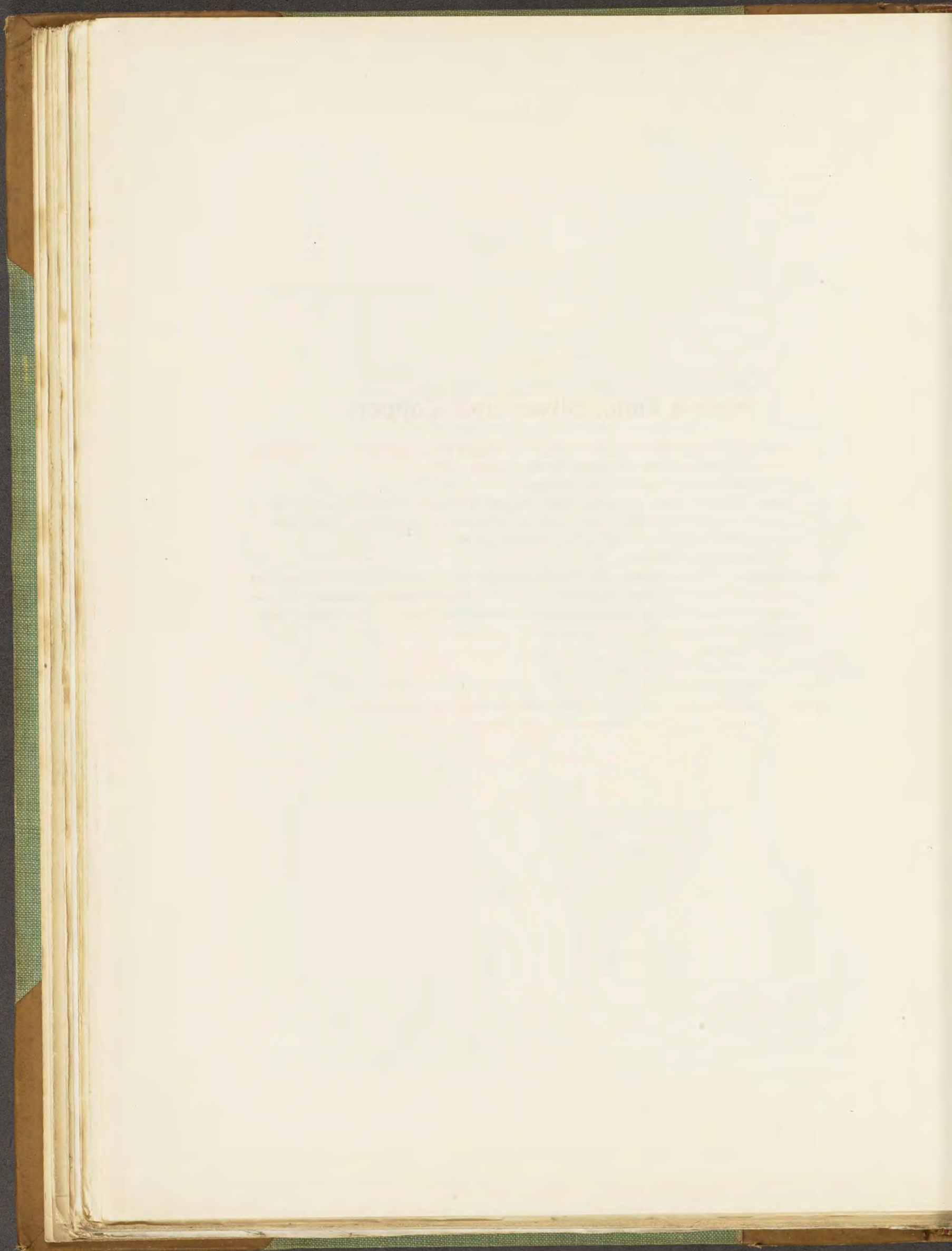
3. **Silver**, enlarged two diameters. The surface markings on this plate of silver are similar to those on the leaf-gold in fig. 1. The triangular markings in the lower left-hand corner are opposite in direction to those in the upper right-hand corner, indicating the presence of twinning.

Kongsberg, Norway.

4. **Silver**, wiry, on calcite. Natural size.

Kongsberg, Norway.

5. **Copper.** A description of the crystalline structure is given in the text. Eagle river, Lake Superior, United States.



but are rarely distinctly developed and their faces are deeply and roughly striated (figs. 10 *a* and *b*). In these figures the striated faces shown are those of the base, and the striations are parallel to the macro-pinacoid. The angle between the prism faces differs from 120° by only one minute, so that the four prism faces and the two faces of the macro-pinacoid apparently form a hexagonal prism: in a truly hexagonal crystal, however, the base would be striated in three diagonal directions. The crystals simulate hexagonal symmetry still more closely by being twinned on the faces of the prism, as in aragonite, giving rise to stellate groups. The crystals represented in figs. 10 *a* and *b* each consist of two individuals twinned together on a prism face, as may be seen by the two sets of striations at 60° on the basal planes.

Dyscrasite is composed of silver and antimony, being an antimonide of silver, but the relative proportion of the two elements is somewhat variable, the silver percentage varying from 72 to 84, corresponding with the formulae Ag_3Sb and Ag_6Sb respectively. With this variation in composition there is a corresponding variation in the specific gravity, from 9.4 to 9.9. The hardness is about the same as that of calcite, namely 3.

As an ore of silver dyscrasite is of little importance, and it has been found at only a few localities. Blocks weighing as much as a hundredweight have, however, been raised at Wolfach in the Black Forest, where the mineral occurs with red silver, galena, calcite and barytes (plate 8, fig. 12). It is also not uncommon in the silver veins of Andreasberg in the Harz (figs. 11 and 13).

Cerargyrite, or horn-silver, owes its name to the fact that the mineral can be cut like horn, and the parings resemble horn both in colour and lustre. It consists of silver in combination with chlorine, bromine and iodine, but usually chlorine predominates, and bromine and iodine may be present only in small amount or completely absent. The pure chloride of silver has been called chlorargyrite, and the pure bromide bromargyrite, while minerals containing both chlorine and bromine are referred to as embolite. The different members of the group are not readily distinguished except by chemical analysis. They are not conspicuous minerals, usually occurring as an encrustation on other minerals (plate 8, fig. 14). Crystals have the form of the cubo-octahedron, but are always small and indistinct. The mineral is translucent, its colour is greyish, yellowish or greenish, and its lustre resinous or horny. On exposure to light the material quickly darkens and becomes dull. The mineral is very sectile and malleable, like argentite. Its hardness is low, $H. = 2\frac{1}{2}$, and the specific gravity of the pure chloride is 5.56.

Cerargyrite occurs in the upper oxidized portions of silver-bearing mineral-veins, and it has without doubt resulted by the action of salt solutions (e. g. sea water) on the sulphide ores of silver. It is found in small amounts at Freiberg and Johanngeorgenstadt in Saxony, and in Cornwall. At several places in Chile and at Broken Hill in New South Wales it occurs in large quantities and is there an important ore of silver. At Broken Hill, the locality of the specimen represented in plate 8, fig. 14, the mineral contains both chlorine and bromine and usually also iodine; but the upper portion of the lode which yielded the secondary minerals has now been completely removed by mining, so that cerargyrite is no longer found here.

The *red silvers*, or ruby-silvers, comprise two minerals, which are distinguished as dark red silver-ore and light red silver-ore. Both contain silver and sulphur with the addition of antimony in the darker and of arsenic in the lighter mineral: hence the former is also known as antimonial silver-blende, and the latter as arsenical silver-blende. Other, more usually adopted names, for the two minerals are pyrargyrite and proustite, respectively.

Pyrrargyrite, or dark red silver-ore, contains 59·8 per cent. of silver, 22·5 per cent. of sulphur, and 17·7 per cent. of antimony; its chemical formula is Ag_3SbS_3 . The presence of each of the constituents can be readily proved by simply heating the mineral with sodium carbonate on charcoal before the blowpipe: a white sublimate of antimony oxide is formed on the charcoal, a bead of silver remains, and the fused mass when moistened with water gives a black stain on a silver coin.

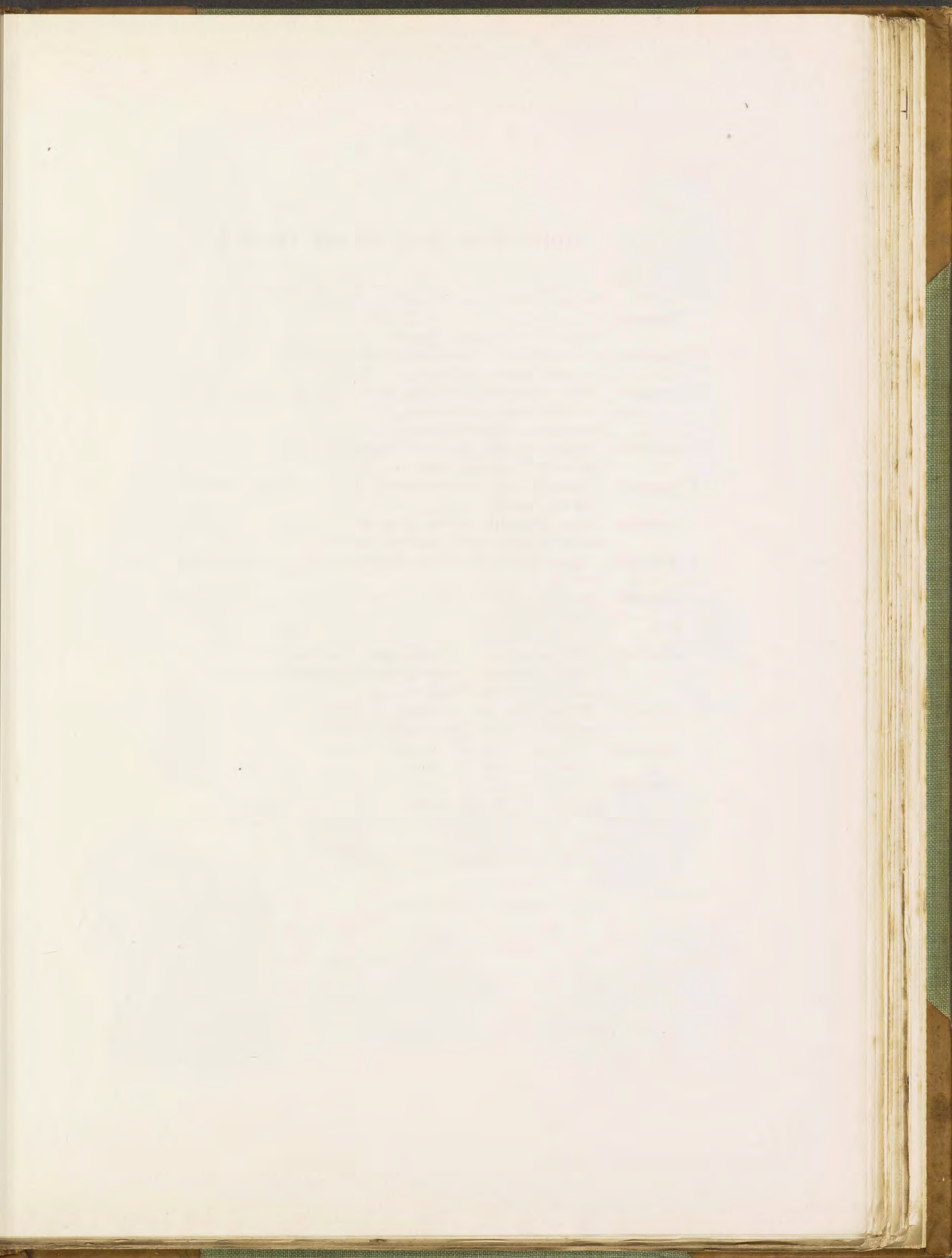
Crystals of pyrrargyrite are represented in plate 9, figs. 1—9. The smaller crystals, or the thinner edges and portions of larger crystals, are transparent with a deep ruby-red colour. Thicker crystals, such as that shown in fig. 4, only transmit a red colour when they are held up to a strong light; otherwise they appear opaque with a lead-grey colour and metallic lustre. Sometimes the surface of the crystals is dull grey and without lustre. In all cases, however, the colour of the streak, or the powder of the mineral, is purplish-red. The red colour of the mineral may often be seen on fractured surfaces, as in fig. 5. The strong metallic to adamantine lustre of the crystals is connected, as in diamond, with the high refractive power, the ordinary index of refraction being 3·08 in pyrrargyrite.

The crystals belong to the rhombohedral division of the hexagonal system. Sometimes they are bounded by only the base and the hexagonal prism (plate 9, figs. 1 and 2), or more frequently a scalenohedron is the predominating form (figs. 3, 4 and 5). An exceptionally fine crystal is represented in fig. 4; it is bounded on all sides by faces of a scalenohedron, which are striated parallel to the median edges, this striation being due to oscillatory combination with the prism of the second order. The scalenohedral crystal shown in fig. 3 is terminated by the basal plane; and the small scalenohedron on the upper part of fig. 5 is remarkable for the sharpness of its edges. The latter quite resembles a crystal of calcite in its form, especially as the angles between the faces differ by only about one degree in the two minerals. In other crystals, especially those from Andreasberg in the Harz Mountains, the prism of the second order is combined with a very obtuse scalenohedron $\frac{1}{4}R3$ (fig. 8), or less frequently with an obtuse hexagonal pyramid $\frac{2}{3}P2$ (fig. 7). On this pyramid the angles over the six edges meeting at the top of the crystal are all equal, being $153^\circ 5'$; but on the obtuse scalenohedron there are two sets of edges meeting at the top of the crystal, the angles between the faces over three of the edges being $160\frac{1}{2}^\circ$ and over the three alternate edges $140\frac{1}{2}^\circ$.

The specimen shown in plate 9, fig. 9, from Andreasberg in the Harz, is remarkable for the size and the form of its crystals. The two large faces on the crystal to the right belong to the scalenohedron $R3$; above are faces of an obtuse scalenohedron $\frac{1}{4}R3$ and an obtuse rhombohedron $-\frac{1}{2}R$; and below are faces of the hexagonal prism $\infty P2$. The directions of the striations on the prism faces sometimes indicate that crystals of pyrrargyrite are hemimorphic, as in tourmaline, but only rarely are the crystals differently developed at the two ends.

The hardness of pyrrargyrite is $2-2\frac{1}{2}$, and its specific gravity is 5·85. The crystals possess three directions of distinct cleavage parallel to the faces of the primary rhombohedron, and the angles between them differ by only a few degrees from those between the more perfect cleavages of calcite. There is thus a certain amount of crystallographic similarity between these two minerals.

Pyrrargyrite is found as crystals and as compact masses in association with other silver ores and with calcite in mineral-veins. Well-known occurrences are those of Andreasberg in the Harz (plate 9, figs. 3, 4, 7, 8, 9), of Freiberg and Annaberg (fig. 1) in Saxony, and Joachimsthal in Bohemia. Small, well-developed crystals are found with galena in the Gonderbach mine at Laasphe in Prussia (fig. 6) and at Wolfach

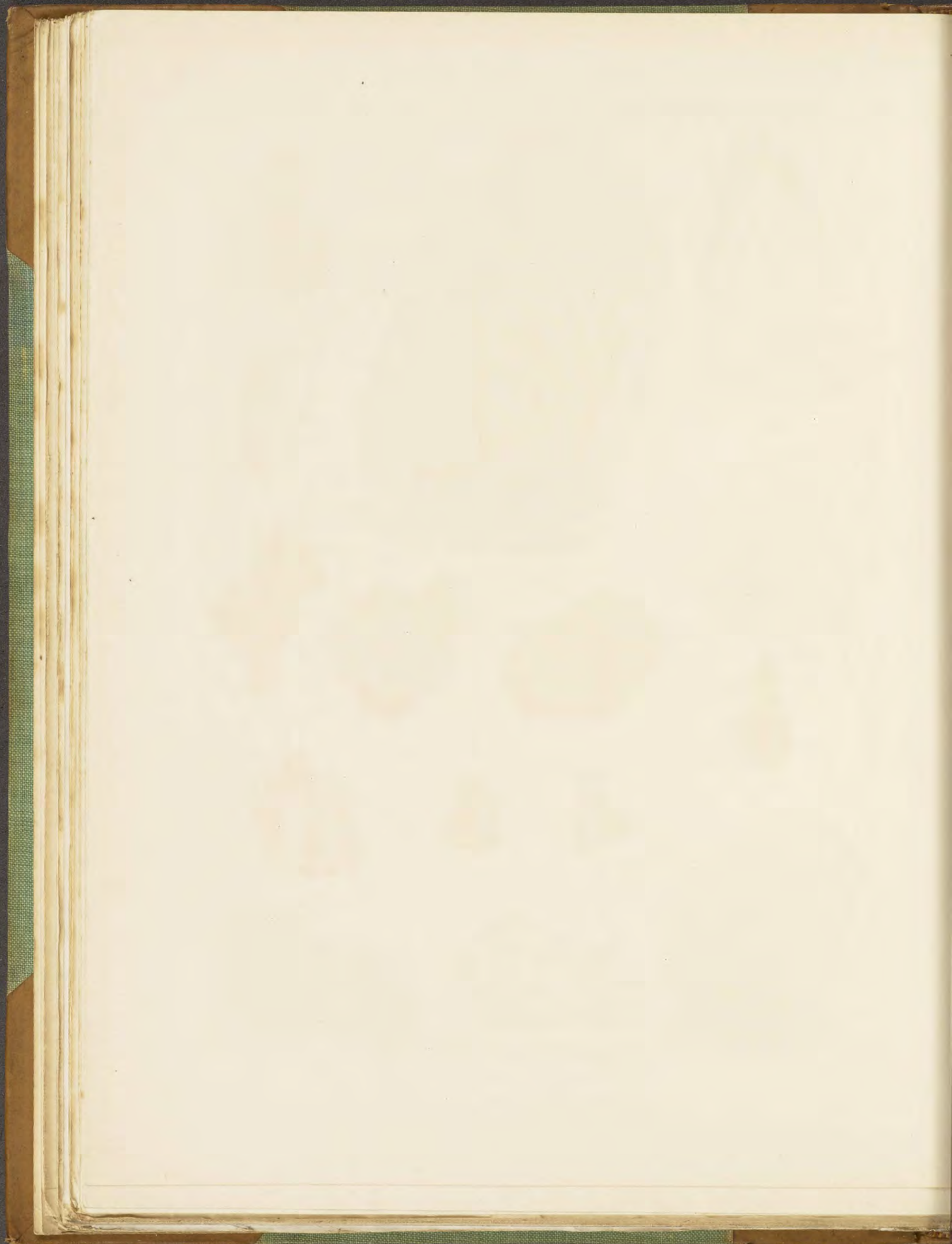


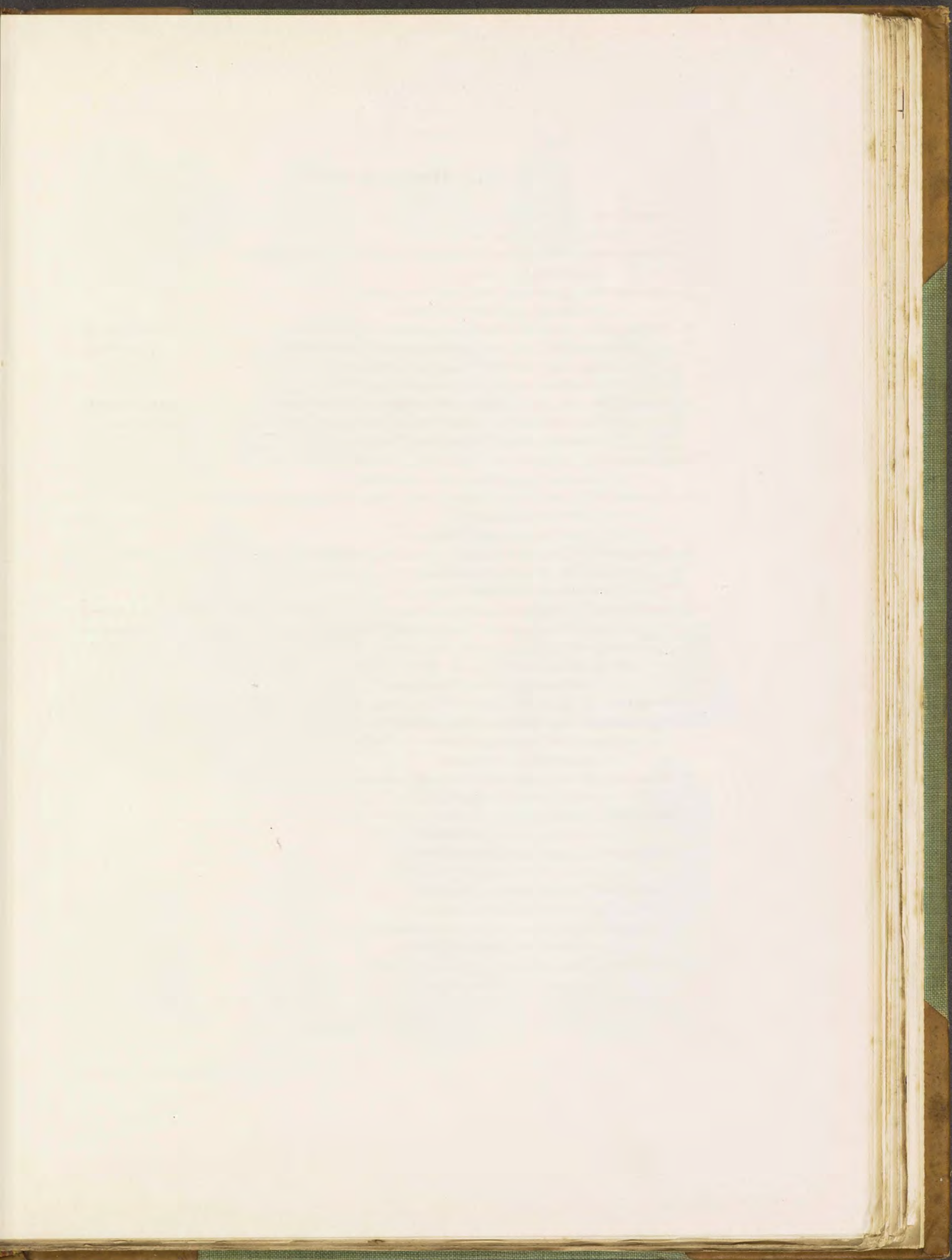
Gold Ores and Silver Ores I.

Fig.

1. **Sylvanite.**
Nagyag, Transylvania, Hungary.
2. **Nagyagite.**
Nagyag, Transylvania, Hungary.
3. **Argentite,** or silver-glance. Small cubo-octahedral crystals.
Freiberg, Saxony.
4. **Argentite.** Cubes with small octahedral faces. The larger crystal has been cut along the front edge of the cube.
Andreasberg, Harz Mountains.
5. **Argentite.** Octahedron with cube faces; implanted on calcite.
Chañarcillo, Copiapó, Chile.
6. **Argentite.** Unusually large cubo-octahedral crystals with dull surfaces.
Freiberg, Saxony.
7. **Argentite.** Large octahedral crystals with drusy surfaces.
Marcus Röhling mine, Annaberg, Saxony.
8. **Argentite.** Aggregation of cubes with octahedral faces; with a yellowish tarnish.
Freiberg, Saxony.
9. **Argentite.** Octahedral crystals with cube faces; elongated in the direction of one of the cubic axes.
Freiberg, Saxony.
10. **Dyscrasite,** or antimonial silver. Two views (*a* and *b*) of the same crystal, consisting of two individuals twinned together; slightly tarnished.
Andreasberg, Harz Mountains.
11. **Dyscrasite.** Prismatic crystals in calcite.
Andreasberg, Harz Mountains.
12. **Dyscrasite.** Untarnished particles in native arsenic.
Andreasberg, Harz Mountains.
13. **Dyscrasite.** Curved crystals in calcite.
Andreasberg, Harz Mountains.
14. **Cerargyrite,** or horn-silver. A brownish crust of crystals (small cubo-octahedra) on manganese ore.
Broken Hill, New South Wales.





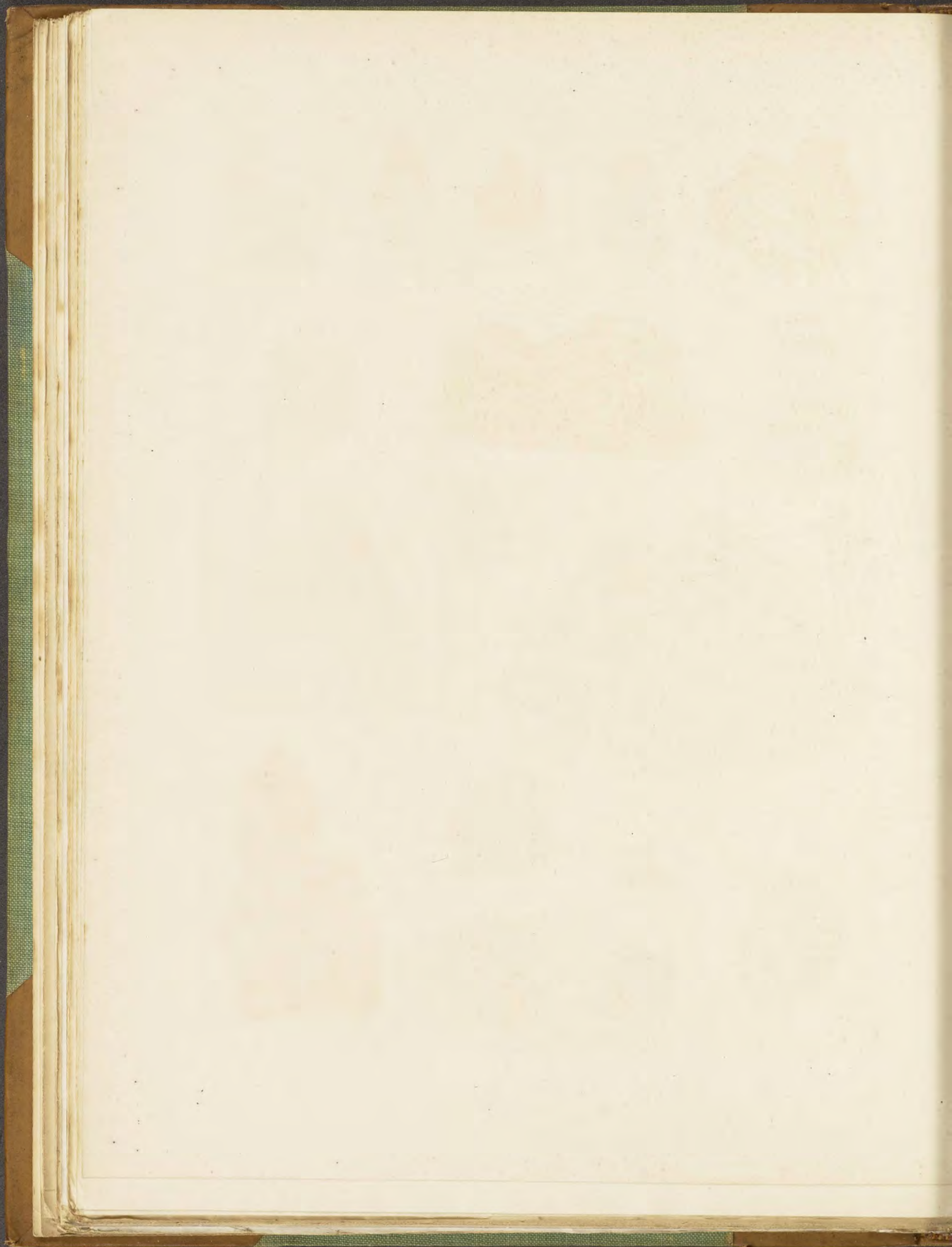


Silver Ores II.

Fig.

1. **Pyrargyrite**, or dark red silver-ore. Group of prismatic crystals with dull surfaces. Annaberg, Saxony.
2. **Pyrargyrite**. Isolated crystal; hexagonal prism with basal plane. Guanajuato, Mexico.
3. **Pyrargyrite**. Scalenohedron $R3$ with basal plane. Andreasberg, Harz Mountains.
4. **Pyrargyrite**. An isolated crystal completely developed on all sides; the faces of the scalenohedron $R3$ are striated parallel their median edges, owing to oscillatory combination with the hexagonal prism $\simeq P2$. Andreasberg, Harz Mountains.
5. **Pyrargyrite**. A small, sharply-developed scalenohedron $R3$ on a matrix of calcite. The fractured surface below the crystal shows the red colour of the mineral. Dolores mine, Chañarcillo, Chile.
6. **Pyrargyrite**. An isolated crystal of long-prismatic habit. Gonderbach mine, Laasphe, Westphalia.
7. **Pyrargyrite**. The crystal at the top is an obtuse hexagonal pyramid of the second order viewed from above. Andreasberg, Harz Mountains.
8. **Pyrargyrite**. Group of crystals on matrix. Hexagonal prism of the second order combined with an obtuse scalenohedron $\frac{1}{4} R3$. Andreasberg, Harz Mountains.
9. **Pyrargyrite**. Group of unusually large crystals. The two large faces on the crystal to the right belong to the scalenohedron $R3$; below are faces of the hexagonal prism $\simeq P2$; and above are faces of the obtuse scalenohedron $\frac{1}{4} R3$ and the obtuse rhombohedron $-\frac{1}{2} R$. Andreasberg, Harz Mountains.
10. **Proustite**, or light red silver-ore. A large, isolated crystal. The triangular prism indicates the hemimorphic character of the mineral; it is vertically striated, and is terminated by rough faces of a scalenohedron. Joachimsthal, Bohemia.
11. **Proustite**. Small, sharply-developed scalenohedra on argentite. Dolores I mine, Chañarcillo, Chile.
12. **Proustite**. Scalenohedra $R3$, with asbestos on calcite. Dolores I mine, Chañarcillo, Chile.
13. **Stephanite**. Large prismatic crystal. Przibram, Bohemia.
14. **Stephanite**. Small prismatic crystal. Andreasberg, Harz Mountains.
15. **Stephanite**. (a) simple crystal; (b) twinned crystal. Andreasberg, Harz Mountains.
16. **Stephanite**. Stellate group of twinned crystals. Andreasberg, Harz Mountains.
17. **Argyrodite**. Botryoidal aggregate of minute crystals. Himmelsfürst mine, Freiberg, Saxony.





in the Black Forest. Other localities are Monte Narba in Sardinia, Guanajuato in Mexico (fig. 2), Chañarcillo in Chile (fig. 5), and Colquechaca in Bolivia.

When found in quantity, pyrargyrite is an important ore of silver. It sometimes has been altered to argentite or to native silver.

Proustite, or light red silver-ore, contains 65.6 per cent. of silver, 19.4 per cent. of sulphur, and 15 per cent. of arsenic, its chemical formula being Ag_3AsS_3 . When heated before the blowpipe it behaves like pyrargyrite, but gives the reaction for arsenic instead of antimony, the former being recognized by the garlic-like odour of the fumes which are emitted.

Proustite is much more transparent than pyrargyrite, and even the thickest crystals allow the passage of a magnificent ruby-red colour; the metallic to adamantine lustre is also more brilliant. On exposure to light the crystals soon become black and opaque with a dull surface. The colour of the streak is scarlet, and this affords an easy means of distinguishing proustite from pyrargyrite, which gives a much darker coloured streak. The crystals have the same degree of symmetry as in pyrargyrite, and sometimes they show indications of a hemimorphic development. Thus, in the fine crystal represented in plate 9, fig. 10, the hemimorphism is shown by the triangular form of the prism; the faces of this triangular prism are deeply striated vertically owing to oscillatory combination with other prism faces; and the dull end faces are those of an obtuse scalenohedron. The more acute scalenohedron $R3$ (figs. 11 and 12) is a commoner form of proustite crystals. The hardness of the mineral is $2\frac{1}{2}$, and its specific gravity 5.57.

Light red silver-ore is of rarer occurrence than the dark red silver ore. It is found in the mineral-veins of Joachimsthal in Bohemia (fig. 10); in the Himmelsfürst mine at Freiberg, at Annaberg and Marienberg, in Saxony; at Wittichen in the Black Forest, and at Markirch in the Vosges. Magnificent crystallized specimens consisting of groups of large scalenohedra are well-known from the silver mines around Chañarcillo in Chile, from which locality come the specimens represented in figs. 11 and 12. On account of the ruby-red colour and brilliant lustre of the transparent crystals such specimens are eagerly sought for by collectors, adding interest and beauty to any collection of minerals; whilst massive material is of value as an ore of silver.

The sulph-antimonite of silver with the formula Ag_3SbS_3 , which we have already met with as pyrargyrite, also occurs in nature crystallized in the form of thin monoclinic plates which are transparent with a hyacinth-red colour. This represents another mineral species, dimorphous with pyrargyrite, and known as *pyrostilpnite* or fire-blende. In the same way the sulph-arsenite of silver, Ag_3AsS_3 , also is dimorphous, occurring as the rhombohedral mineral proustite and also in orange-yellow to dull red monoclinic scales, the latter mineral being known as *xanthoconite*. Both of these monoclinic species of red silvers are of very rare occurrence, and are only of scientific interest; the first is found in the silver veins of Andreasberg, and the second at Joachimsthal in Bohemia and Chañarcillo in Chile.

Stephanite is also known as "black silver-ore" and as "brittle silver-ore" on account of its black colour and its brittleness. The crystals have a bright metallic lustre, but on exposure to light they soon become dull with a sooty surface. The streak is iron-black. The mineral (plate 9, figs. 13—15) crystallizes in the orthorhombic system, but in forms which show a resemblance to hexagonal crystals. The rhombic prism has an angle of $115^\circ 40'$ between its faces, and in combination with the brachy-pinacoid the form resembles a hexagonal prism; in fig. 14 such a combination is terminated by the basal plane. A rhombic pyramid in combination with a brachy-dome produces an apparent hexagonal pyramid, as in fig. 15 *a*, where the pyramid is truncated by the large

basal plane shown to the front. Less frequently the crystals have a long-prismatic habit, as in fig. 13. Twinning on the faces of the prism is frequent, giving rise to stellate groupings (figs. 15*b* and 16) or pseudo-hexagonal crystals.

Besides occurring as crystals, stephanite is often found as compact masses, when it may be easily confused with other minerals. It may, however, be recognized by its blowpipe reactions, which are the same as those given by pyrargyrite. Stephanite and pyrargyrite are composed of the same chemical elements, but these are combined in different proportions in the two minerals. The formula of stephanite is Ag_5SbS_4 , corresponding with the following percentage composition: silver 68.50, antimony 15.22, and sulphur 16.28. This mineral is thus one of the richest of silver ores. Although it shows a certain resemblance in crystalline form to pyrargyrite and gives the same blowpipe reactions, it may be distinguished from this by its black colour and streak. The hardness is $2-2\frac{1}{2}$, and the specific gravity 6.2.

Stephanite is found together with other silver minerals in the veins of Andreasberg in the Harz (figs. 14—16), Freiberg in Saxony, Przibram (fig. 13) and Joachimsthal in Bohemia, and Schemnitz in Hungary. Large quantities of the massive mineral have been raised from the Comstock lode in Nevada (p. 81).

Argyrodite is a mineral of great rarity, and is mentioned in this place as being of special interest in connection with the comparatively recent discovery of the metallic element germanium. The mineral was found in 1886 as botryoidal masses with a minutely crystallized surface (plate 9, fig. 17), in the Himmelsfürst mine at Freiberg, Saxony, and when analysing it Professor Clemens Winkler detected the new element. The colour is black with a violet tinge, and the lustre metallic. Well-developed cubic crystals have been more recently found in Bolivia.

Winning of silver. — Silver is extracted from the minerals mentioned above and also from some others, especially galena, since this often contains the metal in small amounts. A method often adopted is first to obtain the silver in alloy with lead, which may be done by smelting the silver ore with roasted galena, or by adding the ore to molten lead. The litharge, or yellow oxide of lead, formed by the oxidation of the galena, acts on the silver ore, setting free the silver, and this is taken up into solution by the molten lead, while the other constituents of the ore remain on the surface. The silver is then extracted from the alloy of silver and lead so obtained by the process of cupellation, whereby the lead is converted into oxide and the silver left behind as metal. Or, according to a method introduced by Parkes, the silver-rich alloy is fused with zinc, which takes up the silver, together with any gold that may be present; the alloy of zinc and silver is then heated to distil off the zinc, and the last traces of lead are removed from the metallic silver by oxidation.

Uses of silver. — The applications of silver are much the same as those of gold, the larger part of it being used for coinage. The British imperial silver coinage has a fineness of 925, consisting of 925 parts of silver alloyed with 75 parts of copper, or in the ratio of 37 to 3: this is known as standard silver. The silver coins of Germany and the United States, with a fineness of 900, contain rather less silver. During the last few decades the value of silver, compared with that of gold, has depreciated considerably. By the French edict of October 30, 1785 the value of gold was fixed at fifteen-and-a-half (15.5) times that of an equal weight of silver. This "universal" ratio of value had, previous to the edict, held good for two centuries, and it was accepted by the Latin coinage union on December 23, 1865. According to this ratio the value of an ounce of silver on the London market was $60\frac{13}{16}$ pence. This "universal" ratio was for a time subject to only slight variations. The large quantities of gold produced by

California had the effect of increasing the price of silver; but the introduction of a gold coinage into Germany in 1873 and the increased production of silver in America had the opposite effect, so that in the nineties the price of silver had fallen to half its former amount. Thus, to purchase a kilogram of gold required in 1865 only 15.5 kilograms of silver, but in 1895 31.6 kilograms of silver had to be given, and in 1902 as much as 38.6. This rapid decrease in the value of silver is well shown in the following table, in which is given the ratio of the value of silver to that of gold and the corresponding price in pence of an ounce of silver.

Year	Ratio of value of silver to gold	Price of one ounce of silver in pence	Year	Ratio of value of silver to gold	Price of one ounce of silver in pence	Year	Ratio of value of silver to gold	Price of one ounce of silver in pence
1870	1:15.55	60 ⁹ / ₁₆	1883	1:18.58	50 ⁹ / ₁₆	1896	1:30.64	30 ³ / ₄
1871	1:15.56	60 ¹ / ₂	1884	1:18.59	50 ⁵ / ₈	1897	1:34.30	27 ⁹ / ₁₆
1872	1:15.57	60 ⁵ / ₁₆	1885	1:19.31	48 ⁵ / ₈	1898	1:34.97	26 ¹⁵ / ₁₆
1873	1:15.80	59 ¹ / ₄	1886	1:20.69	45 ³ / ₈	1899	1:34.28	27 ⁷ / ₁₆
1874	1:16.01	58 ⁵ / ₁₆	1887	1:21.05	44 ⁵ / ₈	1900	1:33.31	28 ¹ / ₄
1875	1:16.52	56 ⁷ / ₈	1888	1:21.92	42 ⁷ / ₈	1901	1:34.62	27 ¹ / ₅
1876	1:17.69	52 ³ / ₄	1889	1:22.06	42 ¹¹ / ₁₆	1902	1:38.62	24 ⁵ / ₁₆
1877	1:17.20	54 ¹³ / ₁₆	1890	1:19.74	47 ¹¹ / ₁₆	1903	1:38.59	24 ³ / ₈
1878	1:17.86	52 ⁹ / ₁₆	1891	1:20.91	45 ¹ / ₁₆	1904	1:35.66	26 ³ / ₈
1879	1:18.34	51 ¹ / ₄	1892	1:23.64	39 ¹³ / ₁₆	1905	1:33.76	27 ¹³ / ₁₆
1880	1:18.03	52 ¹ / ₄	1893	1:26.58	35 ⁵ / ₈	1906	1:30.41	30 ⁷ / ₈
1881	1:18.16	51 ¹¹ / ₁₆	1894	1:32.52	28 ¹⁵ / ₁₆			
1882	1:18.14	51 ⁵ / ₈	1895	1:31.59	29 ⁷ / ₈			

All attempts which have been made to preserve a constant ratio of value between the two metals have been without success. Any international agreement to increase the price of silver would immediately result in an increased production of the metal and its price would consequently fall. Nevertheless silver remains an important metal for coinage and it can be replaced by no other.

Besides its use for coinage, silver has from the earliest times been used in large amounts for ornaments and utensils of various kinds. Bottles, cups and basins of worked silver have been found amongst the ancient remains of the second settlement of Troy; whilst at the present day silver is the metal preferred for spoons, forks, candle-sticks, basins, cups, table ornaments, and for delicate filigree work. In the chemical laboratory, dishes and crucibles of pure silver are made use of; and in chemical works, silver worms are used for cooling or heating liquids. Compounds of silver also find an extensive application: the nitrate is used in medicine for cauterization, and in the laboratory as a reagent for detecting chlorides. Silver chloride, bromide and iodide are largely used in photography: at the present time with dry plates the bromide is most commonly used, whilst with the earlier daguerrotype and collodium methods the iodide of silver was used.

Production of Silver. — From the following table, giving the production of silver during recent years of different countries, it will be seen that the United States and Mexico produce the largest amounts. Australia takes a third place, but the yield is here much less than that of either the United States or Mexico. A fourth or fifth

place in the list of silver-producing countries is occupied by Germany, but here a large proportion (in 1898 more than one-half) is extracted from imported ores: of ores actually mined in Germany the Kupferschiefer (copper-shale) of Mansfeld yields the largest amount of silver.

Countries	1898		1901		1905	
	Kilograms	Value in Dollars	Kilograms	Value in Dollars	Kilograms	Value in Dollars
North America:						
<i>United States</i>	<i>1827723</i>	<i>34670245</i>	<i>1855425</i>	<i>35165902</i>	<i>1832623</i>	<i>35850955</i>
<i>Canada</i>	<i>137913</i>	<i>2616110</i>	<i>157952</i>	<i>2993668</i>	<i>185844</i>	<i>3605957</i>
<i>Mexico</i>	<i>1768501</i>	<i>33546855</i>	<i>1715416</i>	<i>32512304</i>	<i>2203361</i>	<i>42750773</i>
South America:						
<i>Bolivia</i>	<i>342138</i>	<i>6490000</i>	<i>290191</i>	<i>5500000</i>	<i>205288</i>	<i>3983100</i>
<i>Chile</i>	<i>143514</i>	<i>2722245</i>	<i>179552</i>	<i>3403059</i>	<i>26438</i>	<i>512975</i>
<i>Colombia</i>	<i>51200</i>	<i>971187</i>	<i>78380</i>	<i>1485540</i>	<i>31103</i>	<i>603500</i>
<i>Peru</i>	<i>58368</i>	<i>1107188</i>	<i>207000</i>	<i>3923274</i>	<i>155521</i>	<i>3017500</i>
Australia	<i>534360</i>	<i>10136013</i>	<i>337420</i>	<i>6395144</i>	<i>446738</i>	<i>8667853</i>
Asia:						
<i>Japan</i>	<i>78009</i>	<i>1479759</i>	<i>58953</i>	<i>1117337</i>	<i>100000</i>	<i>1940153</i>
Europe:						
<i>France</i>	<i>80351</i>	<i>1524138</i>	<i>14067</i>	<i>266612</i>	<i>19221</i>	<i>372948</i>
<i>Spain</i>	<i>229000</i>	<i>4343786</i>	<i>183802</i>	<i>3483602</i>	<i>117418</i>	<i>2278281</i>
<i>Germany</i>	<i>480578</i>	<i>9115744</i>	<i>168349</i>	<i>3190721</i>	<i>389898</i>	<i>7565267</i>
<i>United Kingdom</i>	<i>7007</i>	<i>132916</i>	<i>5194</i>	<i>98447</i>	<i>4967</i>	<i>96376</i>
<i>Total for the world</i>	<i>5575335</i>	<i>105364505</i>	<i>5438443</i>	<i>102769792</i>	<i>5904509</i>	<i>114856349</i>

Native Copper and Copper Ores.

Native Copper.

Native copper, like native gold and silver, was one of the metals earliest known to man. The copper ore (aes Cyprium) from the ancient mines on the island of Cyprus was long ago worked by the Phoenicians, and it is from this island that the name copper is derived through the Latin cuprum. The builders of the pyramids of Gizeh are said to have obtained copper in the Sinai peninsula three thousand years before Christ; and amongst the treasure dating back to the second settlement of Troy articles of pure copper have been found. Many of the objects belonging to these remote



Native Copper.

Fig.

1. **Copper.** A distinct rhombic-dodecahedron (at the top of the figure) and irregular masses in the matrix.
Keweenaw Point, Lake Superior, Michigan, U. S. A.
2. **Copper.** Four-faced cube: an unusually large and sharply-developed crystal.
North-West mine, Eagle Harbour, Lake Superior, Michigan, U. S. A.
3. **Copper.** Cubes twinned on an octahedral face.
Turjinsk mines, Bogoslovsk district, govt. Perm, Urals.
4. **Copper.** A twinned crystal elongated in one direction.
Calumet mine, Keweenaw Point, Lake Superior, Michigan, U. S. A.
5. **Copper.** Elongated crystals branching at 60° ; in crystalline limestone.
Turjinsk mines, Bogoslovsk district, govt. Perm, Urals.
6. **Copper.** Dendritic; the branches at 60° .
Damaraland, South-West Africa.
7. **Copper.** Branching at 60° .
Friedrichsseggen mine, Ems, Nassau.
8. **Copper.** Dendritic; the branches at 60° .
Rheinbreitenbach, near Bonn, Rhine.
9. **Copper.** A thick wiry form with a hexagonal cross-section. (See description in the text, p. 98.) Said to be from the Lake Superior district, but possibly of artificial origin.
10. **Copper.** Dendritic; branching at 60° .
Corocoro, La Paz, Bolivia.
11. **Copper.** A curved plate.
Corocoro, La Paz, Bolivia.
12. **Copper.** A thick platy mass, rounded by corrosion and with a dark tarnish. With specks of malachite produced by weathering.
Hohenstein, Reichenbach, Odenwald.



1



3



4



2



6



7



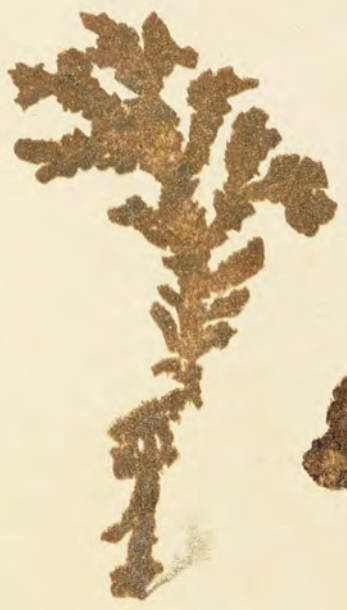
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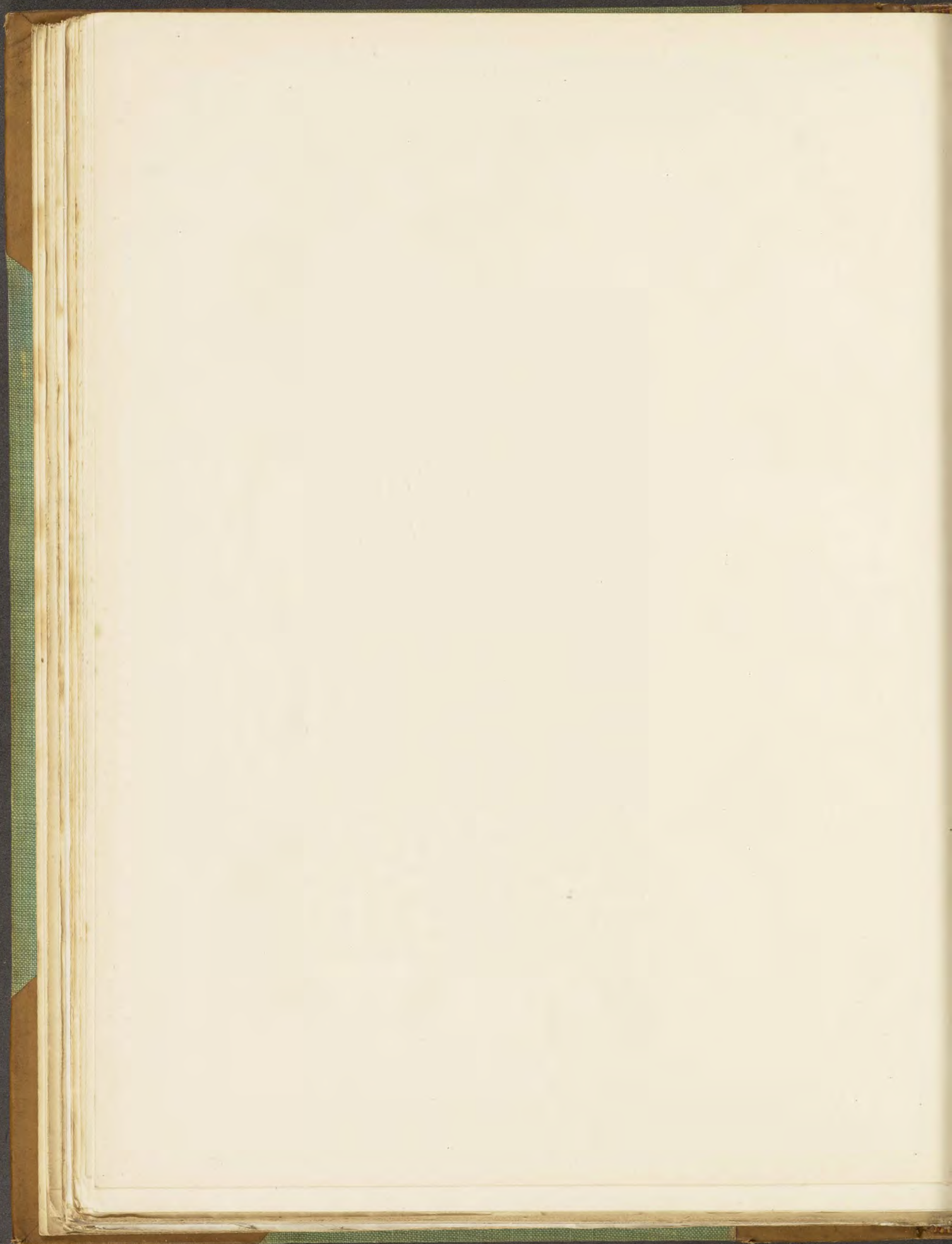
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11



12



times are made of bronze, an alloy of copper and tin, so that ores of both these metals were sought and worked.

It has been pointed out above that silver combines with other chemical elements much more readily than does gold; we have now to add that copper combines with other elements more readily than does silver. For this reason native copper only rarely exhibits the copper-red colour and bright metallic lustre so characteristic of this metal; more usually the surface is tarnished and dull, but the true colour is at once revealed when the surface is scratched with a knife.

Like gold and silver, copper crystallizes in the cubic system, and moreover it frequently also exhibits dendritic and platy forms of growth. The most frequent forms of crystals are the rhombic-dodecahedron (plate 10, fig. 1), the tetrakis-hexahedron or $\frac{7}{2}$ -four-faced cube with the symbol $\infty O \frac{5}{3}$ (fig. 2), and the cube (fig. 3). Large and distinctly developed crystals, like the four-faced cube represented in fig. 2, are of rare occurrence; usually they are much obscured by elongation in one direction (fig. 4), or by twinning on an octahedral face. Most crystals of native copper when closely and critically examined will be found to show evidences of twinning. In the specimen represented in fig. 3 each single crystal is a cube twinned on an octahedral face in such a manner that the crystal has the appearance of a double three-sided pyramid:

such a crystal is distinctly to be seen in the centre of the specimen. This mode of twinning is illustrated in the accompanying text-figure 110: we may imagine a cube to be cut into two equal portions by a plane parallel to the octahedral face which would truncate the upper right-hand corner of the cube, and that one half is rotated through 180° about an axis perpendicular to this plane, that is about a diagonal of the cube. If now, the re-entrant portions of the twinned crystal become filled up with material, the resulting form will have the shape of a double triangular pyramid, as may be readily imagined from fig. 110. This type of crystallization of native copper is well shown in plate 7, fig. 5; the triangular pyramids projecting from the surface of the specimen are each of them twinned cubes, which are arranged in parallel positions along three directions at 60° , parallel to the diagonals of an octahedral face. The fact that these crystals are twinned could not be made out from the figure, and indeed with the actual specimen it is not at first obvious, for the crystals on the opposite side are quite small and not very distinct. On other specimens of native copper the crystals are often flattened parallel to one pair of faces of the octahedron, and they may also be elongated in one direction. Such flattened and distorted crystals are frequently grouped together in parallel positions and intercross one another at 60° , giving rise to the delicate branching and tree-like forms represented in plate 10, figs. 5—8, similar to those already described for native gold and silver. When the flattening of the individual crystals is still more pronounced, the aggregate will have the form of a plate with perhaps still some indications of the dendritic form (fig. 10); or in an extreme case we may have simply a thin plate or foil much twisted and curved (fig. 11).

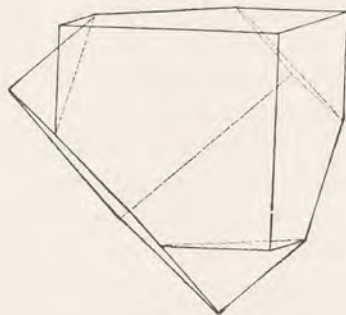


Fig. 110.
Twinned cube of native copper.

The thick plate of native copper represented in plate 10, fig. 12, shows no indications of crystalline structure on its surface: the edges are rounded and the surface marked with concave depressions, two of which completely penetrate the plate. The whole appearance of this specimen suggests that the material has been fused, but this

is excluded by the mode of occurrence, and we must conclude that the rounding of the mass has been produced by corrosion.

Wiry forms, such as are especially characteristic of native silver, are of rare occurrence in native copper. The specimen represented in plate 10, fig. 9, is an example of this; and a close examination of the actual specimen reveals a regularity of crystalline growth. It consists of a six-sided rod with sharp edges and depressed surfaces, the latter being marked by fine feather-like striations; besides being curved, the rod has a helical twist about its long axis, and the short hook-like portion at the upper end is inclined at 60° to the main axis. The six faces of the prism are those of an icositetrahedron perpendicular to an octahedral face, which if present would truncate the prism perpendicularly to its length: the hook at the upper end is due to twinning on a second octahedral face. This specimen is said to be from the Lake Superior copper-mining region, but it is possible that it is of artificial origin, for forms exactly like this have come from the copper refining furnaces at Hamburg.

Native copper is usually almost chemically pure copper, containing sometimes only a little silver. Its specific gravity is consequently subject to only slight variations from the mean value of 8.9. Its hardness is the same as that of calcite, $H. = 3$; and like the other soft metals, it is highly malleable and ductile. The metal is readily attacked by acids, and is soon dissolved by strong acids: it is even soluble in an aqueous solution of ammonia. Pure copper melts at a temperature of 1050° C. and in contact with air the surface of the molten metal becomes coated with a film of black oxide. The usual products of weathering in nature are the red oxide (cuprite) and the green carbonate (malachite).

As a mineral, native copper occurs with various ores of copper in mineral-veins, or it occurs on the surfaces of crevices in sandstone, slates and igneous rocks; it is also sometimes found with calcite and zeolites in the amygdaloidal cavities of melaphyres. Some of the more noteworthy occurrences of native copper are mentioned below; some of them are of importance as commercial sources of the metal, and some are of interest from other points of view.

In Germany, native copper is found only very rarely and never in large amounts. It was formerly found with quartz in veins in the grauwacke of the Virneberg at Rheinbreitenbach, near to Honnef on the Rhine: the dendritic specimen figured in plate 10, fig. 8, is from this locality. Thick platy and corroded masses, up to three kilograms in weight, are found in quartz veins at Hohenstein near Reichenstein in Odenwald (fig. 12). Delicately formed dendritic groups of native copper have been found in the lead and silver mine of Friedrichsseggen near Ems in Nassau (fig. 7). Small scales of copper occur in the Kupferschiefer (copper-shale) of Mansfeld in Prussian Saxony, and in the upper oxidized zone of the veins of copper-pyrites in the Siegen and Dillenburg mining districts.

In Cornwall, native copper has been found in many of the copper mines, particularly those in the neighbourhood of Redruth. In the Lizard district it occurs embedded in the serpentine rock, sometimes in masses of considerable size, one block weighing three tons. In Scotland, at Barrhead in Renfrewshire, thin plates of copper occur in crevices of the ancient volcanic rocks, where the metal is usually associated with calcite and prehnite.

The Turjinsk mines situated in the Bogoslovsk district, in government Perm, Russia, are famous for the many fine and well-crystallized specimens of native copper which they have yielded. The specimens represented in plate 10, figs. 3 and 5, show the crystals embedded in a matrix of crystalline limestone, which occurs at the locality

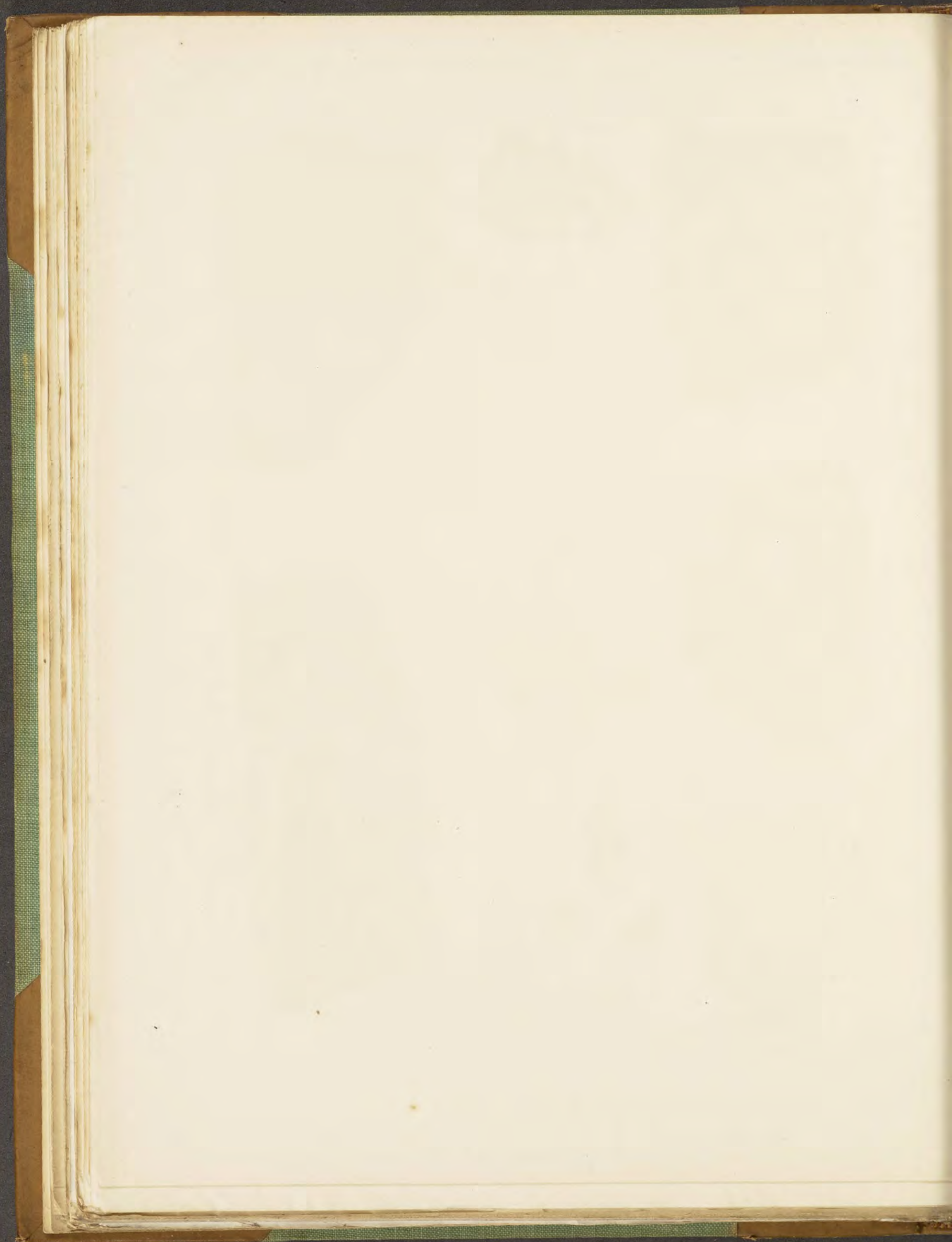


Copper Ores I.

Fig.

1. **Copper-glance.** Crystals on the matrix.
Redruth, Cornwall.
2. **Copper-glance.** Group of crystals.
Redruth, Cornwall.
3. **Copper-glance.** Twinned crystal.
Bristol, Connecticut, U. S. A.
4. **Covellite.** Earthy.
Atacama, Chile.
5. **Copper-pyrites.** Crystals consisting of two tetrahedra in combination; on chalybite.
Carn Brea mine, Redruth, Cornwall.
6. **Copper-pyrites.** Small tetrahedra on chalybite.
Joplin, Jasper Co., Missouri, U. S. A.
- 7a and b. **Copper-pyrites.** Tetragonal scalenohedron with acute tetrahedron.
French Creek mines, Chester Co., Pennsylvania, U. S. A.
8. **Copper-pyrites.** Large crystal of octahedral habit; slightly tarnished.
Wildemann mine, Hüttschen valley, near Clausthal, Harz.
9. **Copper-pyrites.** Twinned crystals on matrix.
Sadisberg, near Altenberg, Saxony.
10. **Copper-pyrites.** Crystals with chalybite and quartz.
Neudorf, Harz.
11. **Bornite.** Massive with white barytes in shale ("Kupferschiefer").
Hettstedt, near Mansfeld, Prussia.





in contact with igneous rocks. Other localities for native copper in the Ural Mountains are in the neighbourhood of Nizhne-Tagilsk, Ekaterinburg, and Kargalinsk. In Siberia, it is found at Zmeinogorsk in the Altai Mountains.

The largest amounts of native copper found in any part of the world are those occurring in the Keweenaw peninsula on the south shore of Lake Superior in the state of Michigan. Resting on the ancient sedimentary rocks of Cambrian age in this district are great thicknesses of melaphyre and quartz-porphry; and it is in these volcanic rocks, or in veins connected with them, that the native copper occurs, together with native silver, calcite, quartz, prehnite, and various zeolites. The best crystals of native copper displayed in mineral collections have come from this district. Masses of enormous size are sometimes found: the largest on record was found in 1857 in the Minnesota mine; it measured 45 feet in length, 22 feet at its greatest width, and more than 8 feet in its thickest part; it contained over 90 per cent. of pure copper and weighed about 420 tons. Copper occurs in this region over an area 200 miles in length, and practically all of it is in the native state. The total production of all the mines during the year 1898 amounted to 62,668 tons of copper. But although the yield is large there are heavy working expenses; for instance, the sinking of one shaft alone to a depth of 1500 metres cost half a million pounds. Native copper also occurs, sometimes in large blocks weighing over a hundred kilograms, at the Copper Queen mine in Arizona; but here it is not an important ore as in the Lake Superior district.

Considerable amounts of native copper occur on the Bolivian tableland in the neighbourhood of the town of Corocoro, to the south of Lake Titicaca. Here the metal is disseminated in a sandstone of Cretaceous age. It occurs in dendritic (plate 10, fig. 10) and platy (fig. 11) forms; and well-shaped six-sided prisms of native copper pseudomorphous after aragonite are not uncommon (plate 74, fig. 10). In this district copper was long ago worked by the Incas; the modern mining operations date from the year 1832, and the average annual production amounts to 2300 tons. In Chile, native copper occurs in veins associated with granitic and other acid eruptive rocks; it is associated with copper ores, free gold, iron-pyrites, quartz and tourmaline. During the year 1898 Chile produced 25,248 tons of copper, but only a small portion of this represented native copper.

In Africa, the richest deposits of native copper are those in Damaraland in the south-west portion of the continent. The dendritic specimen shown in plate 10, fig. 6 is from this region.

Much native copper has been obtained from South Australia, at Burra-Burra, and especially at Wallaroo and Moonta in the Yorke peninsula. The mines at Burra-Burra are now exhausted, but the two other localities yielded in 1897 5100 tons of copper, though not all from native copper. At Broken Hill, in New South Wales, small but well-formed crystals of native copper have been found.

In other copper-producing countries the metal is extracted mostly from the ores. The applications of copper and the amount of its production will be mentioned after we have described the several ores.

Copper Ores.

Since copper readily enters into chemical combination with other elements, the number of minerals which contain copper as an essential constituent is very large. Some of these minerals, when they occur in sufficiently large amounts may be regarded as

ores of copper. Others occur in association with the ores, and have been derived from them by the action of weathering processes; and in certain cases these also may form part of the workable ore. Others, again, may be of quite rare occurrence and not found in association with the ores. Oxygen compounds of silver are unknown in nature, but of copper they are of very frequent occurrence. Copper is not classed with the precious metals (gold, platinum and silver) because of the fact that it oxidizes so readily. Native copper and the metallic ores of copper when subjected to the action of weathering agencies take up oxygen, carbonic acid and water and are converted into a basic hydrated carbonate of copper, which is the common mineral malachite.

The ores and more important naturally-occurring compounds of copper which we shall here describe are tabulated below with their chemical formulae:

Copper-glance, Cu_2S .	Cuprite, Cu_2O .
Covellite, CuS .	Tenorite, CuO .
Copper-pyrites, CuFeS_2 .	Malachite, $\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$.
Bornite, Cu_5FeS_4 .	Chessylite, $2\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$.
Tetrahedrite, Cu_3SbS_3 .	Atacamite, $\text{Cu}_2\text{Cl}(\text{OH})_3$.
Bourbonite, CuPbSbS_3 .	Dioptase, H_2CuSiO_4 .
	Copper-vitriol, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$.

Copper-glance, or chalcocite, when quite pure contains 79·8 per cent. of copper and 20·2 per cent. of sulphur. Sometimes the copper is replaced in part by small amounts of iron or silver, but copper-glance is always one of the purest of copper ores. It contains a higher percentage of copper than any other ore except cuprite, but the latter does not occur so abundantly and in such large masses as copper-glance. The black, massive mineral with dull lustre and unattractive appearance little suggests the presence of such a high percentage of copper. This element may be readily detected by heating the mineral before the blowpipe with sodium carbonate on charcoal: a globule of metallic copper results, which is readily recognized by its malleability and reddish colour. The fused mass on the charcoal when moistened with water produces a black stain on a silver coin, proving the presence of sulphur. The mineral is soluble in nitric acid giving a bright green solution, which on the addition of ammonia in excess becomes deep blue; this reaction may be employed to detect the presence of copper.

The crystals (plate 11, figs. 1 and 2) have hexagonal forms, but in reality they are orthorhombic with a prism angle of very nearly 120° (actually $119^\circ 35'$). The apparent hexagonal pyramid combined with the basal pinacoid, shown in the plate and in text-figure 111, is a combination of a rhombic pyramid $z = \frac{1}{3}P$ and a brachy-dome $e = \frac{2}{3}P \infty$, together with the basal pinacoid $c = 0P$. The fact that the angle between

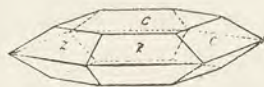


Fig. 111.
Crystal of Copper-glance.

the two faces z and z is not quite the same as the angle between the faces z and e proves that the pyramid is not a hexagonal pyramid: and this is sometimes also shown by the striations on the basal plane c , which when present are in one direction only, namely parallel to the edge between c and e . Like other orthorhombic minerals (e. g. dyscrasite, p. 90, and aragonite) with a prism angle of nearly 120° , copper-glance is frequently twinned on one or on two of the prism faces (plate 11, fig. 3), giving rise to stellate groupings; there may then be on the basal plane three sets of striations at nearly 60° , when the twinned crystal has a still closer resemblance to a hexagonal crystal. Interpenetration-twins on other planes also occur in crystals of copper-glance.

The hardness of the mineral is 2—3, and it is somewhat sectile. Its specific gravity is 5.5—5.8. The colour and streak are blackish lead-grey; and the lustre is metallic, though often dull and tarnished.

Copper-glance is usually met with as compact masses, and is an important ore of copper. Distinctly crystallized specimens are found at only a few localities, the most notable of which are in western Cornwall, in the neighbourhood of Redruth and St. Just. It here occurs in veins of copper ore traversing granite and the adjacent clay-slate or "killas". Crystallized specimens were formerly abundant at Redruth (plate 11, figs. 1 and 2), and on this account the mineral has been named redruthite. In Germany, massive copper-glance occurs in veins with chalybite at Siegen in Westphalia. At Frankenberg in Hesse it forms the material of fossil plants (*Ullmannia Bronni*), which are there known as "ears of corn". It also occurs as a fine impregnation with bornite and copper-pyrites in the Kupferschiefer (copper-shale) of Mansfeld (plate 11, fig. 11) and Sangerhausen in Prussian Saxony. Massive copper-glance is found together with malachite in several of the copper mines of the Ural Mountains; for instance, in the Turjinsk mines near Bogoslovsk and at Nizhne-Tagilsk. Rich deposits are met with in south-west Africa, in Chile, and the United States. It is mined in the Anaconda lode in Montana; and at Bristol in Connecticut, besides the massive ore, fine crystals, very similar to those from Cornwall, are abundant. The twinned crystal shown in plate 11, fig. 3, is from the latter locality.

Covellite is often known as indigo-copper on account of its indigo-blue colour (plate 11, fig. 4). It usually occurs as a thin coating on other metallic ores of copper, to the alteration of which it owes its origin. Less frequently it is found in larger masses, whilst crystals are quite exceptional. The crystals have the form of hexagonal plates or scales with a perfect cleavage parallel to the basal plane, and on this plane the sub-metallic lustre is somewhat pearly in character. The thin plates are soft and flexible.

Although not an uncommon mineral, it rarely occurs in any quantity: as an indigo-blue powdery deposit it may be detected on the copper-pyrites of many localities. Larger amounts are found with copper-pyrites and iron-pyrites in the copper mines of Chile and Peru. Small crystals of the mineral were detected on Vesuvian lava by N. Covelli in 1839, and it is after this mineralogist that the name covellite was given.

Copper-pyrites, or chalcopyrite, with its characteristic brass-yellow colour and bright metallic lustre is one of the most readily recognizable of copper ores. It may perhaps at first sight be mistaken for iron-pyrites or native gold; but it is readily distinguished from the former by its deeper brass-yellow colour and by the fact that it can be scratched with a knife, whereas iron-pyrites cannot be so scratched. From gold it is readily distinguished by its brittleness and lack of malleability. It is the commonest of copper minerals and the most important ore of copper.

Chemically, it is a sulphide of copper and iron with the formula CuFeS_2 , containing $34\frac{1}{2}$ per cent. of copper, $30\frac{1}{2}$ per cent. of iron, and 35 per cent. of sulphur. When heated in a bulb-tube, the mineral decrepitates, that is to say flies into fragments with a crackling noise; and further heating produces a sublimate of free sulphur on the sides of the tube. When roasted on charcoal before the blowpipe, the sulphur expelled from the mineral is oxidized to sulphur dioxide, which is readily recognized by its penetrating odour, and the mineral fuses to a magnetic globule; the magnetic character of the globule proves the presence of iron. If the globule be now moistened with hydrochloric acid and again heated, the blowpipe flame will be coloured first blue (due to copper chloride) and afterwards green (due to copper oxide). The three constituent elements of copper-pyrites may also be readily detected by warming the powdered

mineral in a test-tube with nitric acid: the mineral will be decomposed with the separation of sulphur and a green solution will be formed; on adding excess of ammonia to this, a deep blue solution characteristic of copper and a reddish-brown precipitate of iron hydroxide will be obtained. Since bornite contains the same elements, copper, iron and sulphur, it will of course give the same reactions as copper-pyrites, but these two minerals are readily distinguished by their colour.

Crystals of copper-pyrites are usually rather small and indistinctly developed. They belong to the tetragonal system with inclined or tetrahedral hemihedrism. The crystals on the specimen represented in plate 11, fig. 5, are combinations of two tetrahedra, $\frac{P}{2}$ and $-\frac{P}{2}$, the former predominating. The crystals in fig. 6 are small, sharply-developed tetrahedra, and the large crystal in fig. 8 is a combination of the two tetrahedra with faces of about equal size. The small isolated crystal shown in figs. 7a and b is a combination of a tetragonal scalenohedron and an acute tetrahedron: the form is represented more clearly in text-figure 112, where the faces χ are those of the scalenohedron and φ those of the tetrahedron.

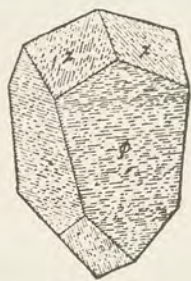


Fig. 112.
Crystal of Copper-pyrites.

The forms of crystals of copper-pyrites are often obscured by twinning, and are not always easy to decipher. The twinning may be according to several laws; a repeated twinning on a face of the tetrahedron being perhaps the most common. The crystals shown in plate 11, fig. 9, are simple twins on a tetrahedron face, but the twinning is not clearly shown in the figure. Crystals of copper-pyrites are usually much grown together, either by regular twinning or in an irregular fashion (fig. 10), and it is consequently not easy to distinguish their forms.

In addition to crystals attached to the surface of the matrix, copper-pyrites very frequently occurs as compact masses embedded in the matrix or as large masses with no definite boundaries. Such material frequently displays a brilliant coloured tarnish on the surface, and for this reason it is known to miners as "peacock copper-ore". Freshly broken surfaces show the brass-yellow metallic colour of the mineral. Copper-pyrites sometimes forms a thin layer on the surface of tetrahedrite (plate 12, fig. 6), zinc-blende (plate 20, fig. 11) or galena (plate 16, fig. 6).

Copper-pyrites is readily attacked by weathering agencies, and under different conditions yields different alteration products. Simple oxidation produces the sulphates which are readily soluble in water, namely copper-vitriol and iron-vitriol. For this reason the water from copper mines is often charged with copper sulphate; and the copper is precipitated as cement copper by allowing the water to flow over scraps of metallic iron. Atmospheric weathering taking place the presence of carbon dioxide or of carbonates produces malachite or chersylite together with limonite. Or again, in the absence of carbon dioxide, copper-pyrites may be oxidized to a mixture of cuprite and limonite; and when this intermixture is intimate the product is known as tile-ore. In some cases, in the presence of reducing agents, native copper may result. These numerous processes which effect the alternation of copper-pyrites are especially active in the upper oxidized portions of the lodes of copper ore, that is in the gossan, and it is consequently here that the secondary copper minerals are found.

Copper-pyrites is mainly found in veins traversing clay-slates, especially in the neighbourhood of masses of igneous rock. It is often accompanied by chalybite (plate 11, figs. 5 and 10), quartz, zinc-blende and galena. It also sometimes occurs in beds with

iron-pyrites, as at Rammelsberg near Goslar in the Harz Mountains; or finely disseminated in sedimentary rocks, as in the Kupferschiefer (copper-shale) of Mansfeld in Germany. Being a common mineral, it has been found at very many localities; and here we select for mention only those localities which have yielded the better crystallized specimens or those which are remarkable for the extent of the deposit of ore.

The deposits of ore in the Rammelsberg near Goslar in the Harz Mountains have been worked since the year 972, and even at the present day they are highly productive. The ore here consists of a compact intermixture of copper-pyrites, iron-pyrites, zinc-blende, galena and barytes, and forms a stratum interbedded in sediments of Devonian age. The percentage of copper in this ore varies from 8—15 $\frac{1}{2}$, and the annual production of copper and lead ore amounts to about 50,000 tons. Copper-pyrites is also present in the similar type of deposit at Rio Tinto in the south of Spain; particulars concerning this important deposit of ore will be given when we come to treat of iron-pyrites.

In the mineral-veins of the Harz Mountains, good crystals of copper-pyrites are often found; for example, with chalybite and quartz at Neudorf (plate 11, fig. 10), and at Clausthal (fig. 8). In the Zilla mine at Clausthal copper-pyrites forms a coating on crystals of tetrahedrite. Copper-pyrites is widely distributed in the Saxon Erzgebirge, though rarely in large amounts: very fine crystals have been found at Freiberg, and the specimen shown in fig. 9 is from Sadisdorf near Altenberg in Saxony. Veins of copper-pyrites are abundant in the slaty rocks of the Rhenish district, and good crystals come from the Heinrich mine at Littfeld.

In Cornwall and Devon, copper-pyrites is the more common ore of copper, and well crystallized specimens have been found in many of the mines, particularly in the neighbourhood of Redruth and St. Agnes; those from the Carn Brea mine near Redruth are often associated with chalybite (plate 11, fig. 5), and those from St. Agnes with clear, prismatic crystals of quartz. A peculiar variety from Cornwall, known as "blister copper-ore", has the form of mamillary and botryoidal masses.

Of the several localities for copper-pyrites in the United States, mention may be made of the French Creek mines in Chester Co., Pennsylvania, where crystals of scalenohedral habit (figs. 7*a* and 6) occur embedded in calcite. Together with these are found the crystals of iron-pyrites shown in plate 2, fig. 1, which, like the crystals of copper-pyrites, are completely developed on all sides. Small, sharply-developed tetrahedra of copper-pyrites are common at Joplin in Jasper Co., Missouri (plate 11, fig. 6); and sometimes these crystals are grouped in parallel position on crystals of zinc-blende. Large quantities of massive copper-pyrites are mined in the Anaconda lode in the State of Montana.

Bornite is often called erubescite, "purple copper-ore", or "variegated copper-ore", because it usually displays a coloured (purple, bluish or reddish) tarnish (plate 11, fig. 11). On a freshly fractured surface it has a bronze or pinchbeck-brown colour, and for this reason it is known to the Cornish miners as "horse-flesh-ore". These differences in the colour of fresh and of tarnished surfaces are especially characteristic of the mineral. The lustre is metallic. Bornite is composed of the same chemical elements as copper-pyrites, but these are combined together in different proportions. The blowpipe and qualitative chemical reactions are the same for the two minerals. Analyses of bornite have shown variations in the amount of copper present from 45 to 71 per cent. This wide variation is, however, to be explained by the presence of other minerals, more particularly copper-pyrites, intimately intermixed and intergrown with the bornite; even apparently pure crystals of bornite when broken

open will usually be found to enclose a nucleus of copper-pyrites. For many years the formula of the mineral has been given as Cu_3FeS_3 , but a series of analyses recently made on carefully selected material have proved the true formula of the mineral to be Cu_5FeS_4 , corresponding with 63.3 per cent. of copper, 11.2 per cent. of iron, and 25.5 per cent. of sulphur.

Crystals of bornite are of rare occurrence: they have usually the form of cubes with rough and curved faces, and often interpenetrating each other by twinning. Most of the crystallized specimens are from the copper mines in the neighbourhood of Redruth in Cornwall, but a few large isolated crystals have been found with native gold in the Tyrol. More usually, the mineral occurs as compact masses without crystalline form, and it is often found in sufficient amounts to be of value as an ore of copper. It occurs disseminated in the Kupferschiefer (copper-shale) of Mansfeld; the specimen represented in plate 11, fig. 11, shows the black slaty rock to the left and a band of bornite and barytes on the right. Considerable amounts of bornite are found in veins traversing diorite-schist at Kupferberg in Silesia. Other localities, where bornite is mined as an ore of copper, are Monte Catini in Tuscany, Acton in Canada, and Bristol in Connecticut.

The "Kupferschiefer", or copper-shale, which has been referred to several times in the preceding pages, is of great importance in Germany as a source of copper and silver. It is a black shale, coloured with bitumen, forming a stratum 0.5—0.6 metre (about 2 feet) in thickness, at the base of the German "Zechstein" formation of Permian age. This bed has a uniform character over a wide area, the principal development being in the Mansfeld basin between the Harz Mountains and the Thuringian Forest; it is also met with at Riechelsdorf near Bebra in Hesse-Nassau, and at Bieber near Gelnhausen. In it are frequently found the fossil remains of fishes which lived in the sea at the time that the copper-slate was deposited as a black mud in this area. The whole of the shaly material is impregnated with copper ore in a very finely divided state: the copper minerals present are mainly copper-glance, bornite and copper-pyrites. The shale contains 2—3 per cent. of copper, together with 0.01—0.02 per cent. of silver; so that a ton of copper obtained from it yields 5 kilograms of silver. The "Kupferschiefer" is not only the most important ore of copper in Germany, but it is also the chief source of silver in that country. In the year 1901 the production amounted to 695,321 tons of ore, from which was extracted 19,080 tons of copper and 99,132 kilograms of fine silver.

The series of strata of which the "Kupferschiefer" forms a part are not infrequently displaced by faults, and in the crevices of the fault-planes there has been a later deposition of cobalt and nickel ores (smaltite, niccolite, and chloanthite) with barytes and calcite, but with very little copper ores. It is clear that these cobalt and nickel ores must have been deposited by solutions rising up along the fault-planes from great depths in the earth's crust: but the origin of the copper in the "Kupferschiefer" itself is not so readily explained. It is probable, however, that the copper was precipitated from the sea-water at the same time that the black mud was collecting on the floor of an inland sea or a shallow gulf. The copper salts held in solution by the sea-water may have been derived by the weathering of pre-existing copper ores, or they may have been brought up by springs from unknown depths in the earth's crust.

Tetrahedrite is a mineral, or rather group of minerals, which varies considerably in chemical composition, though always referable to the same general formula. It is included under the old German term *Fahlerz*, meaning grey-ore, or grey copper-ore.

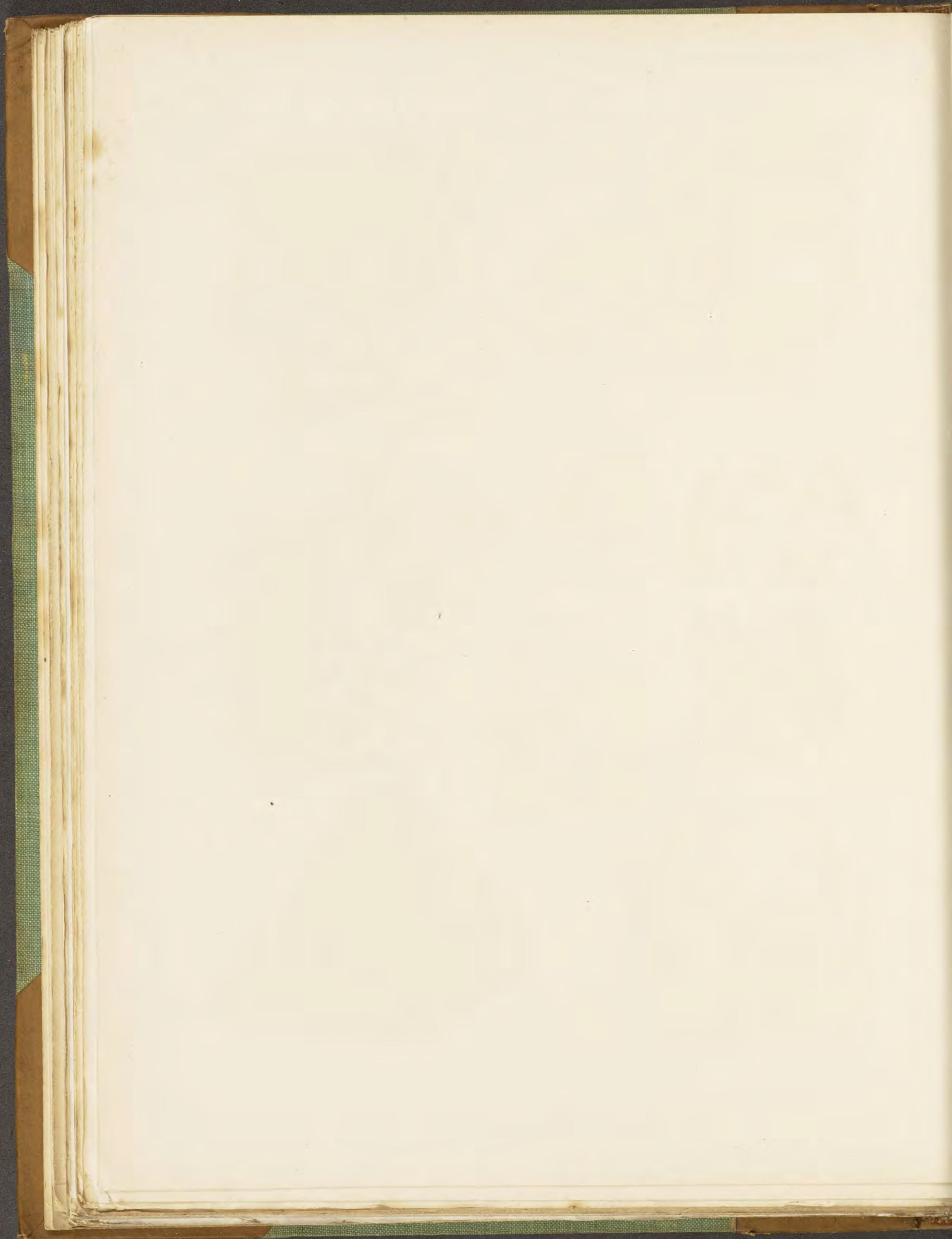


Copper Ores II.

Fig.

1. **Tetrahedrite.** Large tetrahedral crystals with quartz. The large faces of the positive tetrahedron are bright and the small faces of the negative tetrahedron are dull.
Botes, Transylvania.
2. **Tetrahedrite.** Tetrahedral crystals with three-faced tetrahedron, rhombic-dodecahedron and other small faces. The specimen is traversed by cracks produced by weathering.
Aurora mine, Dillenburg, Nassau.
3. **Tetrahedrite.** Three-faced tetrahedron with tetrahedron.
Clausthal, Harz Mountains.
4. **Tetrahedrite.** Tetrahedral crystals slightly tarnished blue; with quartz.
Kapnik, Hungary.
5. **Tetrahedrite.** Rhombic dodecahedron with tetrahedron.
Kleinkogel, Brixlegg, Tyrol.
6. **Tetrahedrite.** A twinned crystal coated with copper-pyrites.
Zilla mine, Clausthal, Harz Mountains.
7. **Bourbonite.** Large tabular crystal.
Horhausen, Coblenz district, Rhenish Prussia.
8. **Bourbonite.** "Wheel-ore" with quartz.
Herodsfoot mine, Liskeard, Cornwall.
9. **Bourbonite.** Crystals with a dull black tarnish.
Herodsfoot mine, Liskeard, Cornwall.





Although there are wide variations in the chemical composition, the crystalline form is always the same.

The crystals belong to the tetrahedral class of the cubic system, and they afford the best example of this type of symmetry; it being on this account that the name tetrahedrite was given to the mineral. The crystals on the specimen represented in plate 12, fig. 1, are a combination of the positive tetrahedron $\frac{+O}{2}$ with the negative tetrahedron $\frac{-O}{2}$, the six-sided faces of [the former being large and bright and the triangular faces of the latter small and dull. The large crystal in fig. 3 shows faces of a three-faced tetrahedron in combination with the tetrahedron; in this figure the tetrahedron face on the left-hand side of the crystal is large, while on the right-hand side a tetrahedron face is wanting, but this is due simply to an irregularity in the development of the crystals, such as is frequently met with amongst minerals. The crystals in fig. 4 have the positive tetrahedron as the predominating form, the edges of which are bevelled by faces of the three-faced tetrahedron $\frac{2O2}{2}$ (as in text-figure 113),

and its corners are replaced by three faces of the rhombic dodecahedron $\sim O$ (as in text-figure 114). Similar faces are also present on the crystals in fig. 2, but on the actual specimen there are several other faces too small to be represented in the figure. The black crystals shown in fig. 5 have a rather different form: here the rhombic-dodecahedron predominates, the three-edged corners of which are replaced by faces of the tetrahedron.

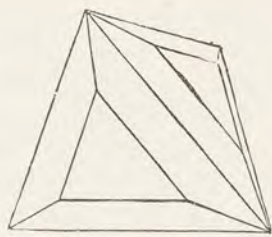


Fig. 113.

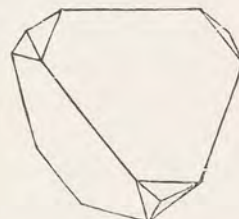


Fig. 114.

Crystals of Tetrahedrite.

The large crystal represented in fig. 6 of the same plate presents several points of interest. It does

not show the true colour of the mineral, for it is completely covered with a shell of copper-pyrites, but this covering is so thin that the form of the crystal is still apparent. The three-faced tetrahedron predominates, its edges being truncated by the faces of the cube, and each of its corners replaced by three faces of the rhombic-dodecahedron. Penetrating the main crystal and standing out as a ridge on its surface is a second smaller crystal in twinned position, the twin-plane being a face of the tetrahedron. On the side of the crystal which is directed towards the front two of the faces of the three-faced tetrahedron are more largely developed than the third and the tetrahedron face is absent; but on the lower side (not shown in the figure) the tetrahedron face perpendicular to the twin-axis is largely developed, and the three faces of the three-faced tetrahedron are narrow. On one crystal in the lower part of fig. 4 there may also be seen a projecting ridge, due to a smaller crystal interpenetrating a larger one in twinned position.

The colour of tetrahedrite is steel-grey to iron black; the lustre is metallic and frequently very brilliant. Sometimes the crystals are slightly tarnished (fig. 4), or they may be dull and black. The mineral is usually quite opaque, but very minute splinters of some crystals transmit a blood-red colour. The streak, or colour of the powdered mineral, is usually black, but sometimes it has a reddish or purplish tinge. The hardness is slightly over 4 on the scale; and the specific gravity varies with the chemical composition from 4.4 to 5.1

Typically, tetrahedrite is a compound of copper, antimony and sulphur, that is, a sulph-antimonite of copper, with the formula Cu_3SbS_3 . The calculated percentage of copper corresponding to this formula is 46.8. The copper is, however, usually replaced to a lesser or greater extent by silver, iron, and zinc, and less frequently by mercury, lead, cobalt, etc. In some instances the silver is present to the extent of 30 per cent., and even when only a small percentage is present the mineral is a valuable ore of silver. Not only is the copper replaced in this way, but there may be a similar isomorphous replacement of the antimony by arsenic and less frequently by bismuth. In certain cases the antimony is entirely replaced by arsenic, and the formula then becomes Cu_3AsS_3 , which corresponds to a calculated percentage for copper of 52.7. This is practically a distinct mineral, to which the name *tennantite* is applied, though still identical in crystalline form with tetrahedrite. Both tetrahedrite and tennantite are included under the general term *fahlerz* or grey copper-ore, the former being sometimes distinguished as *antimony-fahlerz*, and the latter as *arsenic-fahlerz*. Several other special names have been applied to minerals of this group when there is a predominance of certain elements, but such minerals are only to be distinguished by chemical analysis, and it is more convenient to refer to them collectively as *fahlerz*. Tetrahedrite being of far more frequent occurrence than tennantite, we have taken it as the typical example of the group.

When heated before the blowpipe, *fahlerz* readily fuses, and the reactions obtained will depend largely on the composition of the fragment tested. Antimony, if present, will produce a white sublimate on the charcoal, and arsenic will yield the characteristic odour of garlic. The roasted bead when moistened with hydrochloric acid will impart a blue colour to the flame, indicating the presence of copper. The presence of sulphur is also readily detected by fusing the mineral with sodium carbonate and moistening the fused mass on a silver coin.

Tetrahedrite occurs as crystals and masses in mineral-veins, and is usually associated with copper-pyrites, zinc-blende (plate 20, fig. 10), iron-pyrites, quartz (plate 12, fig. 4) and chalybite.

Fine crystals are met with in the veins near Clausthal in the Harz Mountains (plate 12, fig. 3); those from the Zilla mine being coated with copper-pyrites (fig. 6). Crystals rich in faces and often much fractured are found at Dillenburg in Nassau, and brilliant, sharply-developed crystals in the George mine at Horhausen in Rhenish Prussia. Specially large tetrahedral crystals are found at Botes in Transylvania, and a well-known locality for good specimens is Kapnik in Hungary. A variety of tetrahedrite containing mercury is found in the mercury mines of Rhenish Bavaria and at Schwarz in the Tyrol, whilst the large black crystals (fig. 5) from Kleinkogel, near Brixlegg in the Tyrol, are free from mercury. In Russia, a few crystals of tetrahedrite have been found in the Wassiljevski mines and at Beresovsk in the Ural Mountains, but here the mineral is not common.

Very fine groups of large crystals of tetrahedrite were formerly found in the Herodsfoot mine near Liskeard in Cornwall: the crystals are always thinly coated with copper-pyrites, which is either bright and brassy or has a brilliantly-coloured tarnish. The arsenical variety, tennantite, was formerly found in some quantity as small black crystals in several mines in the neighbourhood of Redruth in Cornwall. Tetrahedrite is also found at several localities in Chile, Peru, Bolivia and the United States; in Bolivia it is an important ore of silver.

Bournonite is a sulph-antimonite of copper and lead with the formula CuPbSbS_3 . It thus contains the same elements as tetrahedrite with the addition of lead, and we

may consider two atoms of monovalent copper in tetrahedrite to be replaced by one atom of bivalent lead. The percentage chemical composition corresponding with the above formula is: 13% copper, 42.5% lead, 24.7% antimony, and 19.8% sulphur. The mineral is thus at the same time an ore of lead and of copper.

The crystals belong to the orthorhombic system, and are commonly tabular in habit. The single crystal shown on the matrix in plate 12, fig. 7, is represented in its ideal development in text-figure 115. The crystal is tabular parallel to the basal plane (*c*); there are two macrodomes (*o* and *x*) and one brachy-dome (*n*), and small faces of a pyramid (*u*). Simple crystals like the one figured are of rare occurrence; usually the crystals are much twinned on the prism faces, giving rise to numerous re-entrant angles (figs. 8 and 9). The flat tabular crystals with these numerous indentations on their edges somewhat resemble cog-wheels, hence the mineral is sometimes known as "cog-wheel-ore" or "wheel-ore".

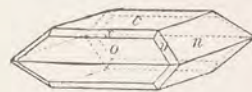


Fig. 115.
Crystal of Bournonite.

Bournonite is steel-grey in colour with a brilliant metallic lustre (fig. 8); sometimes the crystals have a dull black tarnish (fig. 9). Its hardness is about 3, being rather less than that of tetrahedrite, and its specific gravity 5.8. Before the blowpipe, it gives the same reactions as tetrahedrite, and also a yellow sublimate indicating the presence of lead.

Bournonite is not a mineral of very frequent occurrence; it is met with in mineral-veins in association with tetrahedrite, galena, zinc-blende, chalybite and quartz. The specimen represented in plate 12, fig. 7 is from Horhausen in the Coblenz district, Rhenish Prussia. Larger and thicker crystals are found at Neudorf in the Harz Mountains. The more typical "wheel-ore" is from Kapnik in Hungary and Nagyag in Transylvania. Fine, crystallized specimens were formerly found in Cornwall (figs. 8 and 9), in the Herodsfoot mine near Liskeard together with tetrahedrite, and in Wheal Boys at Endellion. It is also found in the Bolivian silver mines.

Cuprite. The sulphide ores of copper so far described are distinguished by their metallic lustre and opacity. On the other hand, the oxygen compounds of copper are transparent without a metallic lustre and they are brilliantly coloured, so that some of them at least find an application as semi-precious stones in addition to being ores of copper. The simplest oxygen compound of copper is the sub-oxide or cuprous oxide, Cu_2O , which contains 88.8 per cent. of copper, and is consequently the richest ore of the metal (with the exception of native copper). This is the mineral cuprite, also known as ruby-copper or as red copper-ore, on account of its characteristic red colour. The crystals (plate 13, figs. 1—3; plate 3, fig. 1) are transparent or translucent with a rich ruby-red or cochineal-red colour, and often a very brilliant adamantine to sub-metallic lustre, which sometimes gives them an almost lead-grey metallic appearance. On holding such a crystal up to the light, however, it will be seen to be red and transparent. The colour of the powder or streak is cochineal-red: this is seen in fig. 3, at spots where the crystals have been bruised. The brilliant, sub-metallic appearance of the crystals is connected with the very high refractive index (2.85) of the mineral, which is higher than that of diamond.

The crystals belong to the cubic system; they have the form of the simple cube (plate 13, fig. 3), or the simple octahedron, or various combinations of the cube, octahedron and rhombic-dodecahedron. Fig. 2 of plate 13 and text-figure 116 show the combination of the octahedron and cube, and fig. 1 and text-figure 117 that of the rhombic-dodecahedron and octahedron. A very remarkable form of growth of crystals of cuprite is presented by the variety known as chalcotrichite: here the crystals have

the form of very fine hairs, being enormously elongated in one direction; and the several hairs are aggregated in velvety tufts with a brilliant red colour.

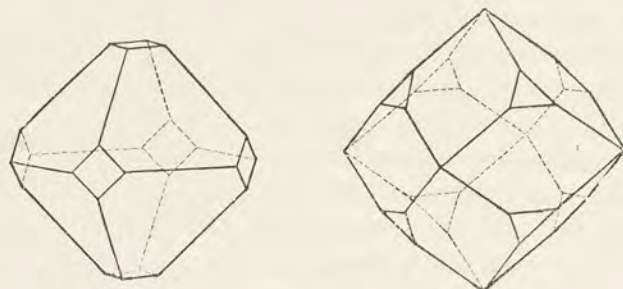


Fig. 116.

Fig. 117.

Crystals of Cuprite.

The hardness of cuprite is $3\frac{1}{2}$ —4, and its specific gravity is 5.9. The crystals possess poor cleavages parallel to the faces of the octahedron and the cube. When the mineral is heated before the blowpipe on charcoal, a bead of metallic copper is readily obtained, and this is the simplest method of identifying the massive ore.

As already mentioned (p 102), cuprite results from the alteration by weathering of copper-pyrites, and for

this reason it is usually found in association with limonite (plate 13, figs. 1—3). By still further weathering in the presence of carbon dioxide and water, the cuprite itself is altered to malachite, as proved by the frequent occurrence of pseudomorphs of malachite after cuprite (plate 3, figs. 2—4; plate 13, fig. 4), which have been already described (p. 49). The alteration of cuprite to native copper is less frequent (plate 3, fig. 5). Being an alteration product of copper-pyrites, cuprite is usually met with in the upper oxidized portions of copper lodes, that is, in the gossany limonite of the "iron hat" of the lodes.

Good crystals of cuprite are found in Rhenish Prussia; the specimen shown in plate 13, fig. 1 is from Kaisersteimel (or Käuser Steimel) near Betzdorf; the capillary chalcotrichite is found at Rheinbreitbach. Isolated crystals developed on all sides are found embedded in clay at Chessy, near Lyons in France; but these crystals are usually partly or completely altered to malachite (plate 3, figs. 1—4; plate 13, fig. 4). Very fine, crystallized specimens were formerly found in abundance at Wheal Phoenix, near Liskeard in Cornwall (plate 13, figs. 2 and 3), and in the copper mines near St. Day. In Russia, excellent crystals have been found, together with massive cuprite, in the copper mines of Gumeshevsk, 56 versts ($7\frac{1}{2}$ geographical miles) south-west of Ekaterinburg, a locality which will be again mentioned under malachite. Crystals of cuprite are also found in the Medno-Rudiansk mine at Nizhni-Tagilsk in the Ural Mountains. Other localities are Damaraland in South-West Africa, where pseudomorphs of native copper after cuprite are also found; Arizona in the United States; and Chile.

Tenorite is the black oxide of copper, cupric oxide, with the formula CuO , and is of much less frequent occurrence than cuprite. As small black scales with a bright lustre, it is found in crevices in Vesuvian lava; but more often it is met with as a black earthy mineral to which the name melaconite has been applied. The latter when occurring in large masses is an important ore of copper; it is so found at the Ducktown mines in Tennessee, and formerly at Copper Harbour on Lake Superior in Michigan.

Malachite (plate 13, figs. 5—10) is the commonest of copper minerals, since at the earth's surface it is the most stable compound of copper, all other copper minerals when subjected to weathering agencies being converted in the course of time into green malachite. The patina, which as a thin green encrustation is to be seen on all ancient bronze remains, consists principally of malachite. The representation of a sky in a Swiss church was long ago painted blue with chessylite, but is now green, the chessylite having become altered to malachite.



Copper Ores III.

Fig.

1. **Cuprite.** Dull crystal (rhombic-dodecahedron with octahedron) in limonite.
Kaisersteimel (or Käuser Steimel), Siegen district, Prussia.
2. **Cuprite.** Dull crystals (octahedron with cube) in limonite.
Wheal Phoenix, near Liskeard, Cornwall.
3. **Cuprite.** Bright cubes on earthy limonite.
Wheal Phoenix, near Liskeard, Cornwall.
4. **Cuprite.** Altered to malachite. Octahedron with rhombic-dodecahedron.
Chessy, near Lyons, France.
5. **Malachite.** Reniform.
Gumeshevsk copper mines, near Sissersk, Ural Mountains.
6. **Malachite.** Polished section.
Gumeshevsk copper mines, near Sissersk, Ural Mountains.
7. **Malachite.** Reniform, showing fibrous structure on the fractured surface.
Medno-Rudiansk mine, Nizhni-Tagilsk, Ural Mountains.
8. **Malachite.** Radially fibrous tufts in limonite.
Gumeshevsk copper mines, near Sissersk, Ural Mountains.
9. **Malachite.** Nodular on limonite.
Australia.
10. **Malachite.** Globular on limonite.
Morenci, Arizona, U. S. A.



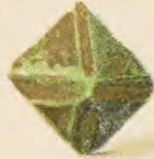
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6



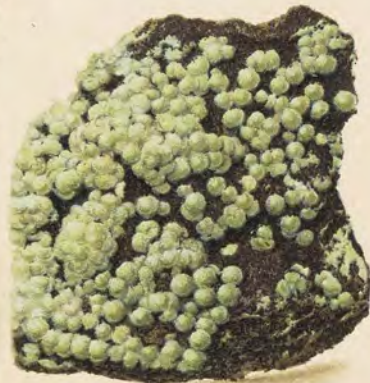
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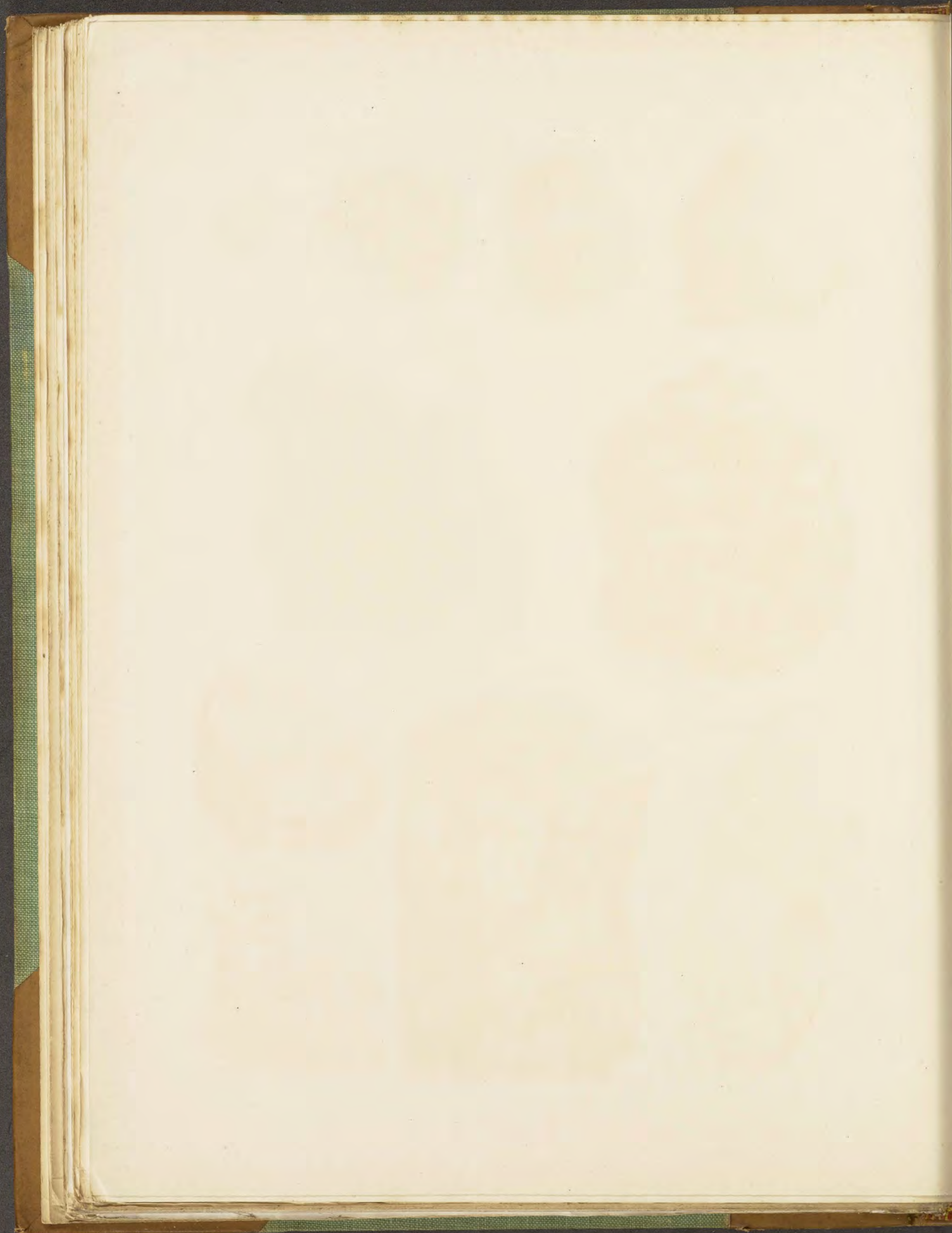
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8



10



Chemically, malachite is a basic carbonate of copper, containing besides copper the atmospheric constituents oxygen, carbonic acid and water. Its formula is $\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$, and when pure it contains 57.4 per cent. of copper. It is readily soluble in hydrochloric acid with effervescence, owing to the evolution of carbon dioxide, and a green solution results. When moistened with hydrochloric acid, it imparts a blue coloration to the flame of a Bunsen-burner. Heated on charcoal before the blowpipe, a fragment of the mineral readily yields a bead of metallic copper.

Crystals of malachite are monoclinic, but they are never distinctly developed, and such a twinned crystal as represented in the accompanying figure (fig. 118) is quite exceptional. The fine, needle-shaped crystals are usually aggregated into radiating tufts and brushes (plate 13, fig. 8). More usually, however, the mineral takes the form of mamillated, botryoidal or nodular masses with a smooth, rounded external surface, and a radially-fibrous internal structure. The form may be more or less globular (figs. 9 and 10) or kidney-shaped (reniform, figs. 5 and 7).

In addition to the radially-fibrous structure (fig. 7) shown on broken surfaces of nodular malachite, the material also exhibits a concentric-shelly structure (figs. 6 and 7). The concentric layers are alternately lighter or darker in colour, and more porous or more compact in texture. Each layer, seen as a band on the broken surface or on an artificially cut section, is uniform in thickness and envelops the inner layers; at a distance further from the centre the larger layers enclose two or more interior concentric systems. The whole structure thus presents a striking resemblance to the banded structure of agate; but while an agate has grown from the outside towards the inside, in malachite the direction of growth has been the reverse. In agate the innermost layer was the last to be formed, while in malachite the outermost layer is the latest.

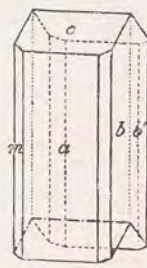


Fig. 118.
Twinned crystal
of Malachite.

The hardness of malachite is low ($H. = 3\frac{1}{2} - 4$), so that the material is easily worked. The specific gravity is about 4. Being an aggregate of minute crystals, the material is opaque in the mass. In finely fibrous aggregates the lustre is sometimes distinctly silky; but otherwise the lustre is dull, although the mineral is capable of taking a good polish when worked.

As to localities for malachite, reference may be made to all of those which have been mentioned above for the various ores of copper. Here we will name only those which are of special importance.

Comparatively good crystals of malachite are found at Betzdorf in Rhenish Prussia. Pseudomorphs of malachite from Chessy, near Lyons in France, have been already mentioned: the crystals of chessylite from the same place are also often more or less altered to malachite (plate 14, fig. 1). The specimen shown in plate 13, fig. 9, is from Australia, probably from Burra-Burra in South Australia, where the mineral occurs in some abundance and of a quality suitable for cutting and polishing: similar material is also found in Queensland and New South Wales. That shown in fig. 10 is from Morenci in Arizona; and large masses are common in the Copper Queen mine in the same State. The remaining four specimens figured in plate 13 are all from the Ural Mountains, a region which has long been famous for its malachite. The largest and best masses have been yielded by the copper mines of Gumeshevsk, situated 56 versts (about 60 kilometres) south-west of Ekaterinburg on the western slopes of the Urals. A detailed description of this locality has been given by Gustav Rose, who in company with Alexander von Humboldt visited the Urals in 1829. These mines

have been worked for centuries, and they have yielded nodular masses of malachite weighing 160 kilograms or even more; whilst the weight of the largest block of malachite met with has been given as 2800 kilograms, or nearly three tons: a portion of this mass is preserved in the collection of the Institute of Mines at St. Petersburg. The masses of malachite are here found embedded in a red clay, and in association with cuprite and native copper. At the present day these mines are no longer worked. A similar occurrence of malachite is that of the Medno-Rudiansk mine at Nizhni-Tagilsk in the northern Urals, from whence came the specimen shown in fig. 7. In this mine was discovered in 1836 the largest mass of malachite on record: it measured $17\frac{1}{2}$ feet long, 8 feet across and $3\frac{1}{2}$ feet in height, and was estimated to weigh 25 to 30 tons. In this, and other mines in the neighbourhood of Nizhni-Tagilsk, the nodules of malachite are embedded in a clayey rock and are accompanied by other ores of copper. It is this district which at the present day yields most of the malachite of value for polishing.

The larger and better marked pieces of malachite are cut and polished in the lapidary works at Ekaterinburg, being made into vases, bowls, table-tops and many other objects and small ornaments. Elaborate ornaments of malachite, in many cases the gift of the Czar of Russia, are to be seen in many museums. The larger objects, such as table-tops and columns, do not consist of solid malachite but are veneered with the mineral. Most of the malachite of the copper mines of the Urals is found as small nodular masses, often not larger than a pea; such material is useless for cutting, but it is of value as an ore of copper, and it is consequently smelted with the other copper ores. The annual production of the Medno-Rudiansk mine amounts to 1240 tons of copper.

Chessylite, or azurite, contains the same chemical elements as malachite, but these are combined in different proportions. Its formula is $2\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$, corresponding with 55.2 per cent. of copper. Both minerals behave the same towards chemical

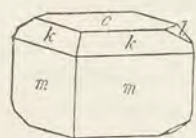


Fig. 119.
Crystal of Chessylite.

reagents, but they are strikingly different in colour, malachite being green and chessylite blue. The name azurite, often applied to this mineral, has reference to its blue colour, which is so intense that only thin crystals and splinters are transparent. Unlike malachite, chessylite is often found as crystals, but as these are usually confusedly grouped together their form is not always distinct. The crystals belong to the monoclinic system, and are usually bounded by a large basal plane (*c*, fig. 119), a vertical prism (*m*), a pyramid (*k*), and a brachy-dome (*l*). Owing to the unequal development of different faces of the same form, the crystals are usually more or less distorted and irregular (plate 14, figs. 1 and 2). The crystals are sometimes of comparatively large size, but as a rule they are quite small and closely aggregated, forming a dark blue crystalline crust. Sometimes the mineral forms an earthy coating on other minerals; the colour is then lighter and may be a brilliant sky-blue. Or again, it may occur, together with malachite, as an impregnation in rocks; for example, in the Triassic sandstone of the Eifel district, and in the Permian sandstone of the Kargalinsk Steppes in Orenburg and other places in Russia.

The hardness of chessylite is $3\frac{1}{2}$ —4, and its specific gravity 3.8. Chessylite owes its origin to the decomposition of other copper minerals, more particularly tetrahedrite; and it is itself readily altered to malachite, with which it is invariably associated.

A noted locality for fine crystallized specimens of chessylite is that from which the mineral takes its name, namely Chessy, near Lyons in France (plate 14, fig. 1). Good crystals have also been found at Zmeinogorsk in the Altai Mountains, and in the

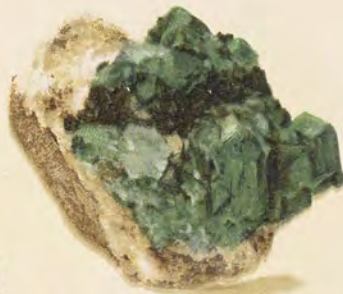
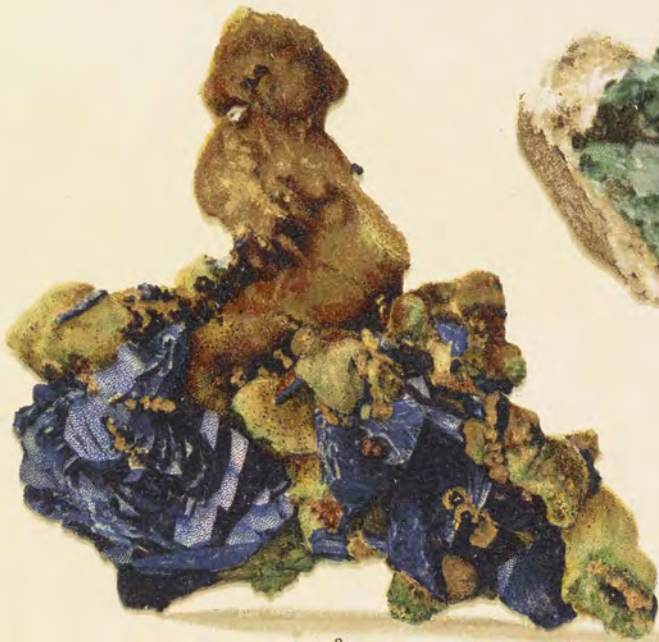


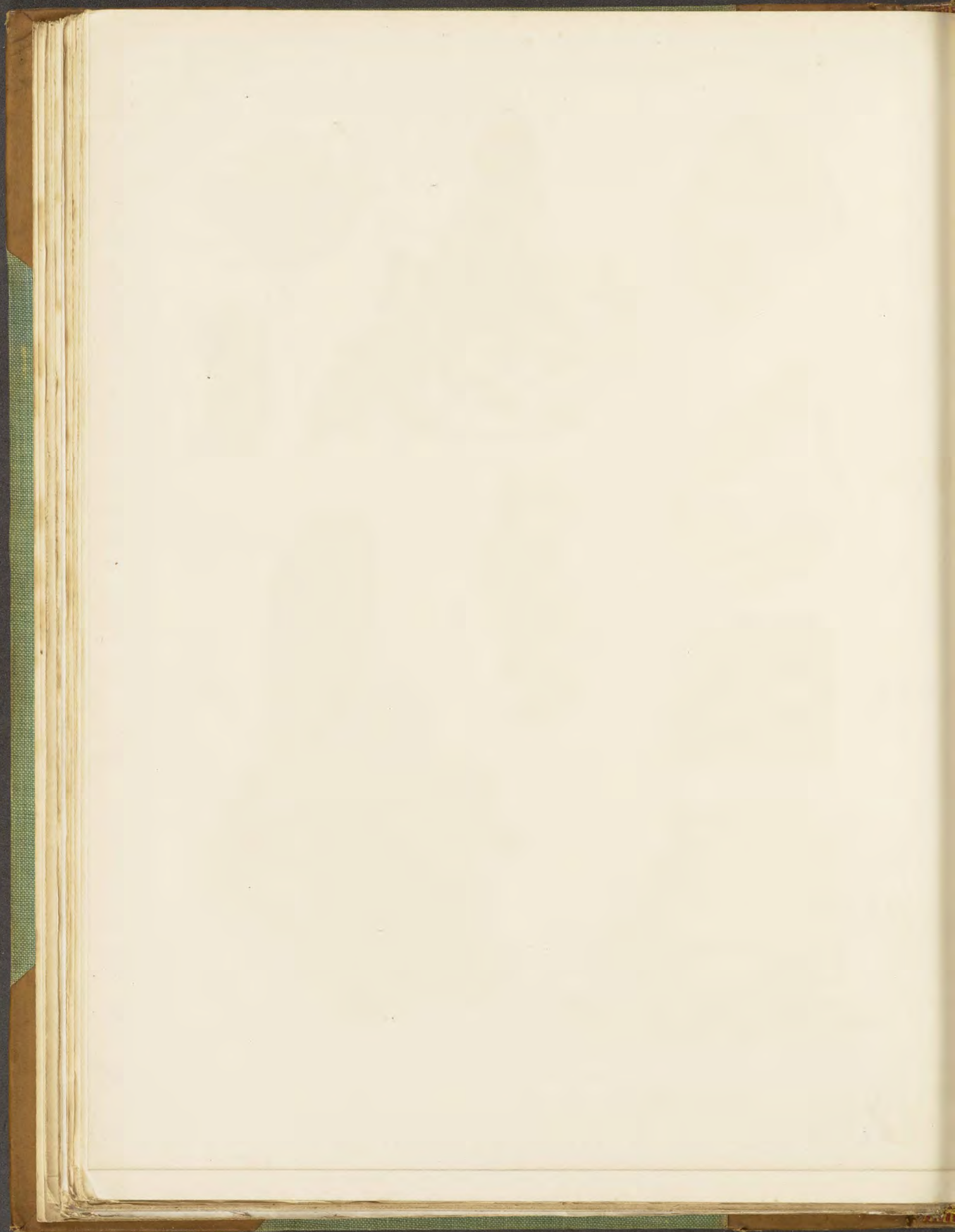
PLATE 14.

Copper Ores IV.

Fig.

1. **Chessylite.** Crystals with malachite.
Chessy, near Lyons, France.
2. **Chessylite.** Crystals with malachite on limonite.
Copper Queen mine, Bisbee, Arizona, U. S. A.
3. **Dioptase.** Crystals with calcite on limestone.
Kirghiz Steppes, Siberia.
4. **Dioptase.** Crystals with calcite on limestone.
Kirghiz Steppes, Siberia.
5. **Atacamite.** An unusually large prismatic crystal terminated by a pyramid and wide
brachy-dome; with limonite.
Burra-Burra, South Australia.
6. **Atacamite.** Isolated, prismatic crystal.
Burra-Burra, South Australia.
7. **Atacamite.** Group of crystals.
Burra-Burra, South Australia.
8. **Euchroite.** Crystals on iron-stained mica-schist.
Libethen, Hungary.
9. **Copper-vitriol on quartz.**
(Probably artificially crystallized on a specimen of quartz).





Copper Queen mine in Arizona (fig. 2), but perhaps the largest and most brilliant crystals are those more recently obtained from Broken Hill in New South Wales. At the Copper Queen mine in Arizona it is found in sufficient quantity to be a valuable ore of copper; it here occurs with malachite in limonite, and has clearly resulted from the decomposition of sulphide ores of copper in the upper part of the lode.

In addition to being used as an ore of copper, chessylite is powdered and used as a colouring material under the name "mountain-blue". This is, however, now almost completely replaced by the blue pigment known as "lime-blue", which is prepared artificially from copper nitrate and burnt lime. In the same way the "mountain green" furnished by malachite is replaced by an artificially prepared colouring material.

Atacamite. This mineral somewhat resembles malachite in its colour, which is, however, a rather darker green; and like malachite it sometimes occurs in fibrous and nodular masses. It also frequently occurs as well-developed orthorhombic crystals of prismatic habit. A magnificent crystal of an unusually large size is represented in plate 14, fig. 5; the original specimen is in the Stuttgart Museum. The habit is prismatic and the prism faces are striated parallel to their length; the crystal is terminated by a dome and a pyramid (the dome being seen in the figure as one large face to the front, and the pyramid as smaller faces on either side of the dome face). The smaller crystal represented in fig. 6 has exactly the same forms, only the crystal is turned round so that the two dome faces slope away to the left and the right. More usually, the crystals are smaller than in the two examples just mentioned, and they are aggregated in irregular groups as in fig. 7. With still smaller crystals there may be all degrees of transition to columnar and fibrous aggregates.

Fibrous aggregates of atacamite may at first sight be mistaken for malachite; but the two minerals are readily distinguished by the fact that atacamite does not effervesce when moistened with a drop of hydrochloric acid. Further, atacamite imparts, without the addition of hydrochloric acid, a blue coloration to the Bunsen-flame, thus proving the presence of copper and chlorine. When a fragment of atacamite is heated in a bulb-tube, water is given off and condenses on the sides of the tube. The mineral is thus easily proved to contain copper, chlorine and water. Quantitative chemical analysis shows the presence of copper 59.4, chlorine 16.6, and water 12.7 per cent., a total of 88.7 per cent. The difference between this total and 100 per cent. is accounted for by oxygen, as shown in the formula $\text{Cu}_2\text{Cl}(\text{OH})_3$ or $\text{Cu}(\text{OH})\text{Cl} \cdot \text{Cu}(\text{OH})_2$. Atacamite is thus a hydrated oxy-chloride of copper.

Like other copper minerals, atacamite becomes altered by weathering to malachite; and when partially altered in this way it will effervesce in contact with acid, and will when heated alone impart a blue colour to the flame.

Atacamite is found at only a few localities. It is of common occurrence in the Desert of Atacama in Chile, and on this account it receives its name: at Remolinos and Ojancos it occurs in large quantities as fibrous aggregates in veins, and at Sierra Gorda brilliant crystals are not uncommon. The larger crystals, such as those figured in plate 14, are all from the Burra-Burra copper mines, north of Adelaide in South-Australia. The mineral was discovered here in 1845, and large amounts were mined until the exhaustion of the deposit in 1877. Formerly in Chile, atacamite was ground to a sand and sold under the name "arsenillo", and was employed for the purpose for which blotting paper is now used.

Dioptase, although a rare mineral, presents several points of interest and deserves some mention here. Its brilliant emerald-green colour at once suggests that it contains copper; but it is to be remembered that such a colour does not necessarily imply the

presence of copper, emerald and green garnet being, for example, free from copper. The presence of copper in dioptase may be readily demonstrated by moistening the mineral with hydrochloric acid and heating in the Bunsen-flame, when a blue colour will be imparted to the flame; or by heating the mineral before the blowpipe on charcoal with

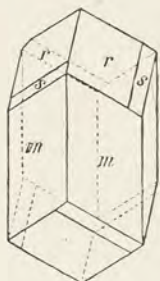


Fig. 120.
Crystal of Dioptase.

sodium carbonate, when a globule of metallic copper is obtained. When warmed in a test-tube with hydrochloric acid, the mineral is decomposed with the separation of a jelly consisting of silica and the production of a green copper solution. Heated strongly in a bulb-tube, the mineral gives off water. The constituents of dioptase are therefore copper, silica and water, and these are combined on the proportions given by the formula H_2CuSiO_4 , corresponding to 41.2 per cent. of copper.

The mineral usually occurs in bright, well-formed crystals, though these are often of small size. They belong to the rhombohedral-tetartohedral class of the hexagonal system. The crystals always show the faces of a rhombohedron (*r*, fig. 120) combined with the hexagonal prism of the second order (*m*); in addition to these faces there are sometimes narrow faces (*s*) of a rhombohedron of the third order truncating alternate edges between the rhombohedron *r* and the prism *m*. The crystals have a vitreous lustre; they are usually translucent, but sometimes transparent. The hardness of the mineral is 5, and its specific gravity 3.3.

The two specimens of dioptase figured in plate 14, figs. 3 and 4, are both from the best known locality for this mineral, namely the hill of Altyn-Tübe in the Kirghiz Steppes, 300 kilometres south of the Kariakovsky outpost in Siberia. The crystals are attached, together with calcite, to the surfaces of crevices in limestone. Other localities are the gold-washings in the government Yeniseisk in Siberia, Copiapó in Chile, Clifton in Arizona, and more recently good crystals have been found at Mindouli in the French Congo.

Dioptase cannot be said to be a mineral of any economic importance, since it does not occur in sufficient quantity to be mined as an ore of copper. Most of the crystals are preserved in mineral collections, and occasionally a clear transparent crystal may have been cut and passed off as an emerald.

In addition to dioptase, there is another hydrated silicate of copper, which occurs in nature as the mineral *chrysocolla*. This forms compact masses and is not crystalline. In appearance it somewhat resembles malachite, but the colour may vary from a light to a dark green and is sometimes a bluish-green. It is mined with other ores of copper, and compact pieces of a good colour have occasionally been cut as a semi-precious stone. Localities are Dillenburg in Nassau, Bogoslovsk in the Ural Mountains, and Chile.

Copper-vitriol, or chalcantite, is readily soluble in water, and for this reason it is but rarely met with as a mineral: it would not be readily deposited from a natural solution and when deposited it would always be liable to be carried away again. The well-known copper-vitriol of commerce is an artificial product. As the name implies, it is a compound of copper and vitriol, that is sulphuric acid; water of crystallization is also present, and the formula for the mineral, as well as for the artificial product, is $CuSO_4 \cdot 5H_2O$. Crystals (plate 11, fig. 9) belong to the triclinic system with acute angles between the faces, but well-formed crystals are quite rare in nature, though they may be readily obtained artificially from a solution of copper sulphate. The colour is bright blue and the crystals are transparent to translucent.

This mineral occurs at Rammelsberg near Goslar in the Harz Mountains, at Rio Tinto in Spain, and at other localities. As already mentioned, it is one of the products of the weathering of copper-pyrites, and it is frequently present in solution in the waters of copper mines. The water pumped up from the mines is allowed to flow over scrap iron, which precipitates the copper in a metallic form known as cement copper.

Other copper sulphates are known in nature as minerals, but these are basic salts insoluble in water. The most important is the mineral *brochantite*, which has the formula $\text{CuSO}_4 \cdot 3\text{Cu}(\text{OH})_2$. Others of rarer occurrence are langite and herrengrundite.

Several mineral phosphates and arsenates of copper are known, but they are of rare occurrence and their crystals are usually quite small. Libethenite, $\text{Cu}_2(\text{OH})\text{PO}_4$ and olivenite $\text{Cu}_2(\text{OH})\text{AsO}_4$ are perhaps the more common, but here we shall briefly describe only *euchroite*, since this occurs in rather larger and distinct crystals (plate 14, fig. 8). Euchroite is a hydrated basic arsenate of copper with the formula $\text{Cu}_2(\text{OH})\text{AsO}_4 \cdot 3\text{H}_2\text{O}$. It crystallizes in the orthorhombic system, and is found at Libethen in Hungary.

Uses of copper. — Metallic copper, either in a pure state or alloyed with other metals, has been extensively used for many purposes from very remote times.

Unalloyed copper is used for the construction of kettles, stills, worms, for wire, sheets and plates for sheathing ships, and for many other purposes. It is of importance for the construction of all kinds of electrical apparatus, since, next to silver, it is the best conductor of electricity. The electrical conductivity increases with the purity of the metal, and the copper deposited by the electrolytic method in the purest. The daily production of copper by this method amounts to 800 tons, of which $86\frac{1}{2}$ per cent. is contributed by the United States.

Alloys of copper are of different composition according to the uses to which they are to be put. The German copper coinage contains 95 per cent. of copper alloyed with 4 per cent. of tin and 1 per cent. of zinc: that of most other European countries (Russia, Sweden, the United Kingdom, and the Rumanian countries) contains $3\frac{1}{2}$ per cent. of tin and $1\frac{1}{2}$ per cent. of zinc. The German "nickel" coins consist of an alloy of 75 per cent. of copper with 25 per cent. of nickel.

Bronze is a copper alloy which has been used from very early times. It consists essentially of copper and tin, but there are several varieties differing somewhat in composition. Art-bronze or statuary-bronze, such as is used for statuary and various ornaments, consists of 86.6 parts of copper, 6.6 parts of tin, 3.3 parts of lead and 3.3 parts of zinc. When fused, it flows readily and takes a good impression of the mould; it can be readily worked, and in the course of time it acquires a dull green oxidized surface — the so-called patina. Gun-metal or steel-bronze consists of 92 parts of copper and 8 parts of tin; it was formerly used for gun-barrels. A bronze of very similar composition (91.8 parts of copper and 7.5 parts of tin) was used at the time of the second settlement of Troy for chisels, and another Trojan bronze (containing 87 parts of copper and 10.6 parts of tin with a little lead, arsenic and antimony) served for dagger blades. Bell-metal contains on the average 78 parts of copper with 22 parts of tin. Phosphor-bronze consists of 90 parts of copper, 9 parts of tin, and 0.5 to 0.75 parts of phosphorus; it is harder than the other varieties of bronze, though still ductile, elastic and tenacious. Slight variations in the composition of phosphor-bronze give alloys with different characters according to the uses to which they are to be put; it is used for the same purposes as gun-metal, bell-metal and art-bronze, and for several special purposes where the metal is subject to sudden and violent shocks. Aluminium-bronze contains 90 to 95 parts of copper and 5 to 10 parts of aluminium; it has a gold-yellow colour and does not readily tarnish, and is consequently used for watch-cases and similar

objects. Brass is another important alloy, containing 60 to 70 parts of copper and 30 to 40 parts of zinc; the greater the amount of copper present, the less ductile and darker in colour is the alloy. An alloy containing 85 parts of copper with 15 parts of zinc is called tombac or red brass. German silver or nickel-silver is an alloy of a silver-white colour consisting largely of copper with nickel and either zinc or tin. "Alfenide" and "christofle" are names given to nickel-silver containing small amounts of silver. Bronze paints contain 81—99 parts of copper.

Of the *salts of copper*, copper sulphate is the one most extensively used. When an electric current passes through a solution of a copper salt, the copper is deposited in the metallic state; in this manner electrotypes are made, and the pure copper so deposited is much used for electrical purposes. Solutions of copper sulphate and lime are used in horticulture for destroying blight. Copper sulphate is also used in the manufacture of paints and printing inks: treated with a solution of lime it gives the so-called lime-blue; with alkali and common salt the so-called Bremen blue; and when ground with oil it gives Bremen green. Another green pigment, known as Scheele's green, is a compound of copper and arsenious acid, and is consequently extremely poisonous. The uses of malachite for ornamental purposes and of chessylite as a pigment have already been mentioned.

In the *production of copper* the United States of North America is far ahead of all other countries. The veins and beds of copper ore are here extremely large and rich. The richest vein is the Anaconda lode in Montana; this has a width of 13 metres (40 feet) and in the year 1900 had been worked to a depth of 600 metres. During the years 1897 and 1898 it yielded almost half a million tons of ore, consisting of copper-glance and copper-pyrites, from which more than 62,000 tons of copper was extracted. The massive ore contains almost 35 per cent. of copper, whilst the ore together with the gangue contains 10 per cent., the average for the whole ore being 16 per cent. of copper. In contrast with this, the European copper ores are poor in copper, the abundant copper ore of Rio Tinto containing only 3 per cent. of copper.

The following table gives the amounts of copper, in tons of 2240 lb., produced in the more important countries. The total production for the whole world in the year 1901 amounted to 528,327 tons, and in 1905 to 689,277 tons.

	1901 Tons.	1905 Tons.		1901 Tons.	1905 Tons.
North America:			Africa (South):	6 400	2 300
<i>United States</i>	267 400	389 122	Europe:		
<i>Mexico</i>	23 795	68 907	<i>Spain and Portugal:</i>		
<i>Canada</i>	18 000	21 248	<i>Rio Tinto</i>	35 348	32 280
<i>Newfoundland</i>	2 000	2 280	<i>Other mines</i>	18 273	12 530
South America:			<i>Germany:</i>		
<i>Chile</i>	30 000	29 165	<i>Mansfeld</i>	18 780	19 565
<i>Peru</i>	9 520	8 625	<i>Other mines</i>	2 940	2 595
<i>Bolivia</i>	2 000	2 000	<i>Russia</i>	8 000	8 700
Asia:			<i>Italy</i>	3 000	2 950
<i>Japan</i>	27 475	35 910	<i>Norway</i>	3 375	6 305
Australia	30 875	36 560	<i>Austria-Hungary</i>	1 015	1 325
			<i>United Kingdom</i>	532	500

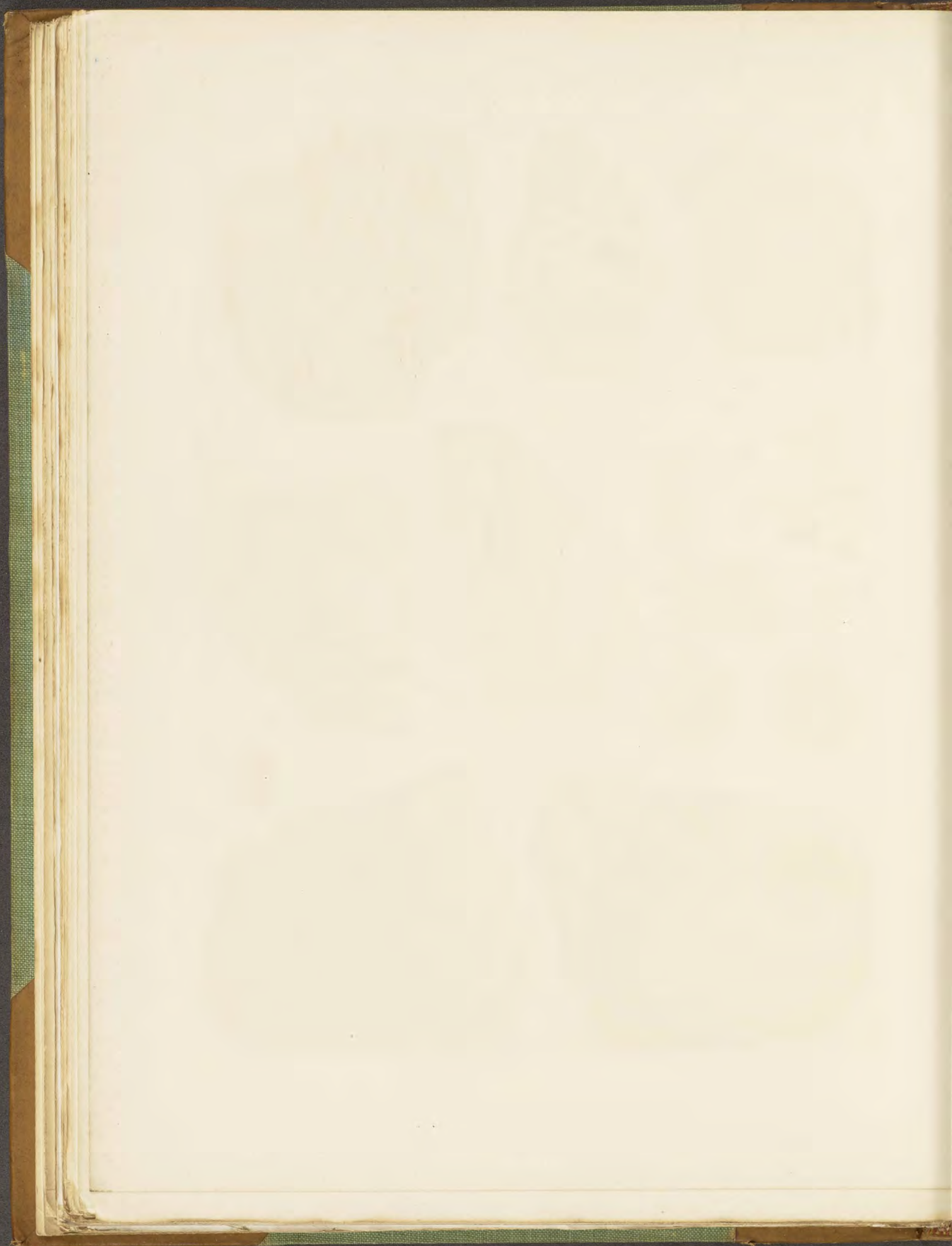


Mercury Ores.

Fig.

1. **Native Mercury**, small globules in rock.
Moschellandsberg, Rhenish Bavaria.
2. **Amalgam**, rhombic-dodecahedron in matrix.
Moschellandsberg, Rhenish Bavaria.
3. **Amalgam**, massive, in matrix.
Moschellandsberg, Rhenish Bavaria.
4. **Cinnabar**, large crystals with dull basal plane and bright rhombohedral faces, on quartz.
Almaden, Spain.
5. **Cinnabar**, crystals with striated rhombohedral faces, on granular cinnabar.
Almaden, Spain.
6. **Cinnabar**, one large and several small crystals, on quartz.
Almaden, Spain.
7. **Cinnabar**, a cleavage fragment — a hexagonal prism.
Almaden, Spain.
8. **Cinnabar**, compact, with rounded surface.
Monte Amiata, Tuscany, Italy.
9. **Cinnabar**, granular, with coating of limonite.
Hohensolms, Giessen, Hesse.
10. **Cinnabar**, columnar.
Wolfstein, Rhenish Bavaria.
11. **Cinnabar**, intermixed with clay and carbonaceous matter ("Coral-ore").
Idria, Carniola, Austria.





Mercury Ores.

Mercury, or quicksilver, holds a unique position amongst metals in being the only one which is liquid at the ordinary temperature. It occurs free in nature, but only rarely and never in large quantities; more usually it occurs in chemical combination with other elements. When combined with sulphur we have the mineral cinnabar, which is the only ore of the metal. Less frequently it is combined with silver as amalgam, and with chlorine as calomel. Mercury is also present in some varieties of tetrahedrite and in some other rarer minerals.

Native mercury, or virgin quicksilver as it is sometimes called, is found as small liquid globules, with a tin-white colour and brilliant metallic lustre, in rock crevices (fig. 1, plate 15), and is usually associated with cinnabar. It is known from Moschellandsberg (or more correctly Landsberg near Obermoschel) in Rhenish Bavaria, from Idria in Carinthia, from Almaden in Spain, from California, and other localities of mercury ores. Since this is a mineral of rare occurrence and the metal is always obtained from cinnabar, we shall defer any mention of its properties and applications till we have dealt with the ore itself.

Amalgam is a mixture or alloy of mercury with other metals: in nature these may be either gold or silver, the latter being by far the more common. As a mineral, the name amalgam is limited to the mixtures of mercury and silver, that is to silver amalgam. This (figs. 2 and 3, plate 15) is sometimes found as brilliant crystals belonging to the cubic system, which are often well developed and bounded by numerous faces. Fig. 2 represents a rhombic-dodecahedral crystal, and fig. 3 represents the more usual massive form of the mineral.

The colour of amalgam is tin-white, and the lustre is brilliant and metallic; the mineral has in fact much the appearance which we should expect frozen mercury to show. The hardness is 3, and the specific gravity about 14, but varying with the relative amounts of mercury and silver.

The best known locality for amalgam is Moschellandsberg in Rhenish Bavaria, from whence finely developed crystals have been obtained; these mines are, however, no longer worked, and the crystals now command a high price. Dendritic amalgam has been found in the Friedrichsseggen mine near Ems in Nassau. Amalgam is, however, a mineral of quite rare occurrence and it has been met with at only few localities.

Cinnabar is a compound of mercury and sulphur with the formula HgS . It is practically the only ore of mercury, and when pure contains 86.2 per cent. of this metal; usually, however, owing to the presence of admixed impurities, the content of mercury falls below the theoretical amount. The characteristic cinnabar-red or vermilion colour is only shown where the mineral is finely granular or earthy; crystals are dark red in colour, and transparent with an almost metallic lustre. The crystals belong to the rhombohedral system, and the predominating forms are usually a rhombohedron and the basal plane. The large crystals represented in fig. 4, plate 15, show a dull basal plane and bright faces of the rhombohedron; in figs. 5 and 6 the rhombohedral faces are striated parallel to their intersection with the basal plane. Larger and better crystals than those figured on plate 15 are of extremely rare occurrence. The crystals may occur with quartz grown on a matrix of quartzite (fig. 4), or on a matrix of granular cinnabar (fig. 5). They possess perfect cleavages parallel to the six faces of the hexagonal prism of the first order; a cleavage fragment is represented in fig. 7. The mineral has a specific gravity of 8, and a low degree of hardness ($H. = 2$).

The optical characters of cinnabar present features of special interest: the indices of refraction and the double refraction are both high, and the crystals have the property of rotating the plane of plane-polarized light, the rotary power being about fifteen times as great as in quartz. A thin plate parallel to the basal plane of a crystal of cinnabar therefore gives in the polariscope in convergent light an interference-figure like that represented in fig. 2, plate 4. The refractive index for the ordinary ray is 2.858, and for the extraordinary ray 3.201: the refractive index is thus greater than that of diamond, and the double refraction stronger than that of calcite, whilst the rotary power greatly exceeds that of quartz.

When heated before the blowpipe on charcoal, pure cinnabar is completely volatilized. Heated alone in a glass tube closed at one end it gives a black sublimate of mercury sulphide, but if mixed with anhydrous sodium carbonate small globules of metallic mercury condense on the sides of the tube.

As already mentioned, crystallized cinnabar is of comparatively rare occurrence; more usually the mineral is found as granular (fig. 9), columnar (fig. 10), or compact (fig. 8) aggregates. Frequently also, it occurs intermixed with clay, as in hepatic cinnabar, so called because of its liver-brown colour; or mixed with carbonaceous matter, and then known as inflammable cinnabar. The so-called "coral-ore" (German, *Korallenerz*), (fig. 11), found at Idria as black masses, is a curved lamellar variety of hepatic cinnabar containing admixed clay and carbonaceous matter. These mixtures have little of the appearance of cinnabar or mercury ore, but the presence of mercury in them may be readily proved by the tests mentioned above.

Cinnabar is found in mineral-veins and as an impregnation in rocks. It is often associated with younger volcanic rocks (trachyte and basalt), and no doubt has been brought up from the greater depths of the earth by hot springs connected with volcanic outbreaks. At the present day cinnabar is being deposited by thermal waters in the mercury mines at Sulphur Bank in California.

The most extensive of all known deposits of mercury ore are those of Almaden in Spain (four of the specimens figured on the plate are from this locality). It is said that the Greeks worked mercury ore here 700 years before Christ; the deposits were also worked by the Romans and mercury was extracted by them from the ore. Until recently, Spain has been the principal mercury-producing country of the world, but lately the United States have taken the first place. The next most important European locality is Idria in Carniola (from whence is the "*Korallenerz*" shown in fig. 11); others are Monte Amiata in Tuscany (fig. 8); Mount Avala near Belgrade in Servia; and the neighbourhood of Nikitovka in the district of Bachmut, government Ekaterinoslaw, Russia. The mercury mines in Rhenish Bavaria yielded in former years not only cinnabar (fig. 10), but also native mercury (fig. 1) and amalgam (figs. 2 and 3), but they have long ago been exhausted. Small amounts of granular cinnabar (fig. 9) have been found in a mine at Hohensolms, near Giessen in Hesse. Curiously, cinnabar, or any other mineral containing mercury, has never been found in the British Isles.

California is rich in cinnabar along a zone 500 kilometres in length in the Coast Ranges. The most important mines are those of New Almaden, and others are situated at New Idria, Sulphur Bank, and Knoxville. In Mexico the principal localities for mercury ores are Guadalcázar and Huitzucó in the State of Guerrero. In Peru the cinnabar mines at Huancavelica were at one time of considerable importance. Recently, extensive deposits of cinnabar have been worked over a wide area in Kwei-chow and other provinces in central China; from this region large and magnificent twinned crystals, having the form of interpenetrating rhombohedra, have been obtained.



Lead Ores I.

Fig.

1. **Galena**, cube with octahedron.
Siegen, Westphalia.
2. **Galena**, with bright cube faces and dull octahedral faces.
Joplin, Jasper Co., Missouri, U. S. A.
3. **Galena**, dull octahedra built up of minute cubes, which reflect light from the cube faces; there are small cleavage surfaces, parallel to the cube faces, on the corners of the crystals.
Scharley, Prussian Silesia.
4. **Galena**, octahedra with cube faces. Portions of the crystals are overgrown with copper-pyrites.
Gondersbach mine, Laasphe, Prussia.
5. **Galena**, octahedra with cube, rhombic-dodecahedron and three-faced octahedron; on chalybite.
Neudorf, Harz, Germany.
6. **Galena**, the same form as in fig. 5, but sharper; on quartz.
Neudorf, Harz, Germany.
7. **Galena**, cube with octahedron; the crystal is elongated in the direction of one of the cubic axes, and the octahedral faces show hopper-shaped depressions.
Gonderbach mine, Laasphe, Prussia.
8. **Galena**, octahedron with cube; a parallel grouping of crystals; with a thin coating of copper-pyrites.
Siegen, Westphalia.
9. **Galena**, octahedral skeletal growth.
Hazelgreen, Wisconsin, U. S. A.
10. **Galena**, cube with octahedron; altered on the surface to lead carbonate (cerussite).
Illinois, U. S. A.
11. **Galena**, cubo-octahedron, altered on the surface.
Gonderbach mine, Laasphe, Prussia.
12. **Zinckenite**, radiating aggregate of acicular crystals.
Wolfsberg, Harz, Germany.



1



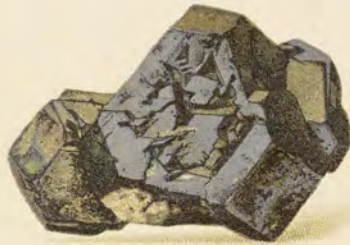
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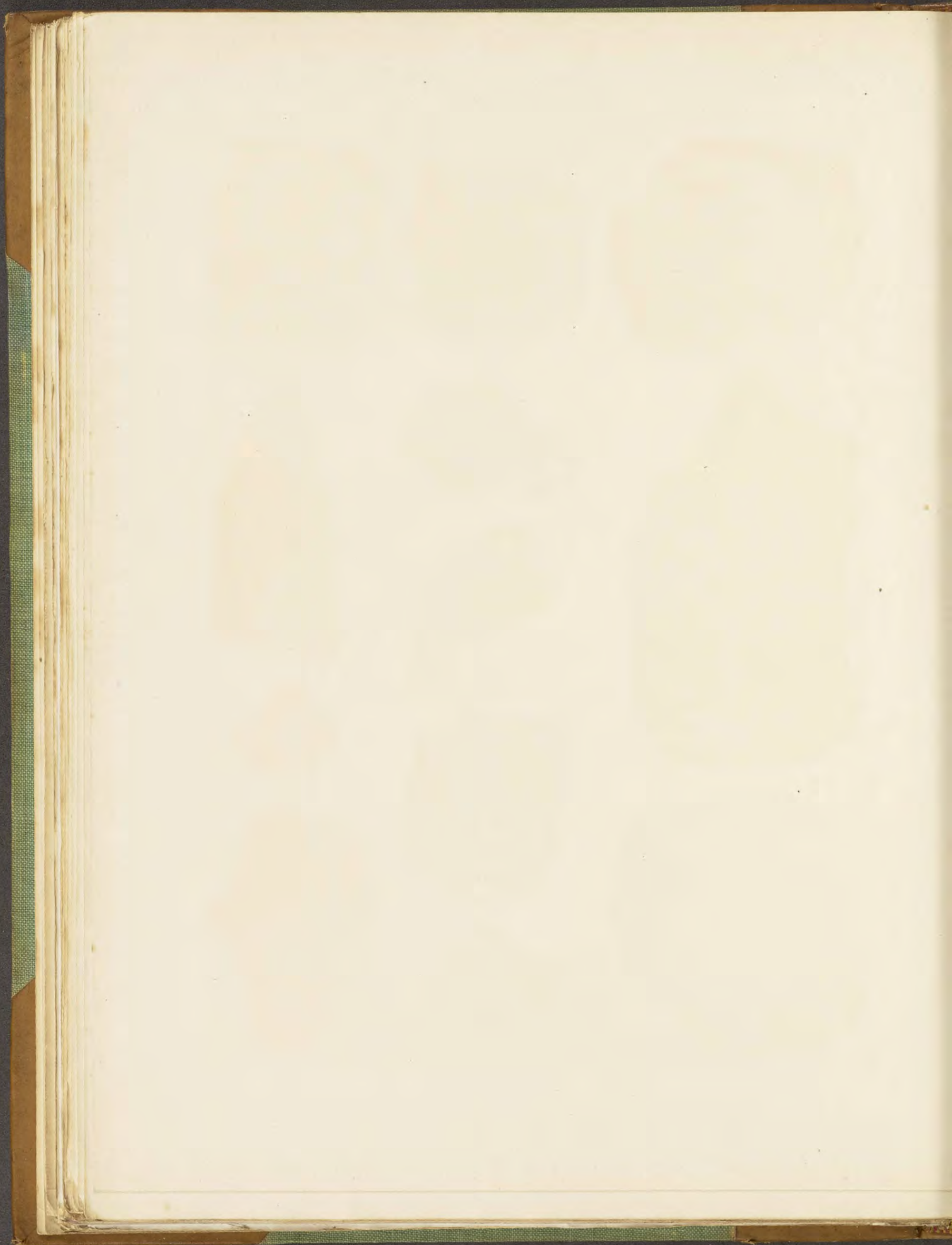
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10



Applications. — Being a liquid metal possessed with peculiar properties, mercury has many important applications. Its property of combining with other metals to form amalgams is utilized for separating finely divided gold and silver from other minerals. This process of collecting gold by amalgamation was described long ago by Pliny, and it is still used to the present day, though the cyanide process is gradually replacing it (see under gold, p. 75). Tin amalgam is used for silvering mirrors; gold amalgam for gilding; and various other amalgams are employed in dentistry. The use of pure mercury for thermometers and barometers is well known. Mercury thermometers can, however, be used for only a limited range of temperature, since at -39.5° C. the metal freezes, crystallizing in cubic forms as does the mineral amalgam; and it boils at 360° C. Owing to its high specific gravity, namely 13.595 at 0° C., and to the fact that when pure it remains unaltered in the air at the ordinary temperature, mercury is much used in physical and chemical apparatus of various kinds.

The salts of mercury are extensively used in medicine, and are extremely poisonous. The compounds with chlorine, calomel (HgCl) and corrosive sublimate (HgCl_2), are the commonest salts. Pure mercury sulphide, HgS , artificially prepared from metallic mercury and sulphur, is the pigment known as vermilion. Fulminate of mercury ($\text{C}_2\text{N}_2\text{HgO}_2 + \text{H}_2\text{O}$) is used for making percussion caps.

The amount of the production of mercury is usually stated in "flasks", the weight of mercury in a flask being 28.54 kilograms, and its value about £9 10s. to £10. In the year 1901 the production in Spain amounted to 864 metric tons (of 1000 kilograms), in the United States 992, Austria 550, Mexico (in 1900) 335, Russia 340, and in Italy 220 metric tons.

Lead Ores.

As a native metal, lead is of rare occurrence, and it is of no importance either as a mineral or as an ore of lead. It has been found at only a few localities as thin plates coating other minerals, and the only interest that it presents lies in the fact that lead does occur in nature in the metallic form.

By far the most important ore of lead is galena, all other lead-bearing minerals being of quite secondary importance as ores of the metal. Galena is a compound of lead and sulphur, being sulphide of lead with the chemical formula PbS . Closely allied chemically to this are the rare minerals clausthalite and altaite, which are selenide of lead, PbSe , and telluride of lead, PbTe , respectively. Of sulphur compounds containing lead, several are known as minerals, but they are of comparatively rare occurrence: the more important are the following:

Sartorite, PbAs_2S_4 .	Dufrenoyite, $\text{Pb}_2\text{As}_2\text{S}_5$.
Zinckenite, PbSb_2S_4 .	Plumosite, $\text{Pb}_2\text{Sb}_2\text{S}_5$.
Galénobismutite, PbBi_2S_4 .	Cosalite, $\text{Pb}_2\text{Bi}_2\text{S}_5$.
Jamesonite, $(\text{Pb}, \text{Fe})_7\text{Sb}_8\text{S}_{19}$.	
Bournonite, CuPbSbS_3 .	

Bournonite has already been described under the ores of copper (p. 106), and zinckenite is the only one that need be briefly mentioned in the following pages.

By the action of various oxidizing solutions on these sulphur compounds of lead, and particularly on galena, secondary minerals are formed. These are oxygen compounds of lead; they are often transparent and brilliantly coloured, and are characterized by their

high refrangibility for light. Some of them, when they occur in sufficiently large quantities are of importance as ores of lead. The more important of these secondary lead-bearing minerals are the following: —

Cerussite, PbCO_3 .	Crocoite, PbCrO_4 .
Phosgenite, $\text{PbCO}_3 \cdot \text{PbCl}_2$.	Wulfenite, PbMoO_4 .
Anglesite, PbSO_4 .	Pyromorphite, $3\text{Pb}_3(\text{PO}_4)_2 \cdot \text{PbCl}_2$.
	Mimetite, $3\text{Pb}_3(\text{AsO}_4)_2 \cdot \text{PbCl}_2$.

These minerals are collected together here in our discussion of lead ores because they all contain lead as an important constituent. If, however, we were to group them according to the acid, as is done in the chemical system of classification in the text-books on mineralogy, we should see that cerussite is closely related in the form of its crystals to aragonite (CaCO_3), anglesite to barytes (BaSO_4), and pyromorphite and mimetite to apatite ($3\text{Ca}_3(\text{PO}_4) \cdot \text{CaCl}_2$).

Galena, or lead-glance, with its metallic lustre and dark colour, is a typical representative of the glances, and for this reason it was formerly referred to simply as glance. It is not only the most abundant of lead ores, but also the richest in lead, containing 86 per cent. of the metal. Silver is almost invariably present in small quantity (rarely more than 0.01—0.5 per cent.), so that galena is at the same time an important ore of silver.

Crystals of galena belong to the cubic system, and the most usual form is a combination of the cube and octahedron (plate 16, figs. 1, 2 and 11). Sometimes the octahedral faces are quite small (fig. 2) or they may be altogether absent; or again they may be larger, as in the cubo-octahedron represented in plate 19, fig. 6; whilst in plate 16, fig. 4, the octahedron predominates over the cube. Finally, though less commonly, we may have crystals of galena bounded only by faces of the octahedron. The octahedral crystals represented in plate 16, fig. 3, have, on close inspection, the appearance of being built up of numerous minute cubes, and in the direction of the cube faces they give a shimmered reflection of light, with here and there bright reflections from the cubic cleavages. An example of a distorted combination of the cube and the octahedron is shown in fig. 7, plate 16, which represents a crystal with the same forms and from the same locality, namely the Gonderbach mine at Laasphe in Prussia, as the crystal shown in fig. 4 of the same plate. Here the cube planes at the side are largely developed, especially in the vertical direction, whilst that at the top of the crystal is absent; the form has then the appearance of a tetragonal prism of the first order in combination with a pyramid of the second order. The material has been supplied from one side, and the growth of the crystal has consequently taken place mainly in that direction.

Another peculiar form of growth of a galena crystal is illustrated in fig. 8. The larger central cubo-octahedron had apparently finished its growth, when there was a later deposit of crystallized galena in parallel position on the corners; this later growth having the form of small cubo-octahedra flattened parallel to the cube faces on which they grew. Finally, the parallel growth of crystals was coated over with a thin crust of copper-pyrites.

Minute octahedral crystals are sometimes grouped in lines in three directions at right angles along the three cubic edges, giving rise to a reticulated structure, as represented in fig. 7, plate 2. A similar structure, but with the secondary branches inclined to the main branches at angles of 60° , is shown in fig. 9 of plate 16.

Finally, the so-called "plates" or "fused" crystals represent another kind of distortion met with in crystals of galena, specially fine examples of which are found in the Gonderbach mine at Laasphe. The crystal shown in fig. 10, plate 16, is tabular in the direction of one pair of parallel octahedral faces, and is bounded at the edges by narrow

faces of the cube and the octahedron. Running across these large octahedral planes at the front and the back of the crystal are to be seen fine suture lines indicative of twinning. A portion of the crystal may be considered to have been rotated through an angle of 180° , so that the front face comes into coincidence with the back face and the back face in coincidence with the front. The twinning is here quite analogous to that previously described for the crystallized plates of gold and silver (p. 76), and frequently the small triangular elevations and pits, placed in reversed positions on opposite sides of the suture line, may be detected on these plates of galena. Tabular crystals of galena are not always so sharply developed as in the specimen here figured; usually their faces are curved and their edges rounded, and the crystals have then quite the appearance of having been partially fused. These "fused" crystals of galena owe their form, however, to peculiarities of growth, for we know that they have been deposited in the mineral-veins from an aqueous solution and that they have not subsequently been exposed to any high temperature.

All the varied forms of galena crystals which we have so far considered are bounded solely by the octahedron and the cube, and although some of them appear at first sight to be irregular they may be seen on closer inspection to conform with the true symmetry of the mineral.

Other forms are not very common. In figs. 5 and 6, plate 16, we see, in addition to the cube and octahedron faces, other faces rounding the edges of the octahedron. Here each edge of the octahedron is replaced by three narrow faces, a face of the rhombic-dodecahedron in the middle and on either side faces of the three-faced octahedron with the symbol 20. On other crystals, the edges between the cube and the octahedron faces may be replaced by faces of an icositetrahedron, though such a form is of rare occurrence in galena.

An important character of galena, and one by which the mineral may always be readily identified, is the perfect cleavage in three directions parallel to the faces of the cube. On the cleavage surfaces the lustre is always brilliant and metallic with a lead-grey colour. Even when the material consists of a coarser or finer granular aggregate the cleavages are prominent and betray the identity of the mineral. The softness ($H. = 2\frac{1}{2}$) and heaviness (specific gravity 7.5) are also characters of importance.

Before the blowpipe, the constituents of galena may very readily be detected and the mineral so identified. The powder heated on charcoal with sodium carbonate gives the hepatic reaction, proving the presence of sulphur; and at the same time metallic lead is liberated as a bright and malleable bead, while around the assay a yellow sublimate of lead oxide is formed on the charcoal.

When subjected to the action of weathering agents, galena passes into carbonate of lead (cerussite), and where veins of galena crop out at the earth's surface they are usually wholly converted into cerussite. The crystal of galena represented in fig. 11, plate 16, is thinly encrusted on the surface with secondary cerussite. When other solutions are present in the surface waters, the alteration of galena may give rise to anglesite, phosgenite, pyromorphite and other secondary oxygen salts mentioned above. These often occur in cavities in partly decomposed galena, as represented on plate 17: fig. 3 showing cerussite, fig. 9 phosgenite, and figs. 10 and 11 anglesite. Not infrequently during the process of weathering of galena a portion of the sulphur is set free as native sulphur, small crystals of which encrust the cavities of the decomposed ore. Native sulphur formed in this manner is met with in the Victoria mine at Littfeld in Westphalia, and in the lead mines of Derbyshire.

Galena occurs usually in veins, but also sometimes in beds, and is usually accompanied by zinc-blende, copper-pyrites, quartz, chalybite and calcite.

In veins, it is found in the Siegen mining district in Westphalia (from whence come the specimens represented in figs. 1 and 8, plate 16), in the Gonderbach mine at Laasphe, Prussia (figs. 4, 7 and 11), at Neudorf (figs. 5 and 6) and Clausthal in the Harz Mountains, and at several other localities in Germany. Beds of galena are met with in the Muschelkalk (Triassic) strata at Scharley (fig. 3) and Tarnowitz in Silesia, and at Welkenraedt in Belgium. Grains of galena occur disseminated through beds of Triassic sandstone at Mechernich on the northern borders of the Eifel.

Other localities of importance, either for the abundance of lead ore or for the finely crystallized specimens which they yield, are Derbyshire and the North of England, Prizibram in Bohemia, Schemnitz in Hungary, Bleiberg in Carinthia, Iglesias in the province of Cagliari in Sardinia, Linares in Spain, and many others. In the United States, the states of Wisconsin, Iowa, Illinois and Missouri are rich in galena. The crystal shown in fig. 2, plate 16, is from Joplin in Missouri, that in fig. 11 from Illinois, and that in fig. 9 from Hazelgreen in Wisconsin. Galena is a widely distributed mineral, and it is not possible to mention more than a few of the numerous localities at which it is found.

Zinckenite may be here briefly described as an example of one of the numerous species of sulphur salts of lead known to mineralogists. It forms radial aggregates or brushes of acicular crystals which are deeply striated in the direction of their length. The mineral is steel-grey with a metallic lustre. It has in appearance a certain resemblance to stibnite, but it is harder ($H. = 3$) and heavier (specific gravity 5.3) than this; further it may readily be distinguished from stibnite by the absence of cleavage. Zinckenite is a compound of lead (35 per cent.), antimony (41.7 per cent.) and sulphur (23.3 per cent.). It is found with stibnite and bournonite at Wolfsberg in the Harz, but like the other sulphur salts of lead it is a mineral of only scientific interest.

Cerussite, also known as white lead-ore, is the commonest of the oxygen salts of lead. It crystallizes in the rhombic system, and the crystals are almost always twinned.

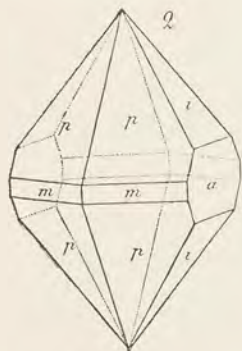


Fig. 121.
Crystal of cerussite.

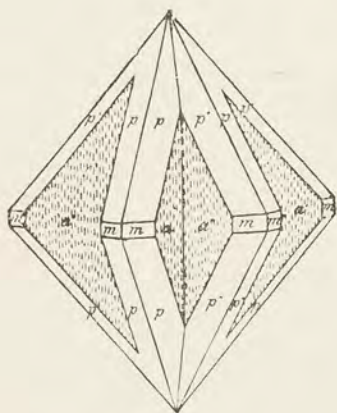


Fig. 122.
Trilling of cerussite.

The upper portion of fig. 4, plate 17, illustrates the form of a simple crystal (the lower portion is in twinned position with respect to this): the large face to the front is one of the two faces of the brachy-pinacoid parallel to which the crystal is tabular; at the sides are narrow faces of the vertical prism, and at the upper end a brachy-dome, pyramid and basal plane. The same forms are shown more clearly in the accompanying text-figure 121: a is the brachy-pinacoid $\infty P\infty$, m the vertical prism ∞P , i the brachy-dome $2P\infty$, and p the primary pyramid P .

In this figure the habit of the crystal is pyramidal, but the tabular habit shown in the plate is more common. The mode of twinning is illustrated in fig. 122, in which the faces are marked with the corresponding letters as in fig. 121. The twin-plane is the unit prism ∞P , and almost invariably the twinning is repeated on two of the faces of this prism; the result being an interpenetration of three crystals in twinned position, which is known as a trilling (fig. 122). Star-shaped groups of twinned crystals with deep re-entrant angles are represented in figs. 1a and 1b, plate 17. When the crystals are more completely

filled up with material, the resulting form (as may be easily imagined from fig. 122) closely resembles a hexagonal bipyramid somewhat like a crystal of quartz and exactly like the twins of witherite (plate 75) to be described later. When, on the other hand, the individual crystals are thinner and more tabular in habit, the star-shaped forms of the twinned groups are more conspicuous, and when the twinning is repeated many times we have the delicate net-like forms shown in fig. 2, plate 17. This twinning of cerussite is an extremely characteristic feature of the mineral, and often of aid in its identification.

Besides the regular forms just described, cerussite also frequently occurs in fibrous aggregates and brush-like forms, as shown in fig. 3 of plate 17. Granular and compact aggregates are also met with.

The mineral is slightly harder than calcite, and it has a specific gravity of 6.5. It is very brittle, and the delicately crystallized masses such as shown in fig. 2, plate 17, are extremely friable. The clearest crystals are colourless and transparent, with a brilliant adamantine lustre, and a correspondingly high index of refraction ($\mu = 2.07$). Often, however, the crystals are white or yellowish and with only a slight degree of transparency; or they may be tinted green or blue (by malachite or chessylite) or black (by earthy galena or limonite).

Being rhombic, crystals of cerussite are optically biaxial; the axial angle is small and the dispersion of the optic axes is strong. Plates cut from crystals parallel to the basal plane are therefore specially suited for demonstrating the phenomenon of the dispersion of the optic axes. In convergent polarized light the interference-figures resemble those shown in figs. 3 and 4, plate 4, only the hyperbolic brushes are closer together and in white light they are much broader, being coloured red on the convex side and blue on the concave side. The blue band marks the position of the wider angled axes for red light, and the red band marks the narrower angle for blue light.

The mineral is readily dissolved in warm dilute nitric acid with a brisk effervescence, owing to the liberation of carbon dioxide. The lead passes into solution as lead nitrate, and when sufficient cerussite has been dissolved for the solution to become saturated the lead nitrate separates out on cooling as cubic crystals. On charcoal before the blowpipe, the mineral fuses readily and yields a bead of metallic lead and a yellow sublimate around the assay.

Cerussite occurs in the upper portions of veins of lead-ore, where it is a product of the weathering of galena; and it is often found, together with limonite and chessylite, in cavities in quartz. The quartz was originally intergrown with the galena, and being more resisting to weathering agents it has remained behind as the matrix of the cerussite. Sometimes the secondary cerussite is disseminated through the ore and acts as a cementing material of the whole; for example, the grains of the galena-bearing sandstone of Mechernich in the Eifel are so cemented by cerussite.

Some of the finest crystals of cerussite are those from the Friedrichsseggen mine between Ems and Braubach in Nassau (figs. 1 and 4, plate 17, and fig. 7, plate 19). Fine crystals are also found at Mies and Przi Bram in Bohemia, and formerly in the lead mines of the Black Forest in Baden. The fibrous aggregates shown in fig. 3 are from the San Giovanni lead mine in Sardinia, and specimens of the same type were formerly found in the Pentire Glaze mine in Cornwall. Fine specimens have also come from the Altai Mountains and from the neighbourhood of Nerchinsk in Siberia: while large crystallized masses, some of them resembling fig. 2, were abundant at Broken Hill in New South Wales. Many other localities might be mentioned, and all those referred to above under galena may be included.

Phosgenite is a chloro-carbonate of lead with the chemical formula $PbCO_3 \cdot PbCl_2$, thus differing from cerussite in containing chloride in addition to carbonate of lead; but whilst cerussite is a common ore of lead, phosgenite is of quite rare occurrence.

In figs. 5—9 of plate 17 are shown some exceptionally fine specimens of this rare mineral. The crystals are tetragonal, and they differ from the crystals of other tetragonal minerals by usually presenting faces of eight-sided prisms and pyramids. The simplest crystal is that shown in fig. 6, which is bounded by an eight-sided prism with a four-sided tetragonal prism (a small face of which is seen to the front over the fractured portion of the crystal), and the large basal plane. The large crystal shown in fig. 5 is similar, but here the edges between the eight-sided prism and the base are truncated by faces of an eight-sided pyramid. In the crystal represented in fig. 7 the faces of the eight-sided pyramid are large and steeply inclined; above the edge in which the two front faces intersect there is to be seen a face belonging to a four-sided pyramid; and below the same edge is a narrow face of a tetragonal prism truncating an edge of the eight-sided prism, whilst the alternate edges of the latter are truncated by the second tetragonal prism. Finally, in fig. 8, we see an eight-sided prism with a four-sided pyramid, the base, an eight-sided pyramid, and (on the left) a tetragonal prism.

The reflection of light from the crystal in fig. 6 indicates the presence of cleavage cracks parallel to one of the tetragonal prisms; and the horizontal crack in fig. 7 is due to a cleavage parallel to the base. The crystals are soft ($H. = 2\frac{1}{2} - 3$) and heavy (specific gravity 6.3); they are yellowish-white, yellow, brownish or greenish in colour, and possess a brilliant adamantine lustre. The refractive index is 2.1.

The crystals are found in cavities in decomposed galena (fig. 9), and the best specimens, including all of those here figured, are from the Monteponi lead mine near Iglesias in Sardinia. Fine crystals have also been found at Cromford near Matlock in Derbyshire, and near Dundas in Tasmania. Pseudomorphous crystals, altered to cerussite, occur in clay at Tarnowitz in Silesia.

The mineral has been found at but few localities and never in any abundance, so that it is of no importance as an ore of lead, but the fine crystals are treasured possessions in mineral collections.

Anglesite is sulphate of lead, and for this reason it is sometimes rather inappropriately known as lead-vitriol, the term vitriol being more usually applied to hydrated salts of sulphuric acid, such as iron-vitriol and copper-vitriol. The name anglesite is from the island of Anglesey, one of the localities of the mineral.

The crystals are rhombic and are crystallographically similar to crystals of barytes and celestite. The group of simple crystals, irregularly grown together, shown in fig. 12, plate 17, are bounded by only a rhombic prism and the base perpendicular thereto. The crystal in fig. 10 shows a vertical prism in combination with a horizontal prism or dome, whilst those in fig. 11 are bounded by a vertical prism and a pyramid.

When transparent, the crystals display a brilliant adamantine lustre; they may be colourless, yellowish or greenish. The mineral has the same hardness as calcite; and, like all lead minerals, it is very heavy (sp. gr. 6.3).

Anglesite occurs in cavities in galena, to the alteration of which mineral it owes its origin. It is probably not the result of atmospheric weathering and simple oxidation, but has no doubt been formed by the action of acid solutions on the galena.

The finest crystals are from the Monteponi lead mine near Iglesias in Sardinia (from whence come the specimens figured); good crystals have also been found in Derbyshire, at Beresovsk in the Urals, Nerchinsk in Siberia, Phoenixville in Pennsylvania, Broken Hill in New South Wales, and large crystals at Dundas in Tasmania.

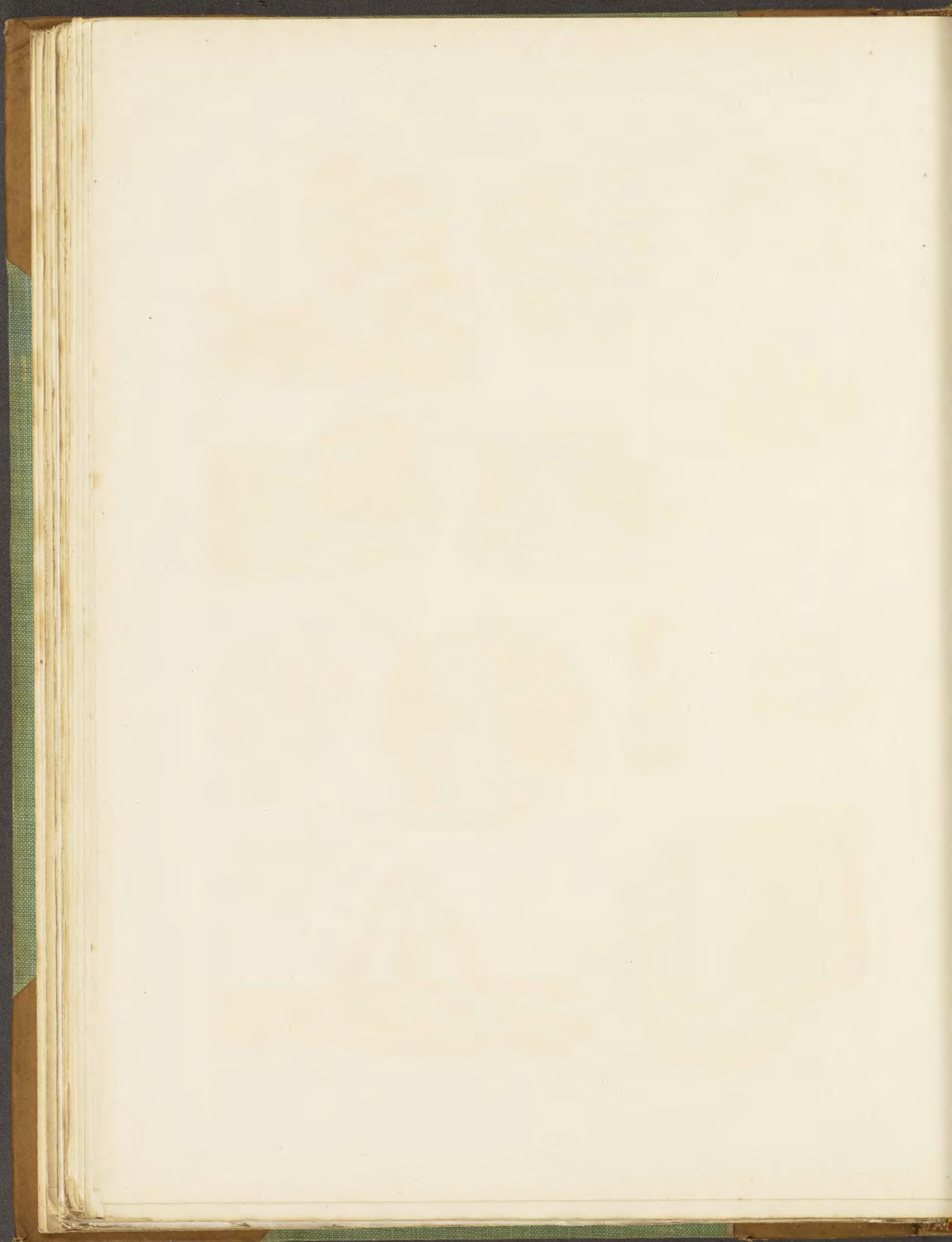


Lead Ores II.

Fig.

- 1 *a* and *b*. **Cerussite**, intercrossing twinned crystals of much the same form as in fig. 4.
Friedrichsseggen mine, Ems, Nassau.
2. **Cerussite**, intercrossing twinned crystals giving rise to a network of star-shaped groups.
Perm mine, Ibbenbühren, Westphalia.
3. **Cerussite**, bundles of acicular crystals on brown-iron-ore (limonite).
San Giovanni mine, Gonnesa, Iglesias, Sardinia.
4. **Cerussite**, tabular crystal: the large face to the front is the brachy-pinacoid, above are a brachy-dome and the basal plane, on the left the vertical prism and a pyramid.
Friedrichsseggen mine, Ems, Nassau.
5. **Phosgenite**, a large crystal; an eight-sided prism with basal plane and pyramid faces.
Monteponi lead mine, Iglesias, Sardinia.
6. **Phosgenite**, eight-sided prism with four-sided prism (a narrow face to the front) and basal plane.
Monteponi lead mine, Iglesias, Sardinia.
7. **Phosgenite**, eight-sided prism $\infty P 2$ with tetragonal prism of the first and second orders ∞P and $\infty P \infty$, eight-sided pyramid $2 P 2$, tetragonal pyramid of first order P , and base $0 P$.
Monteponi lead mine, Iglesias, Sardinia.
8. **Phosgenite**, eight-sided prism with four-sided prism (narrow plane on the left), pyramids, eight-sided pyramid and base.
Monteponi lead mine, Iglesias, Sardinia.
9. **Phosgenite**, crystals in granular galena.
Monteponi lead mine, Iglesias, Sardinia.
10. **Anglesite**, crystals (rhombic prism with dome) in granular galena.
Monteponi lead mine, Iglesias, Sardinia.
11. **Anglesite**, crystals (rhombic prism with pyramid) in granular galena.
Monteponi lead mine, Iglesias, Sardinia.
12. **Anglesite**, are irregular intergrowth of two crystals (rhombic prism with base).
Monteponi lead mine, Iglesias, Sardinia.
13. **Crocoite**, group of prismatic crystals.
Dundas, Tasmania.





Crocoite. The characteristic bright red colour of this mineral is due not to the metal (lead) that it contains, but to the acid radicle; the mineral is a chromate of lead, PbCrO_4 , and its colour is very similar to that of the well-known artificial salt potassium bichromate. Until a few years ago it was known only as small crystals, at the most a centimetre across, which though well suited for the purposes of crystallographic investigation are not sufficiently prominent to show well in illustrations. The group of large crystals represented in fig. 13, plate 17, show the striated prism faces, and the text-figure 123 shows the same prism faces (*m*) in combination with a steep pyramid (*t*) and a steep ortho-dome (*l*); from this figure it may readily be seen that the symmetry of the mineral is monoclinic.

The crystals possess about the same hardness as calcite, and their specific gravity is 6. The colour of the powder and of the streak is orange-yellow. The crystals are usually only translucent.

The presence of lead may be readily detected by heating the mineral before the blowpipe on charcoal with sodium carbonate; and the chromium produces an emerald-green colour in a bead of microscopic salt.

Crocoite has long been known from Beresovsk in the Ural Mountains, where it occurs with quartz and galena in veins of gold ore. It is a product of the alteration of galena, like the other rare lead minerals, such as melanochroite (a basic chromate of lead) with which it is associated. It is also found with gold ores at Congonhas do Campo in Brazil, at Labo on Luzon one of the Philippine Islands, and at Umtali in Rhodesia. The crystals represented in plate 17 are from Dundas in Tasmania, where recently have been found magnificent specimens far surpassing any previously known. The long and slender prismatic crystals from Tasmania are frequently hollow and are terminated by numerous small and brilliant faces.

Wulfenite is a salt of lead with the rarely occurring molybdic acid, being molybdate of lead, PbMoO_4 .

The crystals are tetragonal and are usually tabular parallel to the base, having the form of quite thin plates with a square outline. The single, fine crystal shown in fig. 12 of plate 18 is set up with the large basal plane to the front; the long narrow faces at the margins are those of a pyramid of the first order, and the small ones on the corners are those of a pyramid of the second order; the diagonal striations on the basal plane are due to oscillation with a very flat pyramid also of the second order. The crystals in fig. 10 are still thinner, while those in fig. 11 are rather thicker and show, in addition to the base, the faces of a square prism.

The small crystals shown on the matrix in fig. 14 are terminated at their upper end by an acute pyramid, whilst below they are terminated by the basal plane; the crystals are thus hemimorphic. Crystals of wulfenite sometimes show a pyramidal-hemihedral development, there being only four alternate faces of the rare eight-sided pyramid on the crystals; this, in addition to the hemimorphic character, indicates that the crystals are really tetartohedral.

As indicated by the name "yellow lead-ore", a common colour of the mineral is yellow (figs. 10 and 11), but, as may be seen from the brilliant red crystals in figs. 12 and 13 and the greyish crystals in fig. 14, this name is not always appropriate. The red colour is probably due to the presence of traces of chromium. Small crystals are often transparent, but larger ones are mostly only translucent; the lustre is adamantine to resinous, and often very brilliant. The hardness is 3, and the specific gravity 6.7—7.0.

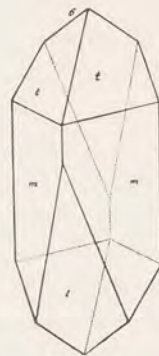


Fig. 123.
Crystal of Crocoite.

Wulfenite occurs as a mineral of secondary origin in deposits of lead ore, and is not very common. The earliest known locality is Bleiberg in Carinthia (figs. 10 and 11); the specimen shown in fig. 14 is from Prizibram in Bohemia. The finest crystals are from the Red Cloud mine and other mines in Yuma Co., Arizona; other American localities are in Utah and the Wheatley mine at Phoenixville, Pennsylvania.

Pyromorphite. On account of the different colours which this mineral assumes it is variously known as "variegated lead-ore", "brown lead-ore", or "green lead-ore". The name pyromorphite is derived from the Greek, and refers to the fact that a globule of the mineral formed by fusion is bounded by a number of minute facets, but a name given on these grounds is scarcely an appropriate one.

It may be readily seen from the figures on plate 18 that the mineral is hexagonal; the true symmetry is, however, pyramidal-hemihedral, like that of apatite, though this can only be determined by studying the form and orientation of artificially produced etching figures. The crystals are usually very simple in form, being bounded by only the hexagonal prism and the basal pinacoid, as shown in fig. 3, plate 18. Sharply-developed crystals are somewhat uncommon; the crystals are more usually of a barrel-like shape, being thicker across the middle portion of the prism than at the ends (fig. 1). This is due to a convex curvature of the prism faces; the basal planes are also often somewhat depressed. It is not often that the crystals are scattered singly over the matrix, as represented in figs. 3 and 4; more frequently they are thickly clustered together in groups (figs. 1 and 2). When pyramidal forms are present, they occur as narrow faces truncating the edges between the prism and the base (as shown for mimetite in figs. 7 and 8).

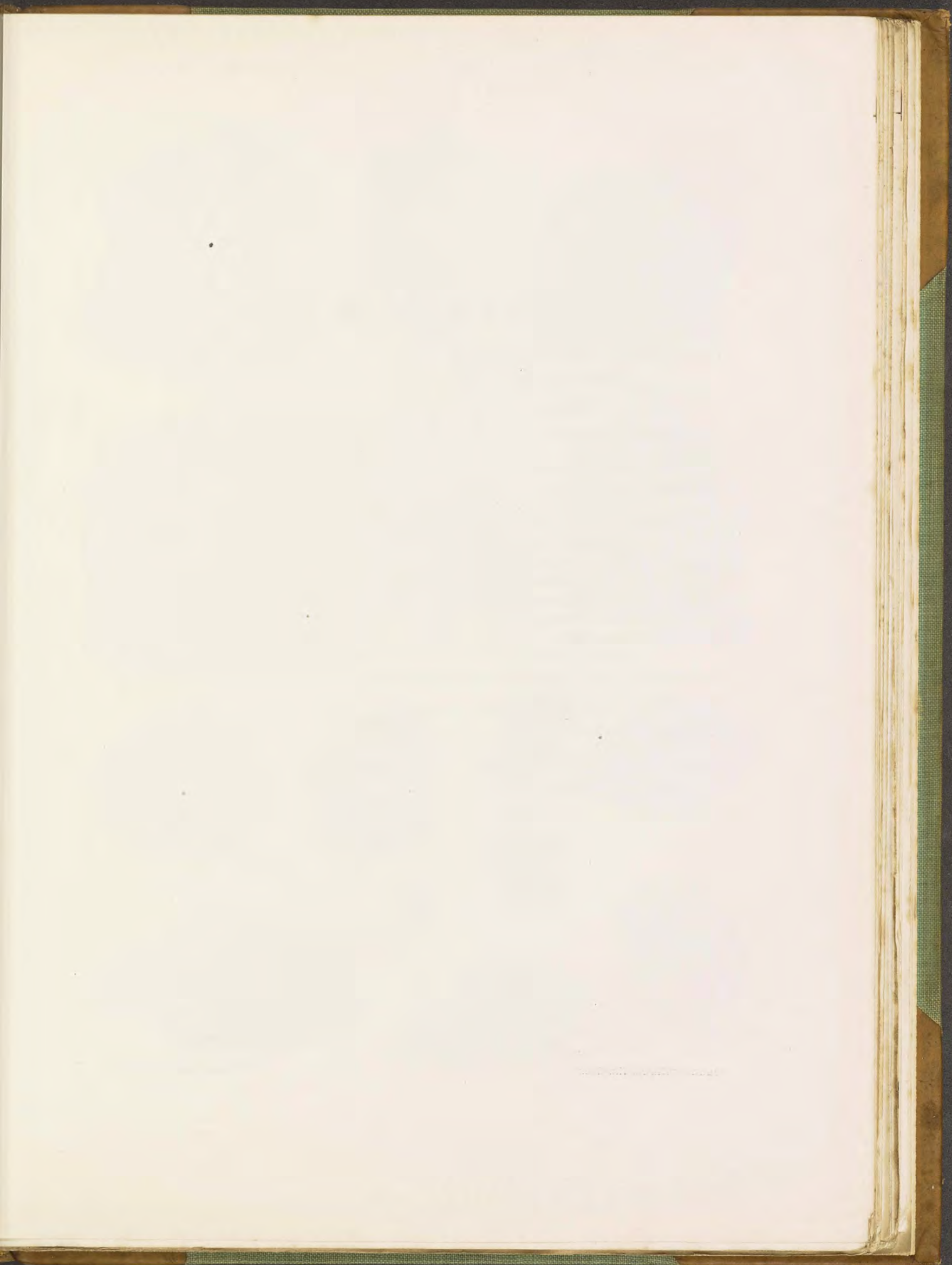
The crystals are at the most only translucent, and they sometimes display a brilliant resinous lustre. In colour they may be yellowish-green, reddish-brown, green, or, less often, a pronounced yellow. The hardness is $3\frac{1}{2}$ —4 and the specific gravity 7.

The mineral is a chloro-phosphate of lead with the formula $3\text{Pb}_3(\text{PO}_4)_2 \cdot \text{PbCl}_2$, corresponding with 45.73 per cent. of phosphous pentoxide, 2.62 per cent. of chlorine, the remainder being lead oxide and lead. Sometimes a small proportion of the phosphoric acid is replaced by arsenic acid, chlorine by fluorine, or lead by calcium, indicating the relation of the mineral to mimetite and to apatite; in fact, with an increase of arsenic acid and a corresponding decrease in the amount of phosphoric acid there may be in a series of specimens a gradual passage from pyromorphite to mimetite.

Pyromorphite has been formed in nature by the action on galena of solutions containing phosphoric acid and chlorine, these constituents having probably been derived from neighbouring deposits of apatite or phosphorite. Conversely, by the action of solutions containing hydrogen sulphide, pyromorphite may be converted back again into galena, and we then have pseudomorphs of galena after pyromorphite: in the specimen shown in fig. 5, plate 18, an alteration of this kind has commenced on the surface of the crystals.

The localities of pyromorphite are often those at which cerussite is found. Fine, large specimens are common from the Friedrichsseggen mine, near Ems in Nassau (fig. 1, 2 and 4, plate 18). In the year 1868 a crystallized mass measuring 4 metres in length, 3 metres in height and 1 metre in breadth was taken from this mine. The green crystals shown in fig. 3 are of an old occurrence at Prizibram in Bohemia. Zschopau in Saxony, Commern on the northern borders of the Eifel, and Hofgrund in Baden have also yielded green crystals. Small crystals have been found in the gold-veins at Beresovsk in the Urals, and at Phoenixville in Pennsylvania. Fine, yellow crystals have been found in Cornwall.

Pyromorphite sometimes occurs in sufficient abundance to be mined as an ore of lead.



Lead Ores III.

Fig.

1. **Pyromorphite**, barrel-shaped crystals.
Friedrichsseggen mine, Ems, Nassau.
2. **Pyromorphite**, aggregate of prismatic crystals.
Friedrichsseggen mine, Ems, Nassau.
3. **Pyromorphite**, sharply developed crystals bounded by a hexagonal prism and the basal pinacoid.
Przibram, Bohemia.
4. **Pyromorphite**, crystals on clay-slate.
Friedrichsseggen mine, Ems, Nassau.
5. **Pyromorphite**, partly altered to galena.
Kautenbach, Bernkastel, Rhenish Prussia.
6. **Mimetite**, hexagonal pyramid with base.
Johanngeorgenstadt, Saxony.
- 7, 8, 9. **Mimetite**, hexagonal prism with pyramid and base.
Johanngeorgenstadt, Saxony.
- 10, 11. **Wulfenite**, tabular crystals.
Bleiberg, Carinthia.
12. **Wulfenite**, tabular crystal with large basal plane and narrow pyramid faces of the first and second orders.
Red Cloud mine, Yuma Co., Arizona, U. S. A.
13. **Wulfenite**, tabular crystals on matrix.
Red Cloud mine, Yuma Co., Arizona, U. S. A.
14. **Wulfenite**, hemimorphic crystals, with pyramid faces at the upper end and the basal plane below.
Przibram, Bohemia.



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Mimetite, or mimetesite, is the corresponding arsenic compound to pyromorphite, being chloro-arsenate of lead, $3\text{Pb}_3(\text{AsO}_4)_2 \cdot \text{PbCl}_2$. The crystals are hexagonal and are almost always bounded by a hexagonal prism, the basal pinacoid and a pyramid, the faces of the pyramid truncating the edges between the prism and the base (figs. 7—9, plate 18). They may be tabular parallel to the base (fig. 6), or prismatic in habit (figs. 7—9). The colour is usually wax-yellow and the crystals only slightly transparent. The hardness is $3\frac{1}{2}$ —4, and the specific gravity 7.1—7.3.

The crystals occur singly or in groups attached to the matrix, and they are not common. The best crystals are those from Johanngeorgenstadt in Saxony, from whence came all the specimens represented in plate 18. Other localities are Badenweiler in the Black Forest, Przibram in Bohemia, and Phoenixville in Pennsylvania.

A variety of mimetite, known as *campylite*, contains a considerable amount of phosphoric acid, and forms barrel-shaped or globular crystals or warty aggregates of an orange-red or yellow colour. It was formerly abundant at Dry Gill near Caldbeck in Cumberland.

Mimetite is so rarely met with, and then in only small amounts, that it is of no importance as an ore of lead.

Extraction and Applications of lead. — The ore from which lead is extracted consists largely of galena; cerussite, anglesite and pyromorphite are of quite secondary importance as ores. The galena is first roasted to drive off the sulphur; the roasted product, consisting of lead oxide and lead sulphate, is then smelted with a fresh lot of unaltered galena, when the sulphur and oxygen of the two portions combine to form gaseous sulphur dioxide, leaving the lead behind as metal. The furnace must therefore be so constructed that air may be admitted or excluded at different stages of the process. The metallic lead so obtained contains silver and gold, if these were present in the ore. The purest lead is obtained by an electrolytic process.

Lead has been known from very early times. In the ruins of ancient Troy Schliemann found, amongst other objects, the image of a goddess cast in lead. Its numerous applications depend on its malleability, its chemical resistance to many agents, its easy fusibility (melting point 300° C.), and its heaviness. The poisonous nature of lead, and of its compounds, places, however, certain limitations on its application.

Leaden pipes have been extensively used in olden times, as well as at the present day, for conveying water; and the reason that they can be used for this purpose without any ill effects depends on the fact that substances in the water (carbonic and sulphuric acids) act on the lead and very soon cover and protect it with a thin coating of an insoluble compound, so that there is no further action on the inside of the pipe. In chemical works sheet lead is used for constructing the chambers in which sulphuric acid (oil of vitriol) is manufactured. Porous lead plates coated with lead peroxide are largely used in electrical accumulators. Various alloys of lead have important applications: shot is hardened by the admixture of about $\frac{1}{2}$ per cent. of arsenic, and type metal used in printing contains about 20 per cent. of antimony.

Numerous pigments contain lead as an important constituent, and, like all lead compounds, they are poisonous. White-lead is a mixture of various basic carbonates of lead, and is extensively used as an oil paint. Chrome-yellow is lead chromate; and this mixed with Prussian blue gives the so-called green cinnabar. Red-lead is the lead oxide Pb_3O_4 ; it is a brick-red powder, also known as minium or Paris red, and is much used as a paint and a cement. The yellow lead oxide PbO , litharge or massicot, is used in the glazing of pottery. Lead acetate, or sugar of lead, is used in dyeing and pharmacy.

The strong refrangibility for light possessed by all transparent lead compounds is likewise a characteristic of lead-bearing glass, which is therefore especially suited for the construction of lenses and for imitation gem-stones.

The principal lead-producing countries are the United States of North America, Spain and Germany. The production of the leading countries during the year 1900 is given in the following table. Since the profitable working of lead ores depends largely on the small amounts of silver which are invariably present, the fall in price of silver has caused the stoppage of lead mining operations in certain districts, for instance at Mechernich in the Eifel and in the Upper Harz.

Country.	Tons.	Country.	Tons.
<i>United States</i>	228 500	<i>Italy</i>	23 900
<i>Spain</i>	154 600	<i>France</i>	17 800
<i>Germany</i>	121 500	<i>Belgium</i>	17 500
<i>Mexico</i>	90 500	<i>Canada</i>	17 100
<i>Australia</i>	66 000	<i>Greece</i>	16 100
<i>Great Britain</i>	35 000	<i>Austria-Hungary</i>	13 000

Zinc Ores.

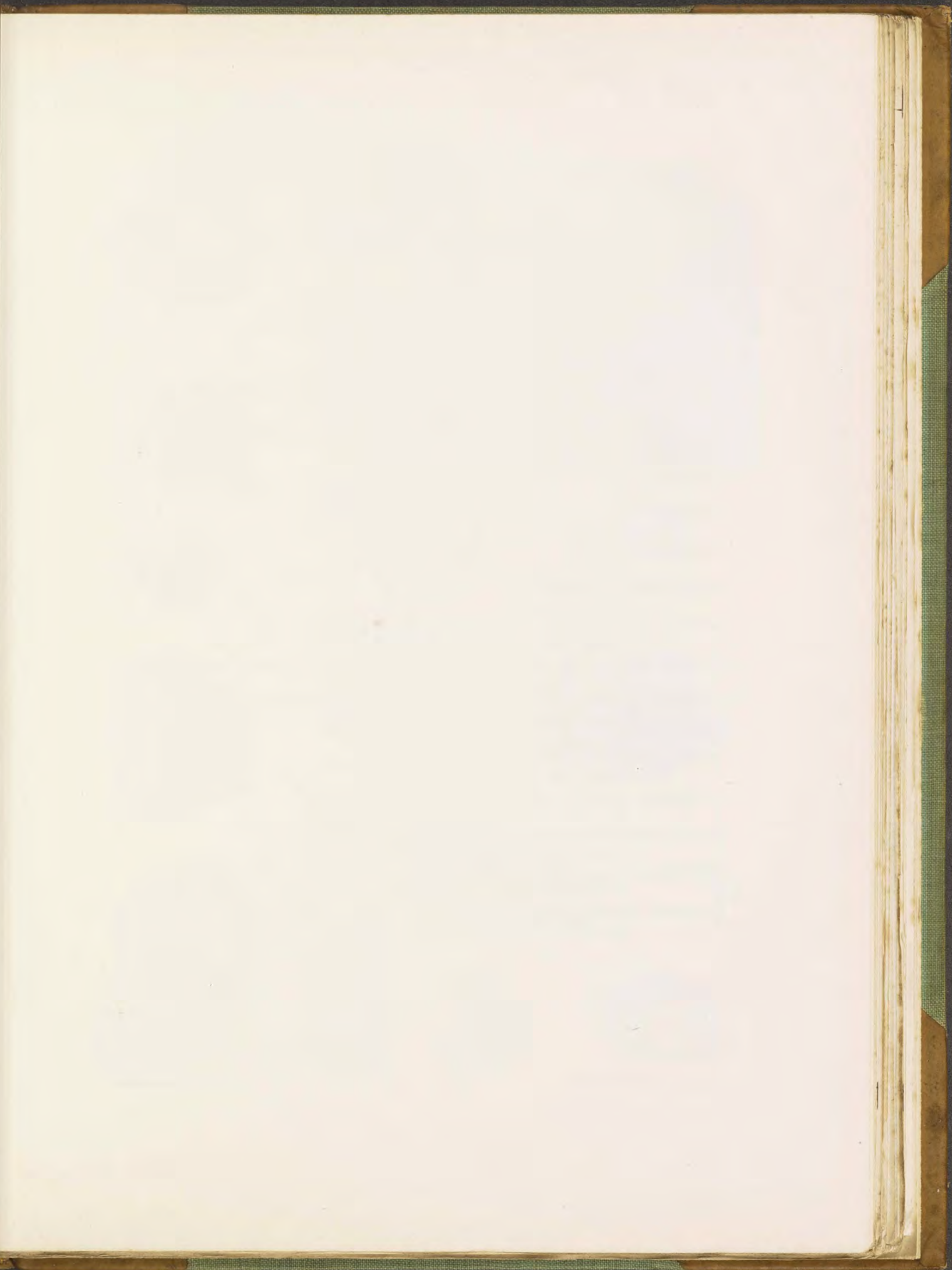
Zinc is not known to occur in nature in the native or metallic state; it is found in combination with sulphur as the simple sulphide, with oxygen as oxide and with acids as oxygen salts. A sulphur salt of zinc is unknown, though zinc is sometimes present in isomorphous mixture in fahlerz. The following are the more important compounds of zinc found as minerals: —

Zinc-blende, ZnS.	Hydrozincite, $\text{ZnCO}_3 \cdot 2\text{Zn(OH)}_2$.
Wurtzite, ZnS.	Willemite, Zn_2SiO_4 .
Zincite, ZnO.	Hemimorphite, $\text{H}_2\text{Zn}_2\text{SiO}_5$.
Zinc-spinel, $\text{ZnO} \cdot \text{Al}_2\text{O}_3$.	Adamite, $\text{Zn}_3(\text{AsO}_4)_2 \cdot \text{Zn(OH)}_2$.
Franklinite, $(\text{Fe, Zn, Mn})\text{O} \cdot (\text{Fe, Mn})_2\text{O}_3$.	Hopeite, $\text{Zn}_3(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$.
Calamine, ZnCO_3 .	Zinc-vitriol, $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$.

The chemical relation between zinc and some other elements is expressed in the isomorphous replacements which take place in some of these minerals: thus in zinc-blende, wurtzite and calamine some of the zinc may be replaced by iron; manganese, together with or without iron, may be present in zincite, zinc-spinel, franklinite and willemite; and cadmium is sometimes present in zinc-blende and calamine.

The species listed above will be described in turn below in more or less detail, with the exception of adamite, hopeite and zinc-vitriol, these being minerals of lesser importance.

Zinc-blende is also frequently known simply as blende, this being an old mining name of German origin, which, with some qualifying prefix, has been applied to a variety of minerals possessing a more or less metallic lustre combined with a certain degree of transparency. Another name, often applied to the mineral, is sphalerite, this being derived from the Greek and meaning the same as blende.



Various Minerals.

Fig.

1. **Zinc-blende**, large rhombic-dodecahedron.
Pitkäranta, Finland.
2. **Zinc-blende**, cube with tetrahedron. The cube faces are striated parallel to one only of the diagonals.
Schlaggenwald, Bohemia.
3. **Zinc-blende**, two tetrahedra with cube. The large tetrahedron faces are hummocky but bright, while those of the small tetrahedron are dull and rough.
Joplin, Jasper Co., Missouri, U. S. A.
4. **Zinc-blende**, tetrahedral crystal with twin-lamella; on crystalline dolomite.
Binnenthal, Wallis, Switzerland.
5. **Sulphur**, crystal on the end of a stalactite of calcite.
Sicily.
6. **Galena**, cubo-octahedron.
Locality unknown.
7. **Cerussite**, trilling.
Friedrichsseggen mine, Ems, Nassau.
8. **Cassiterite**, knee-shaped twin.
Locality unknown.
9. **Rutile**, acicular crystals intergrown in twinned position.
Medels Pass, Switzerland.
10. **Rutile**, similar to the last; the crystals are closer together, forming a net-like structure.
Medels Pass, Switzerland.
11. **Haematite** coated with rutile; the rutile-needles are definitely orientated in three directions on the haematite.
Binnenthal, Wallis, Switzerland.
12. **Haematite** coated with rutile; with magnetite.
Binnenthal, Wallis, Switzerland.
13. **Brookite**, altered to rutile. A paramorph.
Magnet Cove, Arkansas, U. S. A.
14. **Alexandrite**, the same crystal as represented on plate 45, fig. 7.
Takovaya, Ekaterinburg, Ural Mountains.
15. **Euclase**, the same crystal as represented on plate 45, fig. 12.
Sanarka, Orenburg, Ural Mountains.
16. **Euclase**, the same crystal as represented on plate 45, fig. 13.
Boa Vista, Ouro Preto, Brazil.



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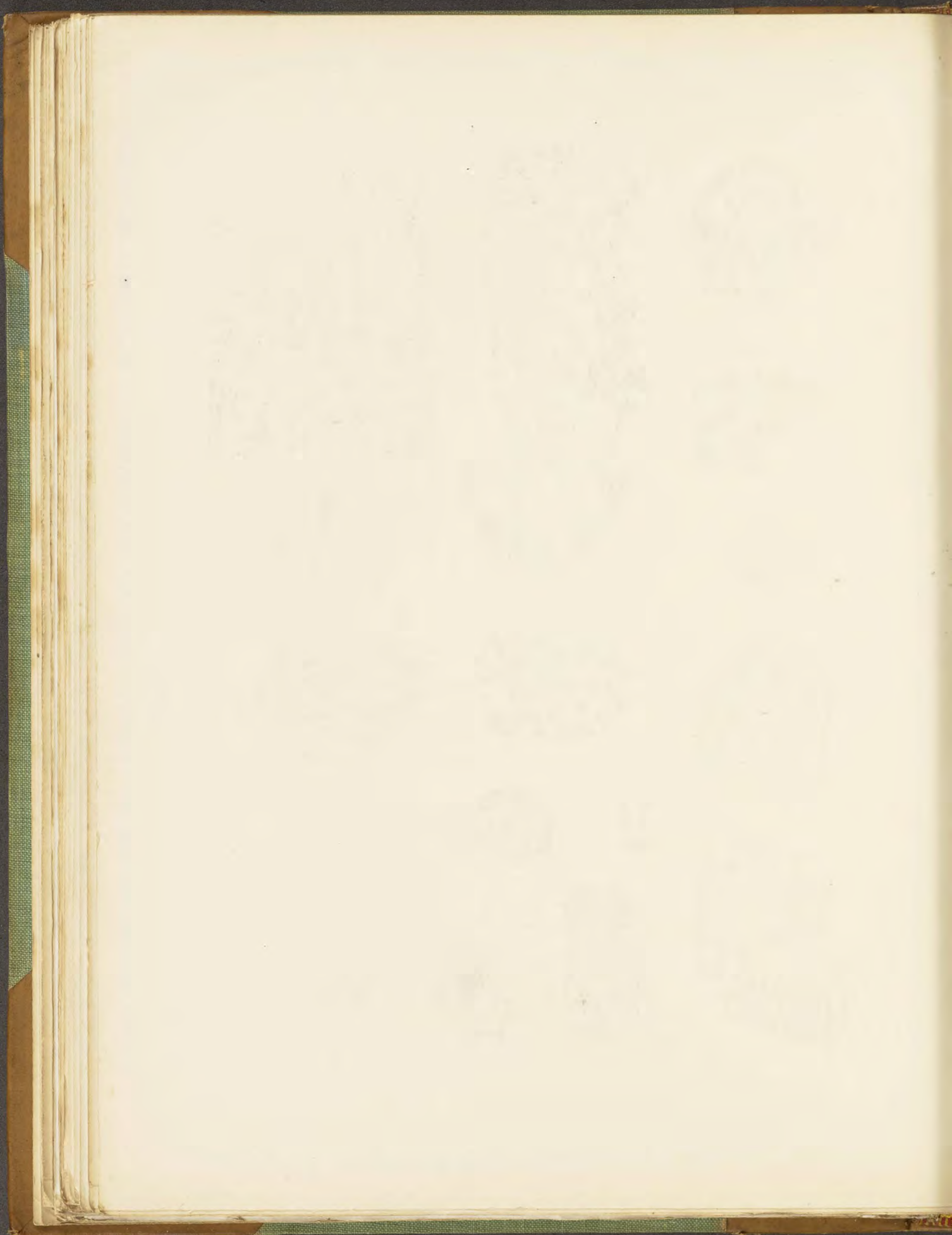
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13



Crystals of zinc-blende are usually very indistinctly developed, and crystals on which the form can be readily made out are only rarely met with. Their symmetry is tetrahedral-cubic, but sometimes the crystals present quite a holohedral appearance and the hemihedral character is then only to be made out on a critical examination. For instance, the crystals represented in figs. 1 and 2 of plate 20 are apparently combinations of the octahedron and the cube. On the crystal shown in fig. 2 all the faces of the apparent octahedron are equally bright and no difference can be detected between them (the darker face to the right as seen in the picture being in the shade). In the crystal shown in fig. 1, on the other hand, the faces of the apparent octahedron are readily seen to differ in their surface character; one set of faces (a face on the right) are bright and hummocky, whilst those of the other set (one face on the left) are dull and rough; this difference is better shown in fig. 3, plate 19, which gives another view of the same crystal. The same is shown diagrammatically in text-figure 124, where it is manifest that the apparent octahedron is really a combination of two tetrahedra.

In fig. 3, plate 20, the tetrahedral development is rendered more evident by the difference in size of the faces, those of one tetrahedron being large and those of the other tetrahedron quite small. The edges of the predominating tetrahedron are truncated by narrow faces of the cube, and on the left a twin lamella is plainly to be seen.

The tetrahedral symmetry is also clearly shown in the crystal represented in fig. 4: only one tetrahedron is here present truncating alternate corners of the cube; and the faces of the cube are striated parallel to only one of their diagonals, whereas in a holohedral crystal the striations would be parallel to both diagonals. The two crystals just described are exceptionally perfect for zinc-blende; they are represented again on plate 19 in figs. 4 and 2 respectively.

In addition to crystals with an octahedral or a tetrahedral habit we may also have crystals in which the habit is dodecahedral: the large crystal shown in fig. 1, plate 19, is bounded by faces of the rhombic-dodecahedron alone. In fig. 10, plate 19, the largest faces are those of the rhombic-dodecahedron, and the faces with the outline of an equilateral triangle belong to the tetrahedron; in addition to these there are other faces with the form of isosceles triangles, which belong to the triakis-tetrahedron with the symbol $\frac{3O3}{2}$. On the specimen represented in this figure the transparent, yellowish-brown crystals of zinc-blende are associated with opaque, grey crystals of tetrahedrite, which possess the same degree of symmetry as the zinc-blende.

Twinning is frequent in crystals of zinc-blende, the twin-plane being a face of the tetrahedron, but the appearance of the twinned crystals differs according to their habit. A simple form of twinned crystal is shown in fig. 5, plate 20; the crystal in the lower part of the figure is octahedral in habit and the twin resembles the well-known twins of spinel and magnetite (fig. 9, plate 29). A repetition of the twinning is shown in the crystals in figs. 3, 6, 7 and 8, plate 20. The crystal in fig. 3 (see also fig. 4, plate 19) shows a thin twin lamella parallel to the large tetrahedron face to the left: in fig. 6 two crystals, each bounded by the cube and the tetrahedron, are grown together; and in fig. 7 three individuals are united together in twinned position. The crystal in fig. 8 is octahedral in habit, the two tetrahedra being of equal size, and the corners and edges are truncated by small faces of the cube and the rhombic-dodecahedron respectively;



Fig. 124.
Crystal of Zinc-blende.
(After G. Tschermak.)

the narrow dodecahedral face reflecting light at the top of the figure shows a zig-zag course across the three portions of the twin and falls in the same plane on all of them.

The colour of zinc-blende is usually brown to black (figs. 1—9, plate 20), yellowish, brownish-yellow (Fig. 10), red (fig. 12), sometimes oil-green; only exceptionally is the mineral colourless or faintly yellow. Sometimes the crystals are perfectly transparent, and they then exhibit a brilliant adamantine lustre; more often, however, they are translucent to opaque, when the lustre is more metallic in character. The streak is brown to white, depending on the depth of colour of the crystals. Sometimes the crystals are covered with a thin coating of copper-pyrites (fig. 11).

The mineral is brittle and cleaves with great ease in six directions parallel to the faces of the rhombic-dodecahedron. Fig. 9 represents the cleavage form of zinc-blende bounded by the twelve faces of the rhombic-dodecahedron. The hardness is $3\frac{1}{2}$ —4, and the specific gravity about 4. Many specimens of massive zinc-blende exhibit the phenomenon of phosphorescence; that is, they show sparks or streaks of light when scratched or when two pieces are rubbed together in the dark.

When pure, zinc-blende contains 67 per cent. of zinc and 33 per cent. of sulphur, the chemical formula being ZnS ; usually, however, a small proportion of zinc is replaced by a corresponding amount of iron (as FeS), and to this constituent the usual yellow or brown colour of the mineral is due. Small amounts of the rarer elements cadmium, indium and gallium are also sometimes present. Gallium is the only metal besides mercury which may be liquid at the ordinary temperature; it melts at $30^{\circ}C.$, but if kept from contact with the solid metal the liquid may be cooled down to the ordinary temperature before it solidifies.

Zinc-blende also frequently occurs in compact and granular masses intermixed with quartz, copper-pyrites and galena. Sometimes it takes the form of botryoidal or reniform aggregates (fig. 13) and it is often difficult to determine whether these belong to the cubic mineral zinc-blende or to the hexagonal mineral wurtzite.

When subjected to weathering, zinc-blende passes into zinc-vitriol. Like galena, zinc-blende occurs in mineral-veins and in beds, and the two minerals are frequently found together. Some of the more noteworthy localities are: in beds at Rammelsberg near Goslar in the Harz, and in veins at Clausthal, Andreasberg, and Neudorf in the Harz. In beds in the Middle Devonian limestone of Brilon in Westphalia; and in veins in the slates of the Rhenish district, for instance, in the Berghäuschen mine near Laasphe (fig. 11). In veins at Freiberg in Saxony, Schlaggenwald in Bohemia (fig. 4), Kapnik (fig. 10) and Schemnitz in Hungary, and Rodna in Transylvania (fig. 5). In beds in the lower Muschelkalk of Beuthen in Prussian Silesia, which here attain the unusual thickness of 12 metres. Beautiful, transparent crystals occur singly in the white saccharoidal dolomite of the Binnenthal in Canton Wallis, Switzerland (figs. 3, 6 and 7); and fine crystals are met with in the lead mine of Bottino near Serravezza in Tuscany, and in the tin mines at St. Agnes in Cornwall. The zinc mines of Derbyshire, the North of England, Wales and the Isle of Man also yield crystals of zinc-blende. Very large, transparent cleavage masses of a pale yellow or yellowish-brown colour are well known from the zinc mines at Picos de Europa in Santander, Spain. The crystal shown in fig. 1 is from Joplin in Missouri, and from the same locality comes the red blende of fig. 12; here the mineral occurs with galena (fig. 2, plate 16) in very large quantities, the production of zinc ore in the state of Missouri amounting to 211,000 tons in the year 1898.

Zinc-blende is smelted for zinc, and the sulphur it contains is sometimes saved for the manufacture of sulphuric acid.

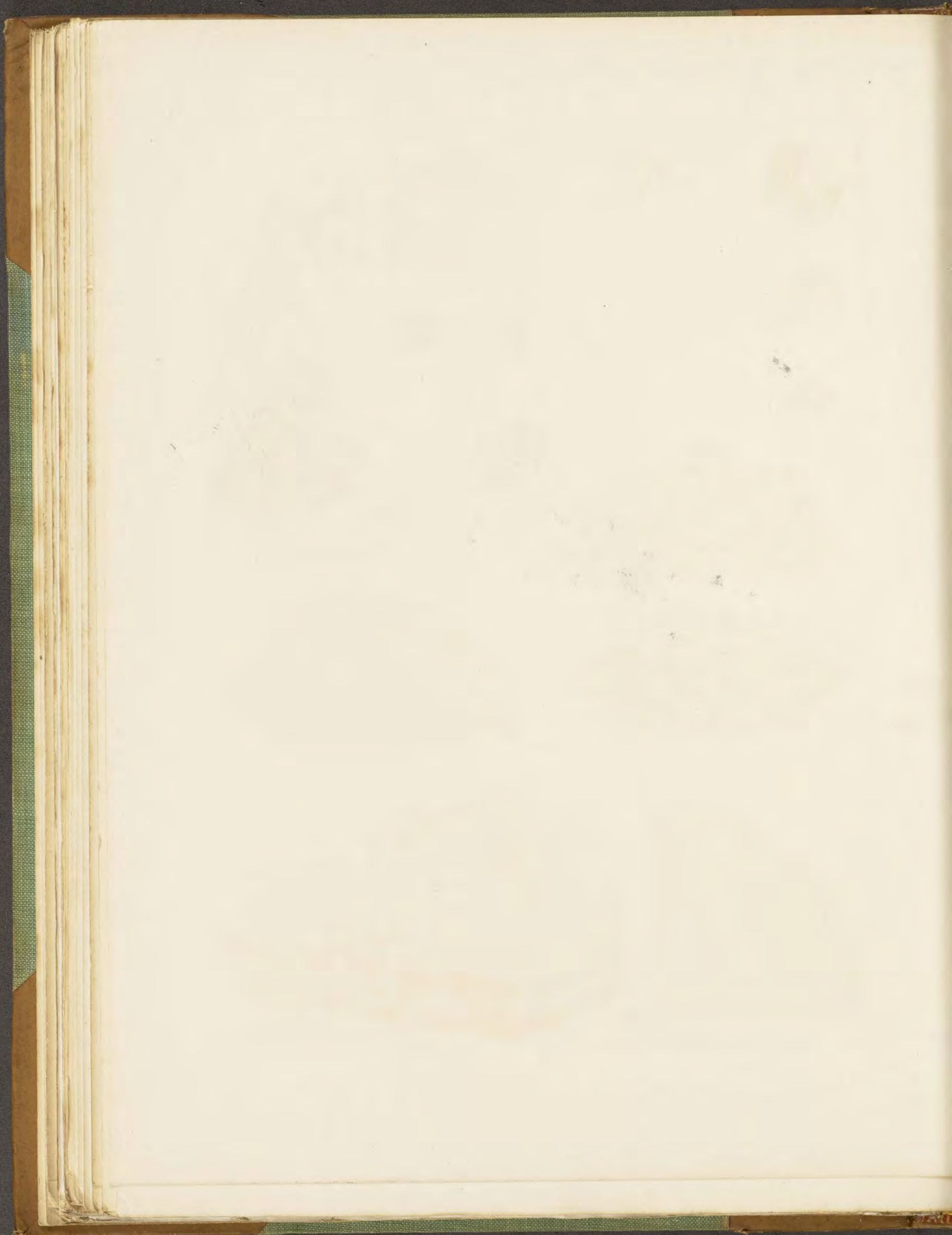


Zinc Ores I.

Fig.

1. **Zinc-blende**, the tetrahedron face to the right is bright and hummocky, that on the left is dull and rough; the cube face to the front is not square in outline, owing to irregularity in the development of the crystal.
Joplin, Jasper Co., Missouri, U. S. A.
2. **Zinc-blende**, black; the two tetrahedra together form the octahedron, the corners of which are truncated by the cube.
Lake City, Colorado, U. S. A.
3. **Zinc-blende**, on crystalline dolomite; the two tetrahedra with cube. Twin-lamellae parallel to the large tetrahedron face to the left.
Binnenthal, Wallis, Switzerland.
4. **Zinc-blende**, cube with a tetrahedron. The cube faces are striated parallel to only one diagonal, in accordance with the tetrahedral symmetry of the crystal.
Schlaggenwald, Bohemia.
5. **Zinc-blende**, black, with crystals of galena. The lower crystal is twinned on a tetrahedron face, and the faces of the two tetrahedra are developed to the same extent. The crystals of galena are bounded by the cube and the octahedron.
Rodna, Transylvania.
6. **Zinc-blende**, repeatedly twinned. The forms are the same as in fig. 3. The white patch on the lower part is dolomite.
Binnenthal, Wallis, Switzerland.
7. **Zinc-blende**, three tetrahedra in twinned position.
Binnenthal, Wallis, Switzerland.
8. **Zinc-blende**, black. A twinned crystal bounded by both tetrahedra (of equal size), the cube and the rhombic-dodecahedron. Rhombic-dodecahedral faces on the two individuals fall in the same plane.
Bottino lead mine, Serravezza, Tuscany.
9. **Zinc-blende**, rhombic-dodecahedral cleavage-form.
10. **Zinc-blende**, brownish-yellow crystals $\left(\infty O, \frac{3O3}{2}, \frac{O}{2}\right)$ with tetrahedrite.
Kapnik, Hungary.
11. **Zinc-blende**, the two tetrahedra are of nearly equal size. The crystal is thinly coated with copper-pyrites and on the front edge a little quartz is attached. Above is galena showing the cubic cleavage.
Berghäuschen, Laasphe, Prussia.
12. **Zinc-blende**, brownish-red crystal with rounded faces.
Joplin, Jasper Co., Missouri, U. S. A.
13. **Zinc-blende**, botryoidal.
Redruth, Cornwall.
14. **Wurtzite**, radiated.
Przibram, Bohemia.
15. "**Schalenblende**", polished; with bands of galena.
Schmalgraf mine, Aachen, Rhenish Prussia.





Wurtzite has the same chemical composition (ZnS) as zinc-blende, but it crystallizes in the hexagonal system instead of in the cubic. Distinctly developed crystals are, however, of very rare occurrence, and the mineral is usually found as fibrous to compact aggregates. For this reason the two minerals are not always easily distinguished, except by an examination in the polariscope, when it will be seen that zinc-blende is singly refracting and wurtzite doubly refracting. By this means it will be found that the more compact masses consist of a mixture of zinc-blende and wurtzite, while the more coarsely fibrous masses consist of wurtzite alone.

A small specimen of typical wurtzite with a coarsely fibrous and radiated structure, and a brown colour and almost metallic lustre, is represented in fig. 14, plate 20. Material of this kind is found at Przibram in Bohemia, and is sometimes known as "Strahlenblende" (radiated blende).

Compact masses consisting of concentric layers of zinc-blende and wurtzite intermixed are known as "Schalenblende" (shelly blende). The concentric shelly structure with alternate bands of lighter and darker material is here (fig. 15, plate 20) very similar to that of malachite and agate. "Schalenblende" occurs in beds of zinc ore in the neighbourhood of Aachen and at Scharley in Prussian Silesia. The specimen represented in fig. 15 shows two bands of galena, and is from the Schmalgraf mine near Aachen.

Wurtzite is used for the same purposes as zinc-blende, but being of less frequent occurrence it is of little importance from a commercial point of view.

Zinc-blende and wurtzite are dimorphous forms of zinc sulphide, and isomorphous with each of them are various other minerals, the more important of which are given in the following isodimorphous group: —

<i>Cubic.</i>	<i>Hexagonal.</i>	
Zinc-blende, ZnS .	Wurtzite, ZnS .	Millerite, NiS .
Alabandite, MnS .	Greenockite, CdS .	Niccolite, $NiAs$.

Zincite, or red zinc-ore, is known to occur only in the neighbourhood of Franklin Furnace and Sterling Hill in New Jersey, U. S. A., but it is there found in considerable quantity. Crystals, which belong to the hexagonal system, are extremely rare, the mineral forming granular and lamellar masses (figs. 1 and 3, plate 21) with a perfect cleavage in one direction. Since pure zinc oxide (ZnO) is colourless, the characteristic red colour of the natural mineral is probably due to the manganese oxide which it invariably contains; the streak is orange-yellow. The hardness is a little over 4, and the specific gravity 5.6. The mineral occurs in association with franklinite and willemite in a crystalline limestone.

Franklinite, an associate of zincite, belongs to the spinel group of minerals, which crystallize in the cubic system, and is closely allied to zinc-spinel and magnetite. Like the other ores of zinc with which it occurs in association, franklinite contains in addition to zinc variable amounts of manganese and iron, and its chemical formula is of the spinel type, namely $(Zn, Fe, Mn)O \cdot (Fe, Mn)_2O_3$. The hardness is about 6, and the specific gravity 5. Crystals are common, and have the form of regular octahedra (figs. 2 and 3, plate 21) with their edges rounded or truncated by the rhombic-dodecahedron. They occur embedded in calcite or in zincite, and are from the district mentioned above for the latter mineral. The common zinc ore at this locality consists of a granular mixture of franklinite, willemite and zincite, with or without calcite.

Zinc-spinel, or gahnite, also belongs, as the name implies, to the spinel group of minerals. Ordinary spinel has the chemical formula $MgO \cdot Al_2O_3$, and in zinc-spinel zinc oxide takes the place of magnesia, so that the formula becomes $ZnO \cdot Al_2O_3$. This

formula corresponds with a theoretical percentage of zinc amounting to 32, but usually this is partly replaced by small, equivalent amounts of iron, magnesium and manganese.

The crystals have the form of the regular octahedron (fig. 4, plate 21), and are sometimes twinned on an octahedral face according to the spinel law (fig. 5). They are greyish-black in colour, and occur embedded in talc-schist at Fahlun in Sweden. In external appearance the crystals closely resemble magnetite, but they may be readily distinguished from this by the fact that they are not magnetic.

As an ore of zinc this mineral is of little importance, but it is of interest from the fact that it is produced artificially in large amounts in the muffles of zinc furnaces. The zinc combines with the alumina of the muffles, and as it cannot be again readily extracted from the compound so formed there is a waste of the material. Further reference will be made to this point when we come to the smelting and applications of zinc.

Calamine is next to zinc-blende the most important ore of zinc, but owing to its inconspicuous appearance it is not a mineral to be readily recognized at sight. Crystals are not common, and are usually quite small and roughly developed; they have the form of rhombohedra, resembling those of chalybite, but are often indistinct and intimately grown together to form crusts. As a rule, however, crystals are not to be seen and the mineral often forms earthy or granular masses, which are usually coloured dark brown by intermixed brown-iron-ore (limonite). Cavities in such masses often present botryoidal, reniform or stalactitic forms on their surfaces (plate 21, fig. 6). When pure, the mineral is white, but more often it is brown or yellowish, or sometimes greenish. The hardness is about 5, and the specific gravity 4.5.

Calamine is a compound of zinc with carbonic acid, that is, carbonate of zinc, $ZnCO_3$; and it is consequently soluble with effervescence in hydrochloric acid. Before the blowpipe on charcoal, the powdered mineral gives a sublimate which is yellow when hot and white when cold. Some calamines contain a small amount of cadmium carbonate, that from Wiesloch in Baden, which is bright yellow in colour, as much as 3 per cent.

The name calamine is often also applied to the hydrous zinc silicate hemimorphite, since these two minerals when in the massive state so closely resemble one another that they cannot be distinguished at sight; and further they frequently occur together under the same conditions. Calamine is usually found in connection with limestone rocks, and owes its origin to chemical processes of a special kind. The weathering of zinc-blende gives rise to sulphate of zinc (zinc-vitriol), a salt readily soluble in water; and when solutions of this salt percolate through the crevices of limestones the zinc is deposited as carbonate and an equivalent amount of calcium is carried away in solution. By such a process — known as a metasomatic process — the limestone may be gradually and completely replaced by calamine. The pseudomorphs of calamine after crystals of calcite mentioned above (p. 50) have been formed in the same manner.

The largest deposits of calamine are those mined at Beuthen in Prussian Silesia, where it occurs as beds in the limestones of the lower Muschelkalk. In the lower levels the ore consists of zinc-blende and "Schalenblende" always in association with marcasite, and forms in the Bleischarley mine beds reaching 12 metres in thickness. Nearer the surface the place of the blende is taken by earthy calamine and hemimorphite; these having clearly been formed by the action of the weathering products of the zinc-blende on the limestones. At the same time the marcasite has been altered to brown-iron-ore (limonite), which being intimately mixed with the calamine imparts to it a brown colour. The production of zinc ores in the mining district of Breslau for the year 1898 amounted



PLATE 21.

Zinc Ores II.

Fig.

1. **Zincite**, massive.
Sterling Hill, near Ogdensburg, New Jersey, U. S. A.
2. **Franklinite**, octahedron with edges slightly rounded, on calcite.
Sterling Hill, New Jersey, U. S. A.
3. **Franklinite**, with zincite in calcite.
Sterling Hill, New Jersey, U. S. A.
4. **Zinc-spinel** (Gahnite), octahedron in talc-schist.
Fahlun, Sweden.
5. **Zinc-spinel** (Gahnite), twinned octahedron in talc-schist.
Fahlun, Sweden.
6. **Calamine** (zinc carbonate), mamillated.
Brilon, Westphalia.
7. **Willemite** ("Troostite"), in calcite.
Sterling Hill, New Jersey, U. S. A.
8. **Hemimorphite**, with concentric fibrous structure.
Sa Duchessa mine, Iglesias, Sardinia.
9. **Hydrozincite**.
Province Santander, Spain.



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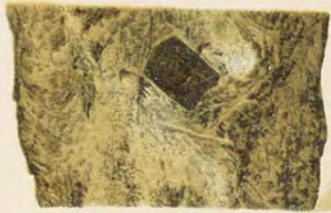
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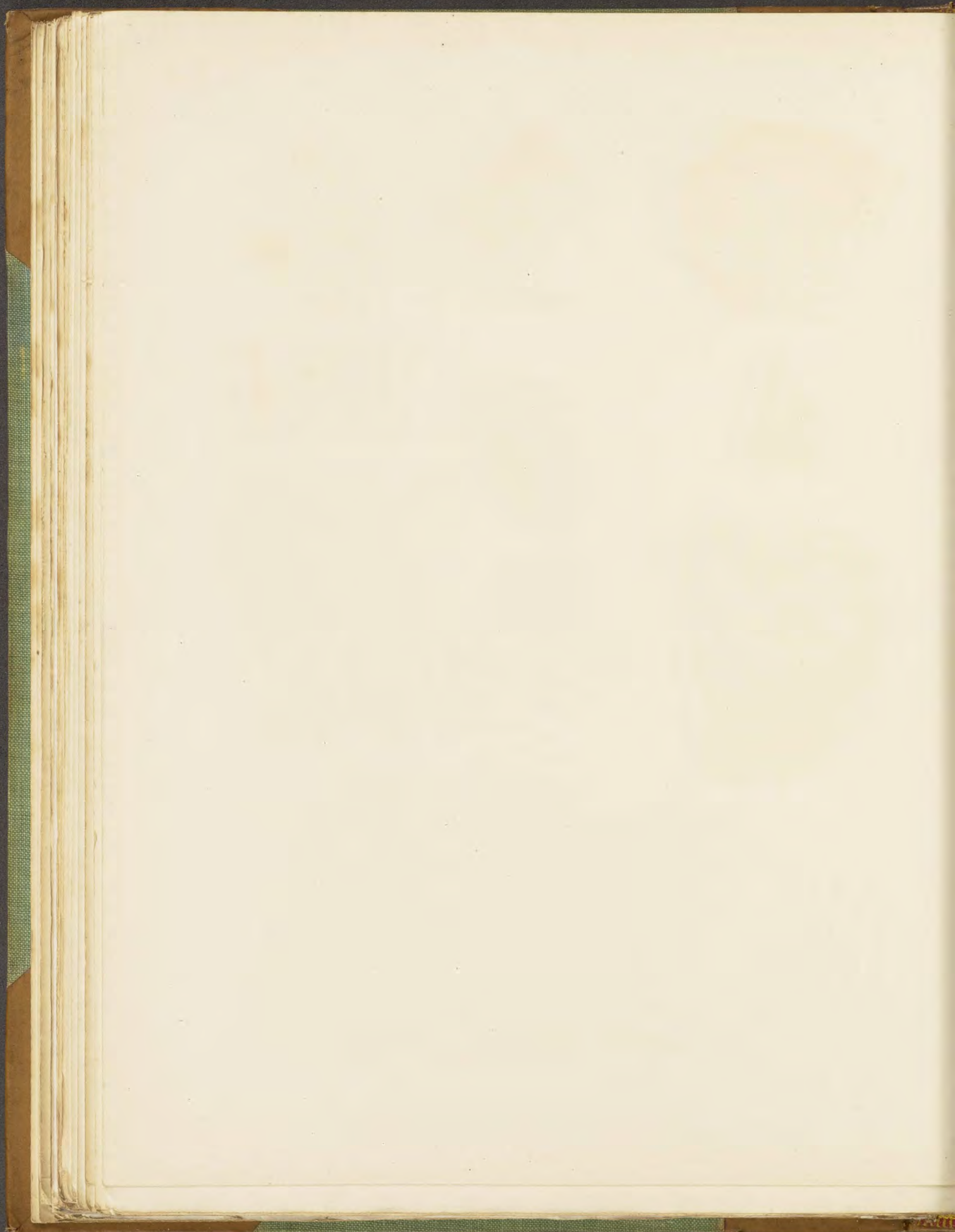
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9



to 522,839 tons, of which 58 per cent. was blende and the remainder calamine and hemimorphite.

Similar deposits occur at Altenberg near Aachen, at Bleiberg and Raibl in Carinthia, Wiesloch in Baden, Iserlohn and Brilon in Westphalia (plate 21, fig. 6), Laurion in Greece, Picos de Europa in Spain, and at several other localities; but never at places where the beds or veins of zinc-blende are unaccompanied by limestones.

Hydrozincite is, like calamine, an alteration product of zinc ores. In addition to the constituents of calamine, it contains some water, being a basic carbonate of zinc with the formula $ZnCO_3 \cdot 2Zn(OH)_2$. It usually takes the form of sinter-like masses (plate 21, fig. 9), or it may have a shelly concentric structure with a stalactitic or botryoidal surface; its colour is white or pale yellowish. It is found in the upper portions of calamine deposits, but is of little importance as an ore of zinc. The best known localities for the mineral are Cumillas and Udias in the province of Santander in Spain.

Willemite is a silicate of zinc, Zn_2SiO_4 , containing 73 per cent. of zinc oxide ($58\frac{1}{2}$ per cent. of zinc). Sometimes a portion of the zinc is isomorphously replaced by an equivalent amount of manganese; the variety called troostite from the zinc mines in New Jersey containing 53—68 per cent. of zinc oxide together with 4 to 12 per cent. of manganous oxide.

The original willemite, in which no manganese is present, has the form of very small, yellow to brown, glassy crystals, which with a lens may be seen to be combinations of a hexagonal prism with a rhombohedron. It was found in the now exhausted zinc mine of Altenberg or Vieille Montagne in the neutral territory of Moresnet, between Liège and Aachen.

The troostite variety, which was at first believed to be a distinct mineral species, is found as much larger crystals (plate 21, fig. 7), which are also bounded by a hexagonal prism and a rhombohedron; the edges of these crystals are usually more or less rounded. It also forms granular masses intermixed with zincite and franklinite. Troostite is from the neighbouring localities of Franklin Furnace and Sterling Hill in New Jersey.

Hemimorphite is also a silicate of zinc, but it contains also the elements of water. This water is not water of crystallization, but water of constitution, and it is expelled only when the mineral is heated to a high temperature. The formula $H_2Zn_2SiO_5$ represents an acid salt. When pure, the mineral contains 54 per cent. of zinc.

The mineral often occurs crystallized, but the crystals are small, at the most 1 cm. long and 2—3 mm. thick, and quite unsuited for representing in a picture drawn true to nature. The form of the rhombic crystals is, however, shown in the accompanying text-fig. 125; this is bounded by the brachy-pinacoid *b*, the vertical prism *g*, and at the upper end by the base *c*, and two macro-domes *o* and *p*, while the lower end is formed by the pyramid *s*. The two ends of the crystal are therefore differently developed and the crystal is said to be hemimorphic (compare p. 35). For this reason the name hemimorphite was applied to the mineral.

This hemimorphic development of the crystals is, however, not often very conspicuous, for they usually grow attached to the matrix at their lower end, and then only the base and the dome faces are present. But when such a crystal is subjected to changes of temperature it develops different charges of electricity at its two ends whether crystal faces are present or not. This pyro-electric character, which is peculiar to hemimorphic crystals (those of tourmaline also), may be most conveniently detected in the following manner. A crystal is heated to about 100° C. in an oven and then allowed to cool slowly; during the cooling it is dusted over with a mixture of flowers of sulphur and red lead

through the meshes of a fine sieve; the negative sulphur is attracted to the positively charged lower end of the crystal, and the positive red lead to the negatively charged upper end, and the two ends become respectively yellow and red.

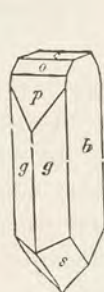


Fig. 125.
Crystal of
Hemimorphite.

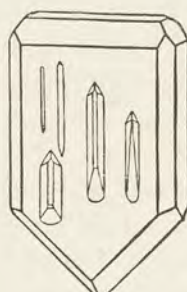


Fig. 126.
Crystal of Hemimorphite
with etching figures.
(After Tschermak).

The etching figures (fig. 126) produced on the broad pinacoidal face when a crystal is immersed in dilute acid also show the hemimorphism. The shallow pits so produced are only of microscopic dimensions, but they are easily seen to be differently shaped at their two ends. The hemimorphic character of the crystals is thus dependent on the internal structure of the crystalline material, and when crystal faces are present they are merely an external expression of this structure.

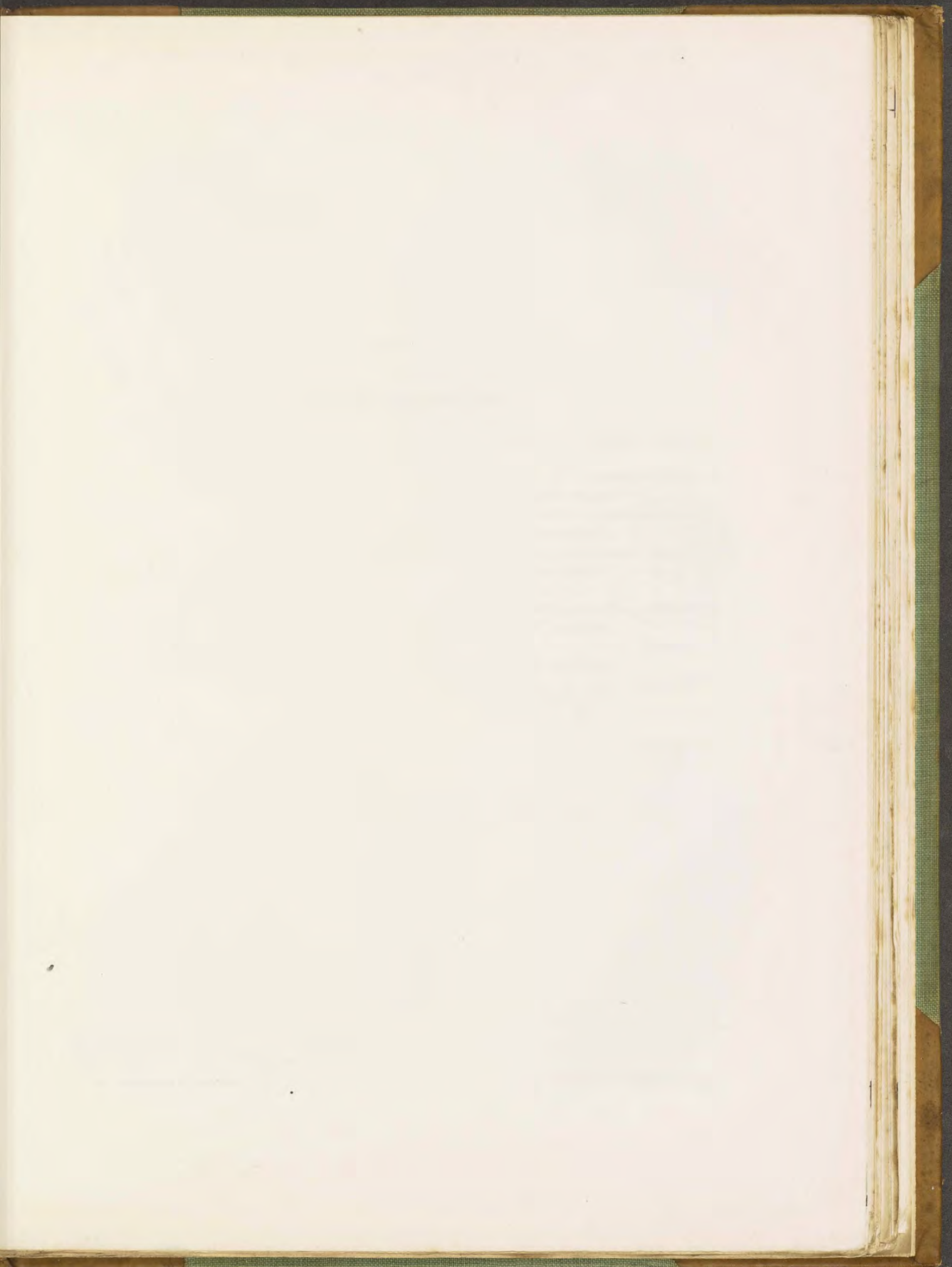
Crystals of hemimorphite are usually colourless or faintly yellowish and are transparent with a vitreous lustre. They occur attached by their ends to the walls of crevices and cavities in

the massive zinc ore or they are aggregated in brush- or fan-shaped groups forming a crust over the whole surface. When massive, the mineral may be granular, or present a fibrous and shelly concentric structure (plate 21, fig. 8). The massive ore is yellowish, brownish or sometimes green or blue (due to the presence of a little copper). The hardness is about 5, and the specific gravity 3.5. When the powdered mineral is warmed with an acid it is readily decomposed with the separation of gelatinous silica.

Extraction of zinc from its ores. — Zinc melts at 420° C. and volatilizes at 950° C.; it cannot therefore be extracted from the ore as molten metal, and it is consequently obtained by distillation after the manner of flowers of sulphur. The ore must first of all be converted into zinc oxide. This can be readily done when the ore is calamine, for when it is heated the carbon dioxide is expelled leaving zinc oxide. With zinc-blende, however, the operation is more difficult, for this mineral is readily converted by oxidation to zinc vitriol, and this is to be avoided; the ore has here to be roasted in specially constructed ovens and the sulphur converted into sulphur dioxide, which is allowed to escape from high chimneys or is conducted into special chambers for the manufacture of sulphuric acid. The zinc oxide so obtained is mixed with coal and heated in retorts, or muffles, made of fire-clay, when the metallic zinc distills off and is collected in special receptacles. In this process there is a certain amount of loss, for at the high temperature of the furnace the zinc combines with the alumina of the fire-clay and forms zinc-spinel. From this zinc-spinel the metal cannot be profitably extracted and it becomes a waste material, being used for road-metal. It has been estimated that the losses of this kind in the Silesian zinc works amount to 44 to 45 million kilograms of zinc per annum, valued at a third of a million sterling. In order to prevent this waste, it has been proposed to construct the muffles of ignited magnesia or of corundum, but these materials present other drawbacks.

Applications of zinc. — Sheet zinc is used for roofing, for domestic utensils and various ornamental objects. Zinc is also largely used as a coating on iron (the well-known galvanized iron) to preventing rusting: by the action of air and moisture the zinc becomes oxidized, but only on the surface, and the skin so formed prevents any further action. It is also used in the construction of galvanic batteries of various kinds. Brass and the other more important alloys of zinc and copper have already been mentioned.

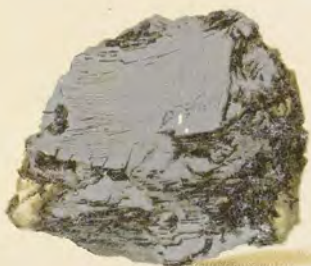
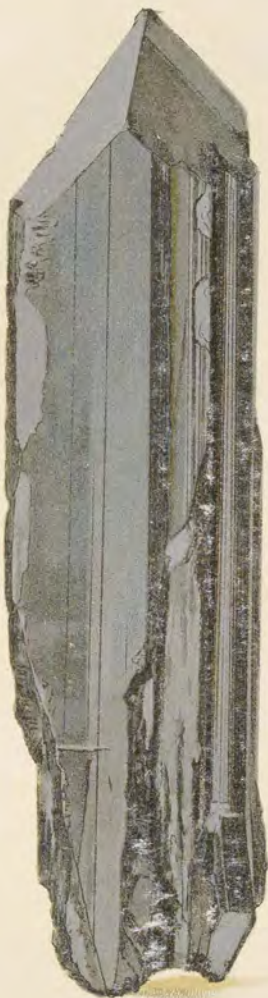
Compounds of zinc have also various uses. Zinc oxide is used as a paint under the name of white-zinc, but less extensively than white-lead. A white paint known in



Antimony Ores I.

Fig.

1. **Native Antimony**, in calcite.
Sala, Sweden.
2. **Native Antimony**.
Andreasberg, Harz, Germany.
3. **Senarmonite**, octahedral crystals.
Ain-Babouch, Constantine, Algeria.
4. **Stibnite** (Antimonite), a large, sharply-developed crystal.
Ichinokawa mine, Ojoin-mura, Saijo, province of Iyo, Island of Shikoku,
Japan.
5. **Stibnite**, radiating aggregate.
Arnsberg, Westphalia.
6. **Stibnite**.
Arnsberg, Westphalia.
7. **Kermesite**, tufts of acicular crystals.
Bräunsdorf, Freiberg, Saxony.





the trade as Griffith's white or lithopone is obtained by mixing solutions of zinc sulphate and barium sulphide. Railway sleepers impregnated with zinc chloride are preserved against the ravages of mould. Zinc sulphate is employed in dyeing and in medicine.

Zinc ores frequently contain a small amount of *cadmium*, and since this metal boils at 770° C. it is distilled in the zinc furnaces before the zinc. Alloys containing cadmium are characterized by their low fusibility, one of the best known being Wood's metal (see under bismuth, p. 137). An alloy of 50% lead, 27.5% tin and 22.5% cadmium is especially suited for clichés. Sulphide of cadmium, prepared by precipitation from a solution of a cadmium salt with hydrogen sulphide, is used as an oil or water paint under the name of cadmium-yellow. A pigment used for colouring paper is obtained by precipitating cadmium sulphate with barium sulphide. An alloy of cadmium and mercury is used in dentistry as a filling. The bulk of the cadmium of commerce is obtained from the Silesian zinc ores; in the year 1897 the production amounted to 15,527 kilograms.

The cadmia of the Romans was calamine, which smelted together with copper ore yielded brass. Metallic zinc was probably unknown to them, although articles of brass are frequently found amongst Roman remains.

The production of zinc during the year 1900 was as follows: —

<i>West Germany, Belgium and Holland</i>	186,320 tons.
<i>Silesia</i>	100,705 „
<i>United Kingdom</i>	29,830 „
<i>France and Spain</i>	30,620 „
<i>Austria and Italy</i>	6,975 „
<i>Russia</i>	5,875 „
<i>United States</i>	110,465 „

Total 470,790 tons.

This total of 470,790 English tons (of 1016 kilograms) is equivalent to a total of 478,323 metric tons (of 1000 kilograms). In the year 1901 the total production amounted to 500,000 metric tons (= 498,590 English tons), and in 1902 it was increased to 536,760 English tons.

The price of a ton of commercial zinc is about £20, but during the past decade it has been subject to considerable fluctuation; in 1901 it fell to £17, and in 1903 it rose to £24.

Antimony Ores.

Antimony occurs in the native state, but more frequently it is met with in nature in combination with other elements. Most frequently it is combined with sulphur, as stibnite; or with sulphur and a heavy metal (silver, copper or lead), forming the so-called sulpho-salts some of which have already been described above under the names pyrargyrite, bournonite and tetrahedrite. In combination with oxygen it is met with as the two minerals senarmontite and valentinite, which though identical in chemical composition are different in crystalline form. Further, in combination with both sulphur and oxygen we have it in the mineral kermesite. Omitting the antimony compounds previously described, we may then give the following list of antimony minerals: —

Native antimony, Sb.	Senarmontite, Sb ₂ O ₃ .
Stibnite, Sb ₂ S ₃ .	Valentinite, Sb ₂ O ₃ .
Kermesite, Sb ₂ S ₂ O.	

Native antimony is usually met with as granular or lamellar masses with a metallic lustre and tin-white colour; often, however, it shows a yellowish tarnish and presents no very distinctive appearance. In plate 22, fig. 1, the mineral is associated with calcite, and in fig. 2 is an isolated fragment showing a large cleavage surface. Antimony crystallizes in the rhombohedral division of the hexagonal system, and possesses cleavages parallel to the base and the faces of an obtuse rhombohedron. Naturally occurring crystals are of the greatest rarity, and the crystalline form of the substance has been determined from artificially prepared crystals. These are cube-like rhombohedra with an angle of $87^{\circ} 7'$ between the faces. The closely allied elements, arsenic and bismuth, crystallize in similar forms, the corresponding angle for arsenic being $85^{\circ} 4'$ and for bismuth $87^{\circ} 40'$.

Antimony is brittle and has a hardness of $3\frac{1}{2}$. Its specific gravity is 6.7. Heated on charcoal before the blowpipe, it fuses readily and is completely volatilized, yielding a white smoke and a white sublimate of antimony oxide on the charcoal.

Native antimony occurs in the veins of silver ore at Andreasberg in the Harz Mountains and at Sala in Sweden; the two specimens figured on plate 22 are from these localities. It is also found at Allemont in France, Sarawak in Borneo, and a few other places, but it is a rare mineral and is of no importance as an ore of antimony.

Stibnite, also known as antimonite or antimony-glance, is not only the most important ore of antimony but also the earliest known. It was employed by the ancients for darkening the eyebrows, and fragments of it have been found in Spartan graves.

That the mineral contains sulphur was known long ago to Basilius Valentinus; and the presence of this element may readily be demonstrated by simply heating the mineral in the air, when it gives the penetrating odour characteristic of burning sulphur. Heated on charcoal before the blowpipe, stibnite fuses very readily and after a time is completely volatilized, leaving a white deposit of antimony oxide on the surrounding surface of the charcoal. The mineral is soluble in hydrochloric acid with the evolution of hydrogen sulphide, which again proves the presence of sulphur. Chemical analysis shows that stibnite contains 71.4 per cent. of antimony and 28.6 per cent. of sulphur, corresponding with the formula Sb_2S_3 .

Stibnite crystallizes in the rhombic system and invariably presents a prismatic habit: the prism is almost square, having an angle of $90^{\circ} 26'$, and two of its edges are usually truncated by the pair of parallel faces of the brachy-pinacoid, while the crystals are often terminated by acute pyramidal faces. As a rule, however, the crystals are small and spear-shaped and frequently aggregated into divergent bunches, so that their form is not readily recognizable. The magnificent crystals from Japan, which first came into European collections about thirty-five years ago, far surpass any crystals previously known. They attain a length of half a metre (20 inches) and a thickness of 5 centimetres, and are moreover extraordinarily rich in faces; thus being not only striking objects in themselves, but also full of interest to the crystallographer. A large and very fine group of these crystals is exhibited in the mineral collection of the British Museum at South Kensington. A single crystal is represented on plate 22, fig. 4, and a group of crystals on plate 23; the forms here shown are the striated vertical prism, the brachy-pinacoid, a pyramid and a brachy-dome.

Not infrequently crystals of stibnite are more or less bent, sometimes in a ziz-zag fashion; the crystal projecting to the left in plate 23 shows a slight bending of this kind.

A very characteristic feature of stibnite is the highly perfect cleavage parallel to the brachy-pinacoid, and very often the brilliant cleavage surfaces exhibit a series of transverse striations (plate 22, fig. 6) due to the bending of the crystals.

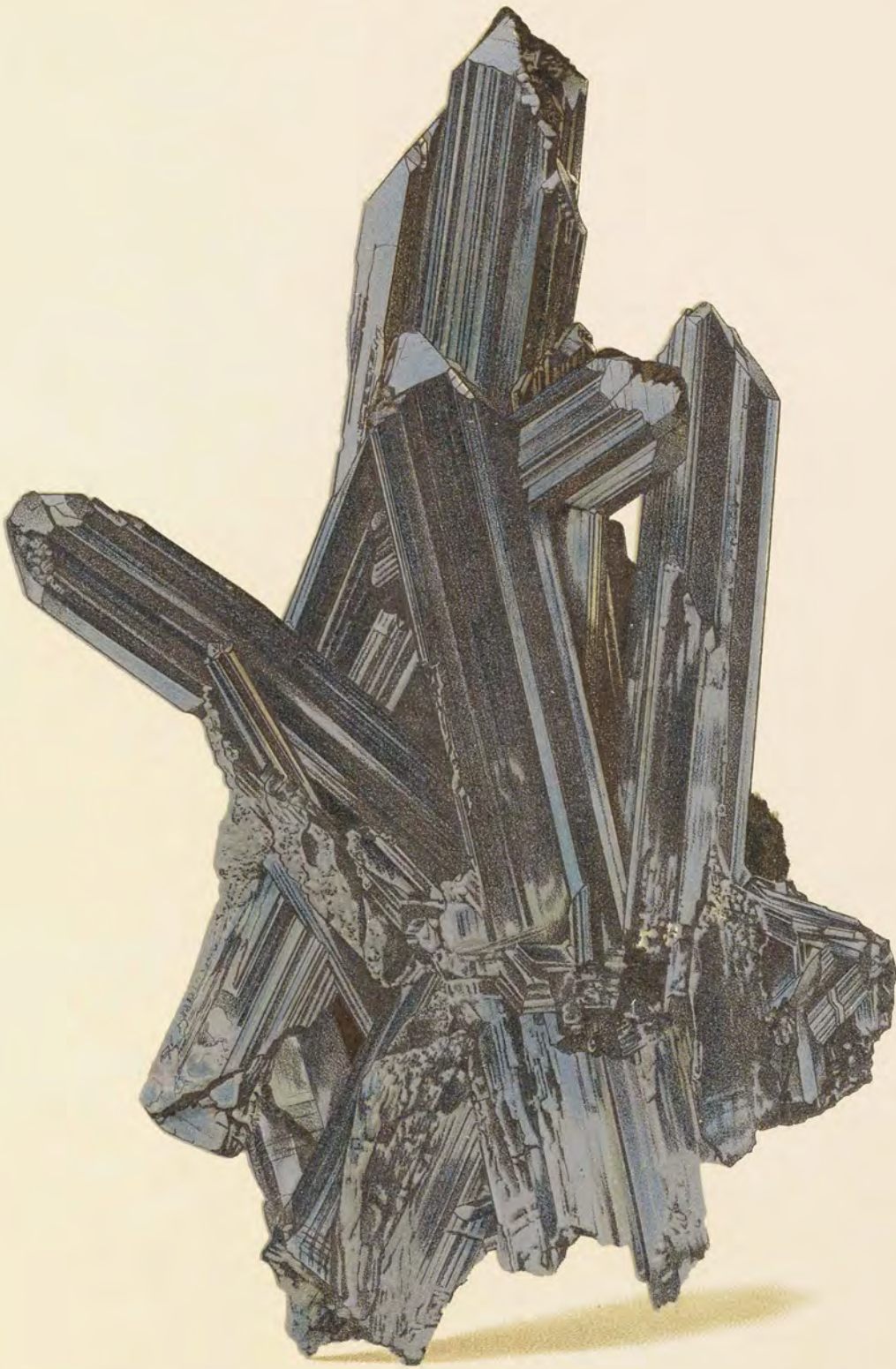


PLATE 23.

Antimony Ores II.

Stibnite (Antimonite), large group of prismatic crystals.

Ichinokawa mine, Ojoin-mura, Saijo, province of Iyo, Island of Shikoku,
Japan.





Stibnite possesses a metallic lustre, which is especially brilliant on fresh crystals and on cleavage surfaces; on exposure to light this gradually becomes dull. The colour is lead-grey to steel-grey, but often there is a bluish or blackish surface tarnish, as represented in the figures.

The hardness is very low, being about the same as that of gypsum, and it is therefore not surprising that the large crystals from Japan are often somewhat damaged in transport. The specific gravity is 4.5.

The larger masses of stibnite, such as are mined as an ore, consist of radiating or confused aggregates with a fibrous or columnar structure, as represented in plate 22, figs. 5 and 6.

Stibnite is, as a rule, not much affected by weathering, though it does give rise to earthy yellow antimony-ochre, to white valentinite and senarmontite, or occasionally to red kermesite.

Beds of stibnite occur in the rocks of the Culm-measures (Carboniferous system) at Uentrop near Arnsberg (plate 22, figs. 5 and 6) and at Nuttlar near Brilon in Westphalia. In veins it is found at Wolfsberg in the Harz Mountains, often as fine acicular and contorted crystals; with native gold at Goldkronach near Berneck in the Fichtelgebirge in Bavaria; at Bräunsdorf near Freiberg in Saxony; at Felsöbanya and other localities in Hungary; at Kostainik in western Servia; with cinnabar at San Martino and Pereta in Tuscany; and in the neighbourhood of Gedis and Uschak in western Anatolia. The fine Japanese crystals are found in veins in crystalline schists, where they line the walls of cavities; these come from the Ichinokawa mine in the village of Ojoin-mura near Saijo, in the province of Iyo, island of Shikoku. Japan takes a third place in the world's production of antimony, but the greater amount there produced is used for home consumption.

Stibnite, besides being used as an ore of antimony, is also used to a limited extent for the preparation of pure hydrogen sulphide.

Senarmontite, named in honour of the French physicist H. de Senarmont, possesses none of the characters of a metallic mineral, but is colourless, white or grey, and transparent to translucent. Crystals have the form of the regular octahedron, as shown in plate 22, fig. 3; they have a more or less resinous lustre, but are often dull on the surface. The hardness is low ($H. = 2$), so that the crystals are easily damaged on their edges.

At Sidi-Rgheiss, in the south-western portion of the province of Constantine in Algeria, the mineral is mined as an ore of antimony, and it is here that the best crystals are found. These occur lining cavities in granular masses of senarmontite, which form beds between clay and limestone in the Chalk formation.

Senarmontite is a cubic form of antimony oxide Sb_2O_3 , a compound which is dimorphous, since it also occurs in nature as the rhombic mineral *valentinite*. The latter forms small tabular crystals, often grouped in fan-shaped aggregates, with a white or greyish colour and a pearly lustre. It occurs together with stibnite, to the oxidation of which it owes its origin, and is found in small amounts at Bräunsdorf, Wolfsberg and Felsöbanya.

Kermesite, formerly popularly known as red antimony or antimony-blende, is also a mineral of little importance, but it is mentioned here because its chemical composition presents some interest. It may be looked upon as stibnite with one atom of sulphur replaced by an atom of oxygen, the formula being Sb_2S_2O . It forms small tufts or brush-like aggregates of acicular crystals, which are cherry-red in colour with a brilliant lustre. The mineral is found at Bräunsdorf in Saxony, Prizibram in Bohemia, and a few other localities.

Applications of antimony. — Metallic antimony is mainly used for making alloys of various kinds. A small amount of antimony increases considerably the hardness of lead; and an alloy of lead with 17 to 20 per cent. of antimony is extensively used for type metal in printing. An alloy containing 10 parts of antimony and 90 parts of tin is the well-known Britannia metal.

Artificially prepared sulphide of antimony, Sb_2S_3 as in stibnite, is used in the manufacture of fireworks; and another sulphide, Sb_2S_5 , known as "gold sulphur", finds an application in medicine. The permanent orange-yellow pigment known as Naples yellow is an antimonate of lead; and tartar emetic is another antimony salt of complex composition.

The countries which produce the largest quantities of antimony are Austria-Hungary, Great Britain and Japan.

Bismuth Ores.

Bismuth is found in nature in the native state, and in combination with sulphur as bismuth-glance, and with oxygen as bismuth-ochre. It is also present in a few other rare minerals, some of which are given in the following list of bismuth minerals: —

Bismuth-glance, Bi_2S_3 .	Matildite, $AgBiS_2$.
Guanajuatite, Bi_2Se_3 .	Emplectite, $CuBiS_2$.
Tetradymite, Bi_2Te_2S .	Galenobismutite, $PbBiS_2$.
Bismuth-ochre, Bi_2O_3 .	Eulytite, $Bi_4Si_3O_{12}$.

Native bismuth may generally be recognized by the reddish tinge of its silver-white colour, but, except on fresh fractures, the surface is often tarnished. Crystals are rhombohedral but very rare, and even when met with they are never more distinct than represented in plate 24, fig. 1. On the other hand, well-formed crystals of bismuth may be readily obtained artificially by fusion; the cube-like rhombohedra (plate 2, fig. 10) have hopper-shaped depressions on their cube faces and they usually display a brilliantly coloured iridescent tarnish. Crystals of native bismuth more frequently present feather-like (plate 24, fig. 2), platy (fig. 3) or net-like aggregates; or the mineral may occur as granular aggregates.

Bismuth fuses very readily, the melting point being as low as 270° C. When heated before the blowpipe, it produces a yellow encrustation on the charcoal. A very characteristic reaction for bismuth, either when in the native state or when in combination with other elements, is given by heating the powdered mineral on charcoal with a mixture of sulphur and potassium iodide; a brilliant red sublimate is thereby produced on the charcoal.

Bismuth possesses a low degree of hardness ($H. = 2-3$); it is sectile though not malleable, and heavy (sp. gr. = 9.8). It is one of the few substances which contract when fused and expand on consolidation, behaving on this respect like ice and water.

Native bismuth occurs in mineral-veins together with smaltite and niccolite, or sometimes with silver ores, and it is usually associated with barytes and quartz; under these conditions it is found at Schneeberg (plate 24, figs. 2 and 3), Annaberg and Johanngeorgenstadt in Saxony. In association with cassiterite it is known from Altenberg and Graupen (fig. 1) in the Erzgebirge between Saxony and Bohemia; in veins penetrating



Bismuth Ores and Arsenic Ores.

Fig.

1. **Native Bismuth.**
Graupen, Teplitz, Bohemia.
2. **Native Bismuth**, with feather-like structure.
Schneeberg, Saxony.
3. **Native Bismuth**, with platy and feather-like structure.
Schneeberg, Saxony.
4. **Bismuth-glance** (Bismuthinite), passing into bismuth-ochre.
Province Chichas, Bolivia.
5. **Native Arsenic**, mamillated.
Andreasberg, Harz, Germany.
6. **Orpiment**, botryoidal.
Felsöbanya, Hungary.
7. **Orpiment**, platy with red realgar.
New-Moldova, Hungary.
8. **Realgar**, crystals on matrix.
Nagyag, Transylvania.



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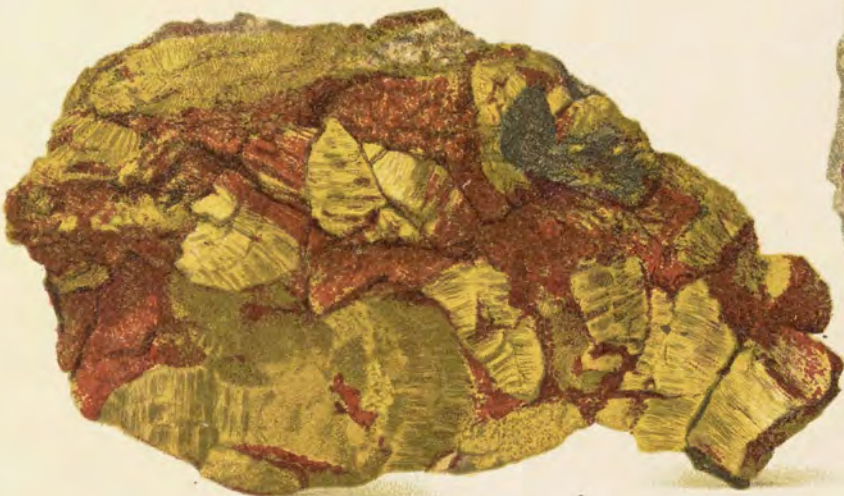
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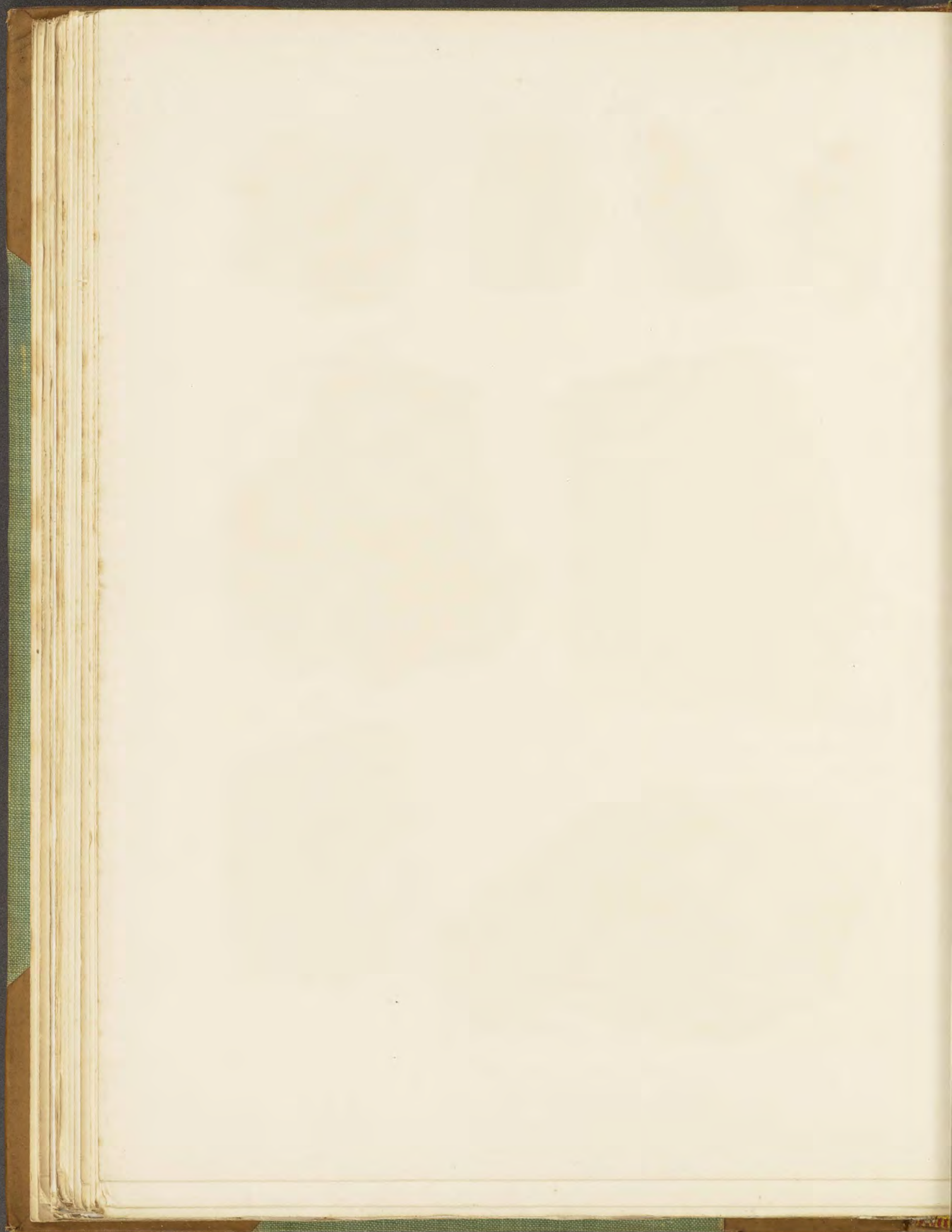
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8



granite at Wittichen in the Black Forest; and in veins with cobalt and nickel ores at Bieber in Hesse. Other localities are known in Cornwall, Bolivia and Australia.

Bismuth-glance, or bismuthinite, has a striking resemblance to stibnite, but is somewhat lighter in colour, being light lead-grey to tin-white, and often showing a yellowish tarnish on the surface. Crystals are orthorhombic with a prismatic habit, but they are small and imperfectly developed, and are usually aggregated to form divergent tufts. They possess a perfect cleavage parallel to the brachy-pinacoid and the cleavage surfaces are transversely striated just as in stibnite.

As a rule, these two minerals can only be distinguished by chemical tests. When heated on charcoal before the blowpipe, bismuth-glance gives a yellow encrustation whilst stibnite gives a white encrustation on the charcoal. Still more characteristic, as mentioned above, is the red sublimate given by bismuth in the presence of sulphur and potassium iodide.

When pure, bismuth-glance contains 81.2 per cent. of bismuth. Its hardness is 2, and specific gravity 6.5. It readily alters to bismuth-ochre; the alteration of the grey, metallic bismuth-glance to yellow, earthy bismuth-ochre is depicted in plate 24, fig. 4.

It is found at Schneeberg in Saxony, and at Rezbanya and Moravieza in Hungary. Crystals were formerly found in the Fowey Consols mine and in the East Pool mine in Cornwall. It is abundant at Huaina Potosi, Tasna, and Chorolque in Bolivia; the specimen represented in plate 24, fig. 4, is from the last named locality and represents the bismuth-glance surrounded by secondary bismuth-ochre and accompanied with iron-pyrites, quartz and tin ore. Bismuth-ores were first known from Bolivia some thirty-five years ago, and now this is the principal bismuth-producing country.

Applications of bismuth. — Metallic bismuth is extracted mainly from bismuth-glance; a certain amount being obtained from bismuth-ochre and still less from native bismuth. The production is mainly in the hands of one firm at Giessen in Germany, who make no returns as to the amount produced; by a secret process they are able to extract every trace of impurity from the fused bismuth.

Alloys of bismuth with other metals are characterized by their low melting points, much lower than that of pure bismuth and often below the boiling point of water. Rose's metal, consisting of two parts of bismuth with one of lead and one of tin, fuses at 94° ; and an alloy of five parts of bismuth, three of lead and two of tin fuses at $91\frac{1}{2}^{\circ}$; such alloys are used for making clichés. By the addition of cadmium the melting point may be lowered still further; Wood's metal, consisting of 50% bismuth, 25% lead, $12\frac{1}{2}$ % antimony and $12\frac{1}{2}$ % cadmium, melts at $60\frac{1}{2}^{\circ}$; Lippowitz metal is similar in composition.

Basic nitrate of bismuth is used as a white paint, and also very extensively in medicine. The refractive index of glass is increased by the addition of bismuth.

Arsenic Ores.

Arsenic is widely distributed amongst minerals. It occurs in the native state, and in simple combination with sulphur, iron, nickel or cobalt; with sulphur and a heavy metal (silver, copper or lead) in the sulpho-salts, the more important of which we have already mentioned (proustite, and tennantite). It is also found in simple combination with oxygen forming the extremely poisonous arsenic trioxide; and in many oxygen salts.

In this place we shall only describe native arsenic and the two sulphides, realgar and orpiment. Those minerals which contain arsenic in combination with iron, nickel or cobalt will be described further on under the latter metals, for they are more nearly related to the ores of these metals, and in the case of cobalt and nickel, at least, they are far more important for the metals they contain than for the arsenic. On the other hand, the bulk of the arsenic of commerce is obtained from the iron compounds, which will be described under mispickel (FeAsS) and löllingite (FeAs_2).

The simple oxygen compound, As_2O_3 , is well known under the name white arsenic, but it is of rare occurrence in nature as the dimorphous minerals arsenolite and claudetite. The oxygen salts of arsenic are products of weathering of the iron, nickel and cobalt compounds, and will therefore be described under these metals. In other oxygen salts of arsenic we perceive a close chemical relation between arsenic and phosphorus, as already explained under lead (p. 124), mimetite being a chloro-arsenate of lead and pyromorphite the corresponding phosphate.

Native arsenic occurs as finely granular masses with a mamillated or reniform surface (plate 24, fig. 5) and a concentric structure with shelly separation. On one side of such a broken mass the surfaces will be convex and on the other side concave, while the convex surfaces of one shell fit exactly into the concavities of the shell next to it. The curvature of these surfaces is often more pronounced than in the specimen represented in the figure, and sometimes the form is stalactitic.

The surface of specimens of native arsenic is dark grey to black and dull, but on a freshly fractured surface the colour is tin-white with metallic lustre. In a short time, however, the lustre is lost, owing to surface oxidation.

When heated, arsenic volatilizes without fusion; before the blowpipe on charcoal it forms a white sublimate of arsenious oxide and gives a very characteristic odour resembling that of garlic. The hardness is a little over 3, and the specific gravity 5.7. The mineral is brittle.

It is found, like native bismuth, in mineral-veins together with ores of silver and cobalt. Specially fine masses with mamillated surfaces are found in the veins of silver ore at Andreasberg in the Harz Mountains, in association with galena, dyscrasite, pyrargyrite and calcite. Other localities are Schneeberg, Johanngeorgenstadt, Marienberg and Freiberg in Saxony, Joachimsthal in Bohemia, Zmeov in Siberia, Copiapo in Chile, and Akatani in the province of Echizen in Japan. At the last named locality numerous small rhombohedral crystals are aggregated into globular masses like balls covered with spines.

Metallic arsenic is mainly prepared artificially from the ores of arsenic, and it is used in the manufacture of shot (see under lead, p. 125).

Orpiment is a sulphide of arsenic with the formula As_2S_3 . It is one of the minerals known to the ancients, the name orpiment being a corruption of the Latin name auripigmentum used by Pliny, which means "gold paint": the form auripigment is used in German. The name alludes to the characteristic bright lemon-yellow colour and brilliant lustre of the mineral. Another important character is the highly perfect cleavage in one direction, allowing the mineral to be easily split up into thin flexible plates, which are transparent and exhibit a bright pearly lustre on their surface. The mineral is very soft ($H. = 1\frac{1}{2}$ —2). These characters alone always enable the mineral to be readily recognized. When heated, it easily burns with a blue flame giving off fumes of sulphur dioxide and arsenious oxide. Being a transparent sulphur compound, the mineral has been known as "yellow arsenic blende".

Crystals are only rarely met with; they are small and rounded and grown together in crusts, so that it is not possible on inspection alone to make out that they are rhombic with a short prismatic habit. Most frequently, the mineral is found as platy (plate 24, fig. 7) or granular masses. Sometimes, the massive material presents a rounded or botryoidal surface (fig. 6) with a dark colour on the exterior; this form is probably due to the pseudomorphous alteration of native arsenic to orpiment, as is suggested by a comparison of figs. 5 and 6, and confirmed by the fact that specimens showing all stages of the passage from native arsenic to orpiment have been found at Kapnik in Hungary.

Orpiment frequently occurs in association with the red realgar (plate 24, fig. 7), and in some instances it is possible that it has been derived from this. It is found in a grey sandy clay at Mount Szokolova near Tajova in Hungary, at New-Moldova (fig. 7), in the mineral-veins of Felsöbanya (fig. 6), and at Kapnik, all in Hungary. Also at Allehar near Rozsdan in Macedonia, and Julamerk in Asiatic Turkey. Occasionally it is found in small amount as a volcanic sublimation product, as at Vesuvius and Guadeloupe in the West Indies.

Orpiment is used as a pigment, but most of the material so employed is prepared artificially by fusing arsenious oxide or realgar together with sulphur, or by distillation from a mixture of mispickel and iron-pyrites; the yellow, transparent glassy material so obtained is known as "yellow glass", and as it often contains an excess of arsenious oxide it is very poisonous. The King's yellow used in oil painting is prepared by precipitation in the wet way.

Realgar. While orpiment is characterized by a bright yellow colour, realgar, on the other hand, is distinguished by a bright red colour. On account of its striking colour, the mineral attracted the attention of the ancients, and it was known to the Greeks as *sandarache*, being mentioned by Aristotle under this name. Like orpiment, it is also a sulphide of arsenic, but with the formula As_2S_2 . The action of light on the mineral gives rise to a remarkable change, as is often seen in the specimens exhibited in collections; the beautiful red and transparent crystals after a time become transformed to a heap of yellow powder. Oxygen has been absorbed and the compound As_2S_2 has been decomposed into a mixture of powdery yellow orpiment (As_2S_3) and white arsenious oxide (As_2O_3). The presence of the latter in the yellow powder can readily be demonstrated in the following manner: a little of the powder is warmed with a drop of water on a microscope slide and allowed to cool, when it will be seen that colourless regular octahedra of arsenious oxide separate out from the solution. The presence of this free arsenious oxide makes the powder of the decomposed crystals very poisonous, whilst the fresh crystals are not poisonous. When protected from the light, crystals do not undergo any alteration of this kind.

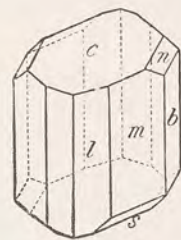


Fig. 127.
Crystal of Realgar.

Crystals of realgar are usually quite small; they belong to the monoclinic system and have a short prismatic habit. The crystal shown in text-fig. 127 is bounded by the two vertical prisms (*l* and *m*), the clino-pinacoid (*b*), the obliquely-placed basal pinacoid (*c*), a clino-dome (*n*), and a pyramid (*s*). Crystals are transparent, while the more frequently occurring granular aggregates are only translucent. The hardness is 1—2, and the specific gravity 3.6.

Good crystals of realgar are found at Nagyag in Transylvania (plate 24, fig. 8); in the white saccharoidal dolomite of the Binnenthal in Switzerland; at Allehar near Rozsdan in Macedonia; and in the Solfatara of Pozzuoli near Naples. Granular masses of realgar often occur intermixed with orpiment as represented in fig. 7.

Like orpiment, much of the realgar used in commerce is prepared artificially; it is a ruby-red, glassy product known as "red glass", and since it usually contains some free arsenious oxide it is very poisonous. When mixed with saltpetre and ignited, it gives an intense white light, this being the "white fire" of pyrotechnic displays. Realgar is also used in cotton printing, in tanning for removing the hair from skins, and in the manufacture of shot.

In addition to the applications mentioned above, these minerals are also used for the manufacture of white arsenic and other preparations of arsenic. The latter are, however, more largely prepared from other arsenical minerals (mispickel, löllingite and niccolite), which will be described further on.

Sulphur.

Sulphur is neither a metal nor an ore, and strictly it does not belong to the group of minerals we are at present considering. Since, however, its principal applications from an economic point of view are mainly identical with those of the two metallic minerals to be next described, it may be most conveniently mentioned in this place.

Not infrequently, native sulphur is referred to as sulphur ore; this is, however, not quite correct, for by ore we understand a mineral from which a metal can be extracted. But, since native sulphur has to be freed from the rocky matrix, in which it occurs embedded, by a process somewhat similar to that employed in extracting a metal from its ore, there exists a certain analogy in the two cases. From this point of view, then, we may consider native sulphur, as well as the minerals (iron-pyrites and marcasite) which are employed for the same purpose, as ores of sulphur. The chemical characters of sulphur are those of a non-metal, and in text-books on mineralogy it is consequently classed with the other naturally-occurring non-metallic elements, namely diamond and graphite.

Native sulphur is often found as magnificent and brilliant crystals with the well-known sulphur-yellow colour. They belong to the rhombic system, and their predominating form is almost always that of an acute rhombic pyramid truncated by the basal plane (plate 25, fig. 2). The two upper pyramid faces to the front of the crystal are inclined to one another at an angle of $106^{\circ} 38'$, and each of these faces is inclined to the base at $108^{\circ} 21'$. Very often the edges between this pyramid

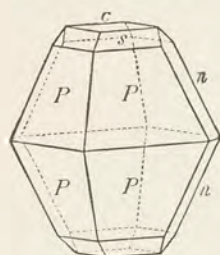
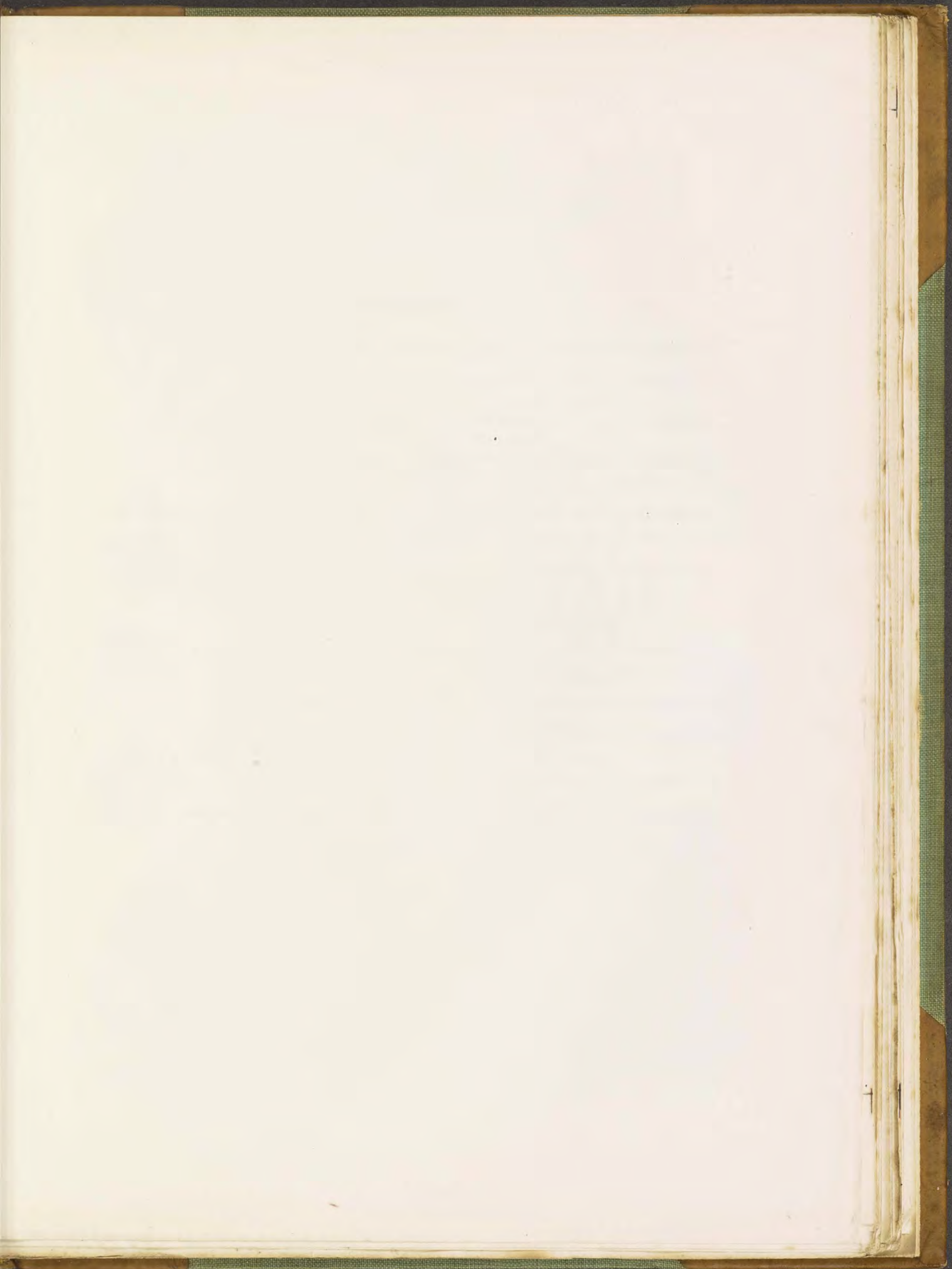


Fig. 128.
Crystal of Sulphur.

and the base are truncated by the faces of an obtuse pyramid (figs. 4 and 5) inclined at an angle of $134^{\circ} 52'$ to the base. Taking the acute pyramid to be the primary pyramid P , the symbol of the obtuse pyramid becomes $\frac{1}{3}P$. The acute sloping edges of the primary pyramid are also often truncated by the faces of the brachy-dome $P\infty$; which is to be seen as a narrow face to the left in figs. 3, 4 and 7, while in fig. 6 it is represented as a broad face to the front of the crystal. In addition to the forms mentioned, the brachy-pinacoid $\infty\check{P}\infty$ is also rarely present, as shown on the left in fig. 4. The ideal development of a sulphur crystal is represented in the accompanying text-fig. 128; here P is the primary pyramid, s the obtuse pyramid $\frac{1}{3}P$, c the base, and n the brachy-dome $P\infty$.

When quite pure, native sulphur shows the characteristic sulphur-yellow colour, but this colour may be somewhat masked by the presence of impurities: the varying

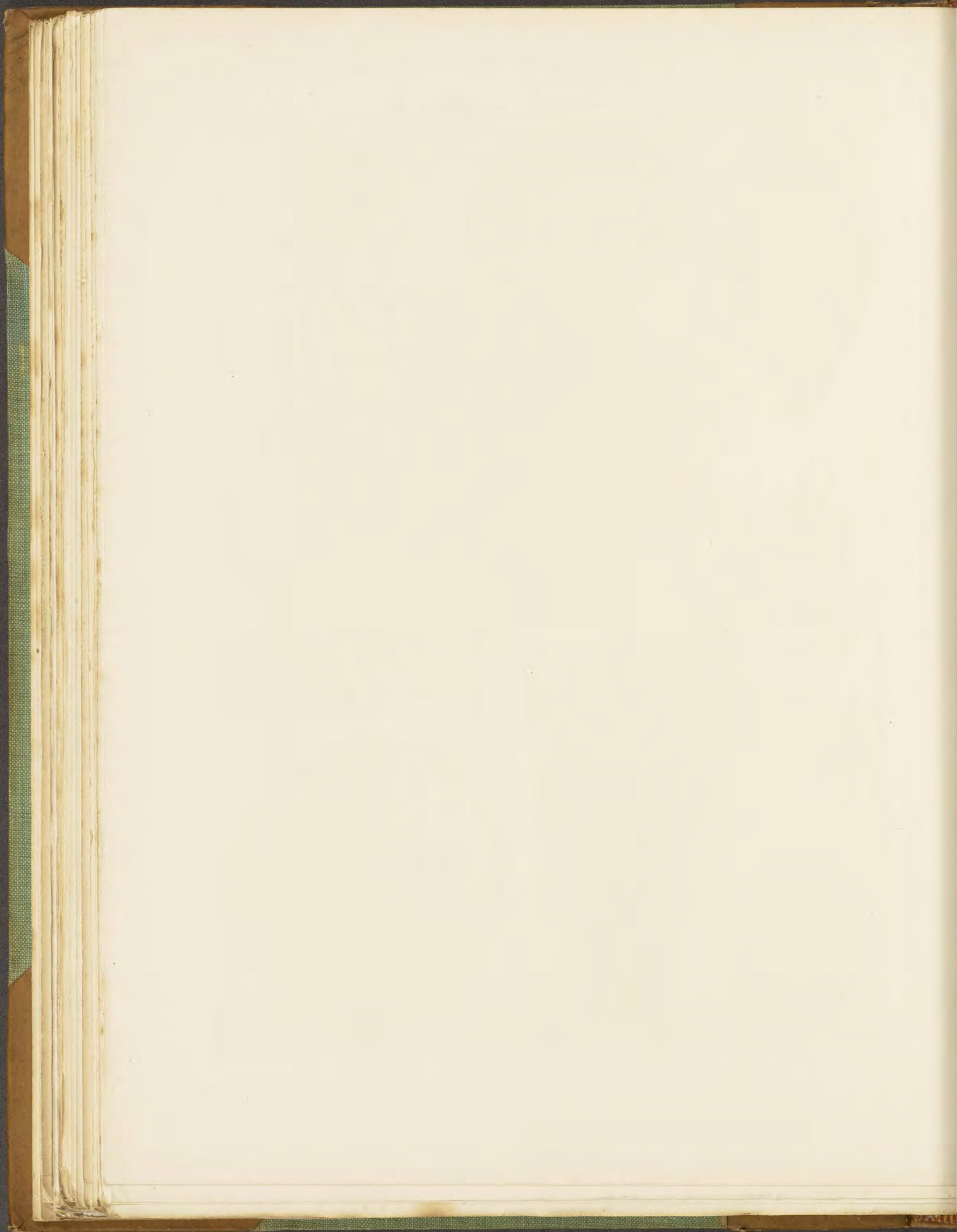


Sulphur.

Fig.

1. Sulphur, large pyramid P , dull, fractured, and with enclosures of asphalt.
Romagna, Italy.
2. Sulphur, pyramid with basal plane, P , $0 P$.
Girgenti, Sicily.
3. Sulphur, small, sharply-developed crystal, P , $\frac{1}{3} P$, $0 P$, $P \infty$.
Perticara, Romagna, Italy.
4. Sulphur, pyramid with obtuse pyramid, the base, a brachy-dome and the brachy-pinacoid, P , $\frac{1}{3} P$, $0 P$, $P \infty$, $\infty P \infty$.
Perticara, Romagna, Italy.
5. Sulphur, pyramid with obtuse pyramid and base, P , $\frac{1}{3} P$, $0 P$. The re-entrant angle on the left is the result of parallel growth.
Leonforte, Sicily.
6. Sulphur, pyramid with obtuse pyramid, drusy basal plane and wide brachy-dome, P , P , $0 P$, $P \infty$. The crystal is placed with the unusually wide brachy-dome to the front (in the other figures this is at the side).
Girgenti, Sicily.
7. Sulphur, amber-yellow crystals enclosing asphalt. Several crystals are grown together in parallel position. Forms, P , $\frac{1}{3} P$, $0 P$, $P \infty$.
Perticara, Romagna, Italy.
8. Sulphur, group of crystals of the same form as in fig. 4.
Racalmuto, Sicily.
9. Sulphur, crystals on calcite.
Girgenti, Sicily.
10. Sulphur, massive; in gypsum.
Weenzen, Lauenstein, Hannover.
11. Sulphur, massive; fragment of a nodule coloured brown with bitumen.
Radoboj, Croatia.
12. Sulphur, earthy. Deposit from a hot spring.
Iceland.





colours of the crystals in fig. 4, 4 and 7 are due to the presence of enclosures of asphaltum, while the brown colour of the massive sulphur represented in fig. 11 is due to the admixture of only 0.2 per cent. of a bituminous substance. The colour of earthy sulphur is yellowish-white. Crystals are transparent to translucent, but they are opaque to the Röntgen rays. The index of refraction is high, being 2.0, and corresponding to this the material possesses a brilliant resinous lustre. The faces of crystals are frequently very bright and smooth.

A fractured surface of sulphur is conchoidal and resinous. The material is not wetted by contact with water, neither is it dissolved. It is very soft ($H. = 2$) and is not at all heavy (sp. gr. = 2.07). When sulphur is held in the warm hand it emits a crackling noise and becomes fissured, so that crystals must be handled with care. When rubbed it becomes negatively electrified. Sulphur burns with a small blue flame, combining with the oxygen of the air to form sulphur dioxide; this gas, as is well known, has a most penetrating odour and bleaches organic colouring matters. In the neighbourhood of furnaces in which sulphurous ores are roasted, the vegetation is all destroyed, as may be seen in the Harz Mountains; and for this reason the chimneys from such furnaces are built high so that the noxious fumes may escape into the upper strata of the atmosphere. The property that the gas possesses of destroying the low forms of vegetable and animal life is extensively made use of in the simple operation of fumigating with sulphur.

Sulphur is readily soluble in carbon disulphide, and as the solution evaporates crystals with the same form as native sulphur are deposited.

Sulphur usually melts at $114^{\circ} C.$, but sometimes not until 120° is reached. This peculiar behaviour is due to the fact that at a temperature of 96° the rhombic sulphur may become converted into another modification the melting point of which is 120° . When this alteration takes place the high melting point is reached, and when there is no such alteration the melting point is lower. Molten sulphur, when allowed to consolidate by cooling, does not crystallize in the pyramidal rhombic form characteristic of native sulphur, but in the form of acicular and spear-shaped crystals with a dark amber-yellow colour and belonging to the monoclinic system.

Sulphur is therefore capable of existing in two distinct modifications differing not only in crystalline form but also possessing different physical characters; for example, a different melting point and a different specific gravity, that of rhombic sulphur being 2.07 while that of monoclinic sulphur is only 1.96. This phenomenon was discovered by E. Mitscherlich in the year 1823 and described by him as dimorphism. It is now known, however, that sulphur is not dimorphous, but polymorphous, since it can exist in no less than eight different forms. These are, however, all unstable and pass gradually into the rhombic form, which is the only modification that occurs in nature as a mineral. The acicular crystals of monoclinic sulphur obtained from a fused mass also become changed in the same manner: after a short time cloudy patches of a pale yellow colour appear in the amber-yellow crystals and these gradually spread until the whole crystal becomes converted into a confused aggregate of minute rhombic crystals, when we have a pseudomorph of rhombic sulphur after monoclinic sulphur.

When molten sulphur is heated at a temperature somewhat above the melting point, it gradually becomes darker yellow and viscous; and when poured into water in this condition, it forms a tough plastic mass known as amorphous sulphur. This after an interval of time becomes brittle and paler in colour, owing to its gradual passage into the rhombic modification.

Sulphur volatilizes even at the ordinary temperature, though only in minute traces; a piece of bright silver shut up in a box with sulphur will be blackened by the

silver sulphide formed on its surface. The quantity of sulphur volatilized increases with the temperature, and at the boiling point, 450° C., it gives a brownish-red vapour. As this vapour cools, the sulphur is deposited as a fine, mealy powder, known as "flowers of sulphur". During the process of subliming sulphur, air must, of course, be excluded, otherwise the sulphur would burn.

In nature, sulphur is deposited by the interaction of sulphurous gases emitted by volcanoes. It is also deposited by the waters of some springs, owing to the sulphur compounds they contain being decomposed by contact with the oxygen of the air: in this case, the deposit is earthy with a sinter-like appearance or is stalactitic in form, and is known as mealy sulphur. Small crystals of sulphur are sometimes formed by the weathering of galena: and it is also possible that some of the extensive deposits of sulphur may have been formed by the decomposition of some other mineral, such as gypsum (hydrated sulphate of calcium). That sulphur may be deposited from solution is rendered evident by the specimen represented in plate 19, fig. 5, where a crystal of sulphur is deposited on the end of a stalactite of calcite. It is also worthy of note that free sulphur is present in the substance of some algae.

The preceding remarks on the genesis of native sulphur will help us to realize under what conditions the mineral occurs. Small amounts are found in volcanic materials, in the deposits of sulphur springs, in mineral-veins and in beds of lignite and coal. The most important deposits, however, occur with gypsum (plate 25, fig. 10) and limestone in sedimentary rocks of Tertiary age, where sulphur is often accompanied with crystals of celestite (plate 78, fig. 3), aragonite, calcite, and a few other minerals.

In Europe, the most extensive deposits of sulphur are those of Sicily, in the neighbourhood of Girgenti, Racalmuto (also written Roccalmuto), and Caltanissetta. Here the massive sulphur occurs in beds of limestone, marl, gypsum and clay; and the fine crystals (plate 25, figs. 2, 5, 6, 8, 9) are found in crevices which cross the beds obliquely, or in irregular cavities. Fine crystals, often coated over with or enclosing asphaltum, are also found in the sulphur mines at Perticara in Romagna, Italy. Sublimed sulphur is met with at the Solfatara of Pozzuoli near Naples, on Etna, and in the crater of the Island of Vulcano in the Lipari Islands.

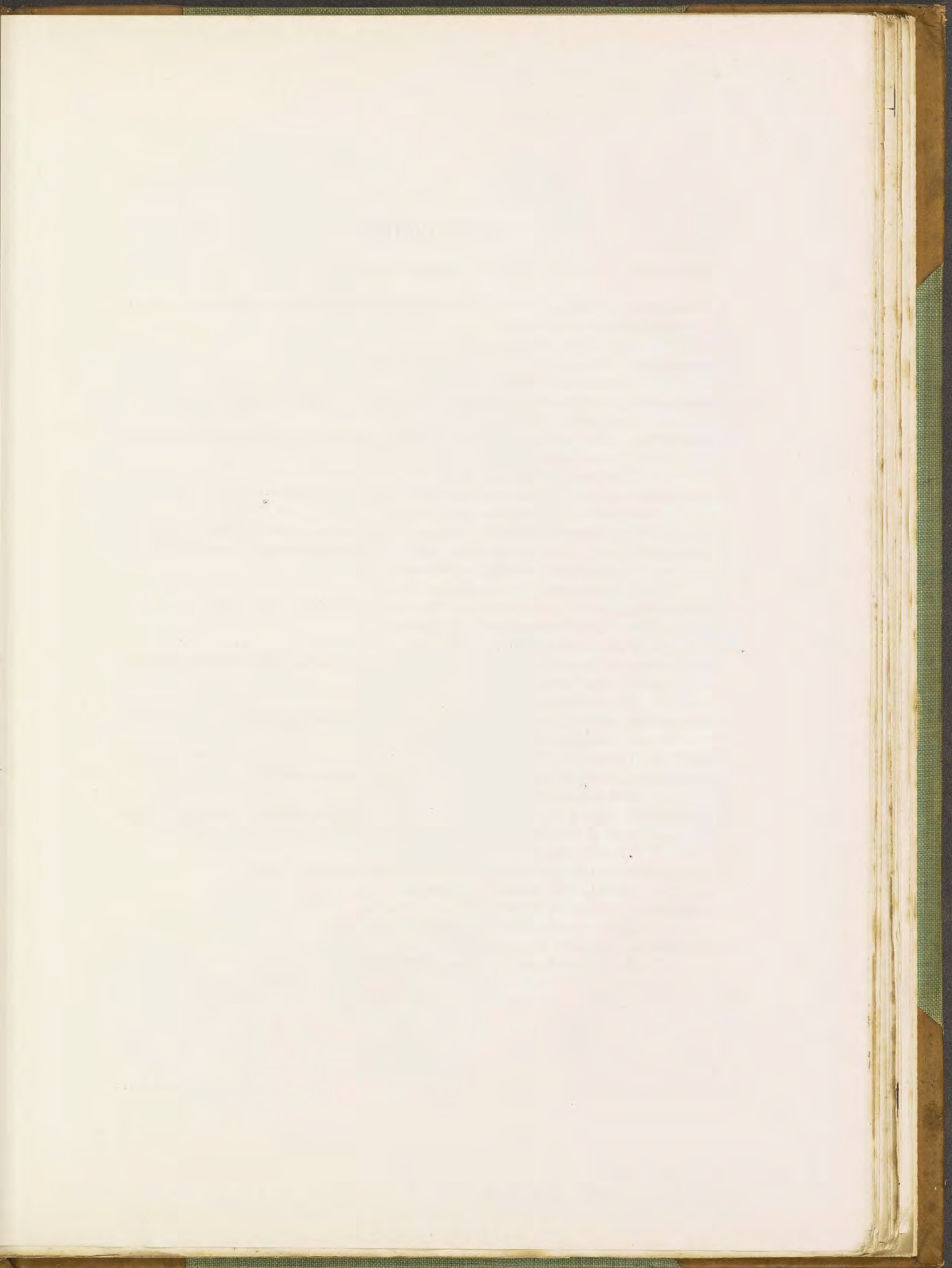
Deposits of sulphur, similar to those of Sicily, are mined at Conil, near Cadiz in Spain: here also the mineral occurs in Tertiary limestone and marl and is accompanied by gypsum, calcite and celestite. At Teruel, in Aragon, sulphur is the petrifying material of fresh-water shells, innumerable shells of *Planorbis* and *Paludina* being filled with this mineral.

In Germany, sulphur is of only sparing occurrence. It is found in gypsum at Weenzen, south-east of Lauenstein in Hannover (plate 25, fig. 10); as minute crystals in the veins of lead ore in the Siegen district of Westphalia (p. 119); and here and there in beds of lignite.

Nodules of pale brownish, massive sulphur are found in a marly shale of Tertiary age at Radoboj in Croatia (fig. 11); and beds of earthy and massive sulphur are found in Caucasia, namely in the Trusso valley to the west of [the military road, and in eastern Daghestan.

As a deposit from hot springs, earthy sulphur is met with in Iceland, in the geysers of the Yellowstone Park in the United States, and in Napa Valley in Sonoma county, California. Extensive deposits of sulphur are also known in the states of Utah and Louisiana.

Extraction and Applications of Sulphur. — In the year 1898 there were no less than 720 sulphur mines in Sicily. The native sulphur is separated from the rock by

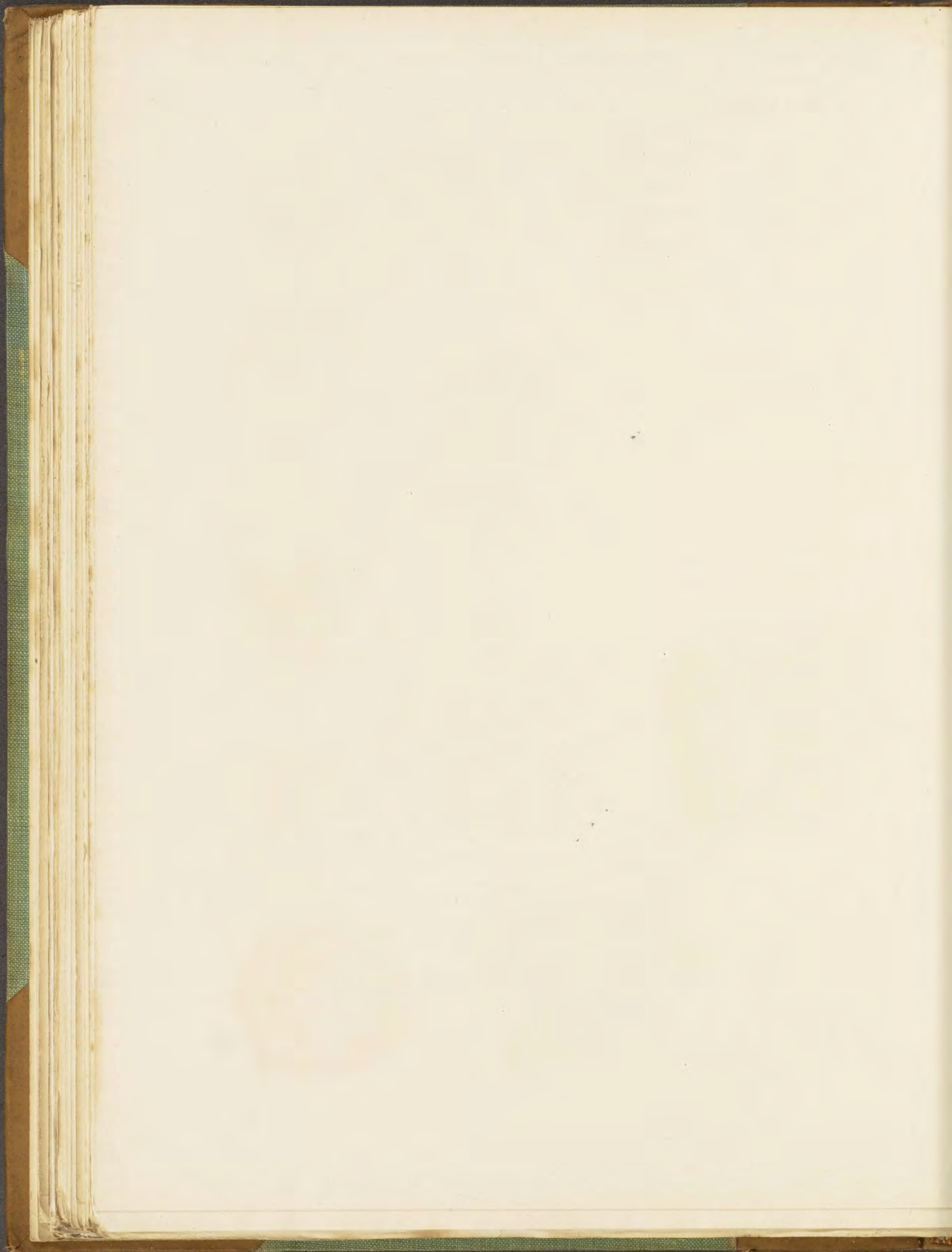


Iron-pyrites.

Fig.

1. **Iron-pyrites** (or Pyrite), cube with deeply striated faces.
Tavistock, Devonshire.
2. **Iron-pyrites**, octahedron with the faces obliquely striated by combination with the pentagonal-dodecahedron.
Traversella, Piedmont, Italy.
3. **Iron-pyrites**, octahedron with cube; faces smooth.
Traversella, Piedmont, Italy.
4. **Iron-pyrites**, pentagonal-dodecahedron with very small faces of the octahedron.
Traversella, Piedmont, Italy.
5. **Iron-pyrites**, group of pentagonal-dodecahedra; the faces are striated perpendicular to the three cubic edges.
Traversella, Piedmont, Italy.
6. **Iron-pyrites**, pentagonal-dodecahedron with small octahedral faces. In pits on the surface is haematite (micaceous iron-ore).
Rio iron-mine, near the village of Rio Marina, Island of Elba, Italy.
7. **Iron-pyrites**, pentagonal-dodecahedron with dyakis-dodecahedron; the faces of the former are striated parallel to the cubic edges.
Rio iron-mine, Island of Elba, Italy.
8. **Iron-pyrites**, altered to haematite and limonite. The edges of the cube are replaced by faces of the pentagonal-dodecahedron.
Pelican Point, Utah Lake, Utah, U. S. A.
9. **Iron-pyrites**, on haematite. Pentagonal-dodecahedron with octahedron and dyakis-dodecahedron on haematite.
Rio iron-mine, Island of Elba, Italy.
10. **Iron-pyrites**, cube with pentagonal-dodecahedron and dyakis-dodecahedron. Encrusted in part with haematite (red-iron-ore).
Traversella, Piedmont, Italy.
11. **Iron-pyrites**, interpenetration-twin of two pentagonal-dodecahedra.
Rio iron-mine, Island of Elba, Italy.
12. **Iron-pyrites**, altered to iron hydroxide (limonite). The so-called "iron-cross" twin, consisting of two interpenetrating pentagonal-dodecahedra with cube faces.
Vlotho, near Minden, Westphalia.
13. **Iron-pyrites**, pentagonal-dodecahedron embedded in Keuper marl.
Vlotho, near Minden, Westphalia.
14. **Iron-pyrites**, altered to limonite. Form as in fig. 7.
Rio iron-mine, Island of Elba, Italy.
15. **Iron-pyrites**, disc with radial markings.
From a coal-mine at Sparta, Illinois, U. S. A.





fusion; the source of heat employed is that given by the sulphur itself, this being a cheaper fuel than coal at the mines. The crude sulphur so obtained is generally further purified by distillation, and this product ("flowers of sulphur") is then fused and cast into sticks to give the well-known roll-sulphur. During recent years the production of Sicilian sulphur has been on the increase: in 1900 the amount exported was 557,668 tons. The larger part of this (162,000 tons in 1900) goes to the United States, where it is used in increasing quantities in the cellulose and paper industries.

Sulphur is used in the manufacture of matches, gunpowder and fireworks, in the vulcanizing of india-rubber, and in the preparation of ultramarine. From it is prepared sulphurous acid, which is largely used for disinfecting, bleaching, and in the paper industry. Flowers of sulphur is used in wine making to destroy the *Oidium* fungus. The largest quantities of sulphur are, however, used in the manufacture of sulphuric acid (oil of vitriol) which is an important reagent, not only in chemical laboratories, but also in all the chemical industries. The greater part of the sulphur used for this purpose is now obtained from iron-pyrites and also to a lesser extent from zinc-blende and other sulphides.

Iron-pyrites Group.

The minerals to be now described (and figured on plates 26 and 27) form a kind of connecting link between arsenic and sulphur (plates 24 and 25) on the one hand, and the iron ores (plates 28—30) on the other. These minerals include iron-pyrites, marcasite, mispickel, löllingite and pyrrhotite, and consist of iron in combination with arsenic or sulphur or of both of these together. They are not used as ores of iron, but of arsenic and sulphur.

Iron-pyrites and marcasite are identical in chemical composition, being disulphide of iron, FeS_2 ; this compound is therefore dimorphous, crystallizing in a cubic modification as iron-pyrites, and in a rhombic modification as marcasite. Closely allied to marcasite both in chemical composition and in crystalline form are the rhombic minerals mispickel and löllingite; in the former one atom of sulphur is replaced by arsenic, and in the latter both sulphur atoms are so replaced.

Pyrrhotite, which is also included in the present group, often contains, in addition to iron, a small amount of nickel, and it thus forms a connecting link with the nickel and cobalt ores to be described further on. The latter crystallize in cubic and rhombic forms like iron-pyrites and marcasite and are also chemically related to them. The whole series of related minerals thus forms an isodimorphous group as indicated in the following lists: —

Cubic.	Rhombic.
Iron-pyrites, FeS_2 .	Marcasite, FeS_2 .
Hauerite, MnS_2 .	Löllingite, FeAs_2 .
Gersdorffite, NiAsS .	Mispickel, FeAsS .
Cobaltite, CoAsS .	Glaucodote, CoAsS .
Smaltite, CoAs_2 .	Safflorite, CoAs_2 .
Chloanthite, NiAs_2 .	Rammelsbergite, NiAs_2 .

The close relation existing between the minerals listed in each of these columns is illustrated by the fact that the chemical compounds that they represent are capable of mixing together to form one and the same crystal; in other words, the minerals are isomorphous. As a result of this, some of them are not known in an ideally pure condition:

for instance, smaltite always contains some iron and nickel isomorphously replacing the cobalt, and chloanthite always contains some iron and cobalt.

The cobalt and nickel ores, with the exception of the rare safflorite and rammelsbergite, are described further on (plates 35 and 36); and the description of the iron compounds to be now given will be followed by that of the iron ores proper.

Iron-pyrites. The name pyrites was used by the Greeks for a stone which gave sparks of fire when struck. No doubt several different minerals were included under this term, while in more recent times the name has often been used as a generic one (e. g. copper-pyrites, arsenical pyrites, etc.). The mineral to be now described is also often referred to as simply pyrites or pyrite, but to avoid any confusion the name iron-pyrites is here adopted.

The mineral contains iron (46.6 %) and sulphur (53.4 %) in the atomic ratio of 1:2, the formula being FeS_2 . When heated out of contact with the air, one half of the sulphur is driven off; and when heated in the air, the mineral burns with a small bluish flame like that of sulphur. The sulphur is thereby converted into sulphur dioxide; and if the mineral be roasted for some time the whole of the sulphur will be expelled, while the iron combines with oxygen to form red iron oxide, or in the presence of silica to form iron silicate. In the manufacture of sulphuric acid from iron-pyrites, the mineral is roasted in a current of air and the sulphur dioxide so formed is afterwards converted into sulphuric acid.

Iron-pyrites frequently contains traces of gold, which is set free when the mineral is weathered (p. 75). Traces of the rare metal thallium are also sometimes present; it collects in the dust in the flues of the sulphuric acid plant. Silver, copper, manganese, cobalt, nickel and arsenic also occur as traces in iron-pyrites, but the mineral never contains large amounts of these elements in isomorphous mixture.

Crystals of iron-pyrites belong to the cubic system, and they almost invariably clearly exhibit a parallel-hemihedral symmetry (p. 27), which is indeed so characteristic of this mineral that it is often referred to as pyritohedral hemihedrism. The faces of the cube are almost always striated parallel to only one of their edges, as shown in plate 26, fig. 1, though sometimes these faces may be quite smooth and free from striations (fig. 3). This striation is due to an oscillation between the faces of the cube and the pentagonal-dodecahedron, narrow strips of first one and then the other being alternately developed, although the latter may not always be developed as a definite face upon the crystals. The faces of the octahedron may also show by their striations the hemihedral symmetry (plate 26, fig. 2); the striations in this case being produced by an oscillation between the octahedron and the pentagonal-dodecahedron. In fig. 3, however, neither the cube nor the octahedron faces are striated, and the crystal shows no indications of the hemihedrism, being simply a combination of the cube and the octahedron. The most characteristic form of crystals of iron-pyrites is the pentagonal-dodecahedron (text-fig. 129), which form on this account is often called the pyritohedron. This is shown by the crystals in plate 26, figs. 5 and 6, though on the latter small faces of the octahedron are also present: the faces may be smooth, drusy, or striated either parallel (fig. 7) or perpendicular (fig. 5) to the cubic edge of the form. Another simple form is the dyakis-dodecahedron (text-fig. 130), though this is rare except in combination: in plate 26, fig. 4, it shows in addition small faces of the octahedron, and in fig. 7 we have a combination of the pentagonal-dodecahedron $\frac{\infty O 2}{2}$ and the dyakis-dodecahedron $\frac{3 O \frac{3}{2}}{2}$. Fig. 9 (and text-fig. 133) shows the two last forms together with the octahedron, the faces of the dyakis-dodecahedron being here quite narrow. In fig. 10 the cube predominates and is

combined with the dyakis-dodecahedron and the pentagonal-dodecahedron; the same combination, with the omission of the narrow faces of the last form, being shown in text-fig. 131. Finally, in the pseudomorphous crystal represented in fig. 8 (text-fig. 132) we have a combination of the cube and the pentagonal-dodecahedron.

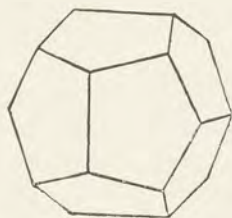


Fig. 129.
Pentagonal-dodecahedron.

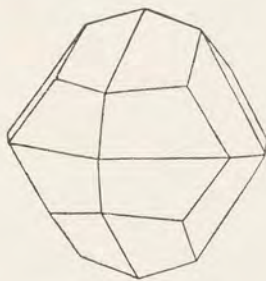


Fig. 130.
Dyakis-dodecahedron.

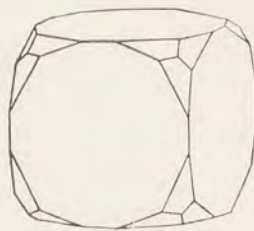


Fig. 131.
Cube with dyakis-dodecahedron.

Twinned crystals of iron-pyrites usually consist of an interpenetration of two pentagonal-dodecahedra (fig. 11 und text-fig. 134), the cubic axes of the two individuals being parallel; and one individual may be brought into the position of the other by a rotation of 90° about any one of these three axes. The cubic edges therefore intercross at right angles, and when these edges are truncated by faces of the cube they show a cross, as in the altered crystal represented in fig. 12. For this reason these twins of iron-pyrites are known as "iron-cross" twins.

Peculiarities in the form of growth of iron-pyrites are not very frequently met with; instances of this have been mentioned on p. 40 (plate 2, figs. 2—4). Here we may

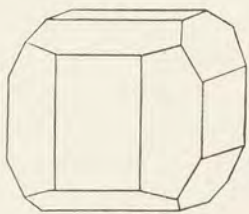


Fig. 132.
Cube with pentagonal-dodecahedron.

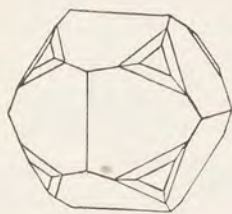


Fig. 133.
Pentagonal-dodecahedron with octahedron and dyakis-dodecahedron.

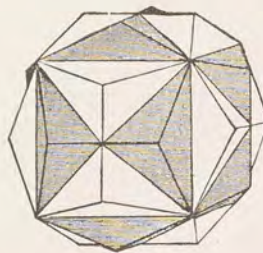


Fig. 134.
Interpenetration-twin of iron-pyrites.

draw attention to the thin discs with radial structure (plate 26, fig. 15) which have recently been found between the laminae of a black shale at Sparta in Illinois, where they are popularly known as "pyrites suns". Not infrequently, numerous smaller or larger crystals of iron-pyrites are aggregated to form balls or irregular nodular masses.

The colour of iron-pyrites is a pale brass-yellow with a metallic lustre; and the powder or streak is greenish- or brownish-black. The brownish-yellow or reddish colour shown by the crystals in plate 26, figs. 8, 12 and 14, and plate 3, figs. 7 and 8, is due to the alteration of the iron-pyrites to iron hydroxide or oxide. Iron-pyrites is very susceptible to an alteration of this kind, and pseudomorphs of limonite ($2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$) or of goethite ($\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$) are by no means uncommon. Still more frequent is the alteration of iron-pyrites to iron-vitriol and sulphuric acid, but in this case the form of the crystals is destroyed. Here there is an absorption of oxygen from the air, just as in the process of burning, and when the alteration proceeds rapidly there may be a

considerable rise in temperature. In this way beds of coal or lignite containing finely disseminated iron-pyrites may become ignited by the oxidation of the latter. The iron-vitriol formed during this weathering of iron-pyrites is soluble in water, and becomes further oxidized to a basic iron sulphate or to iron-ochre; while the free sulphuric acid acts on the surrounding rocks and produces sulphates, such as gypsum, glauber-salt, alum, etc. When limestone or calcite is so attacked, carbonic acid is liberated, and this is carried away by circulating waters and may act on other minerals. In this way the weathering of one mineral gives rise to a series of chemical processes in the earth's crust, whereby other minerals are destroyed and new ones are generated.

The hardness of iron-pyrites is 6. When struck with a steel the mineral gives sparks, owing to the ignition of the sulphur in the detached fragments. On this depended the use of iron-pyrites in the old tinder-boxes and firearms. The specific gravity is 5.

Iron-pyrites is very widely distributed, being one of the commonest of minerals. J. F. Henckel in his "Pyritologia" (1725) speaks of it as 'Jack in every street'. It occurs as small amounts in igneous rocks of almost all kinds, but it is more frequent in sedimentary rocks, especially in clay, clay-slate, limestone and coal; and it sometimes forms the material of fossil shells and fruits. Still more frequently does it occur in mineral-veins and as thick bedded deposits in sedimentary rocks. The iron-pyrites in mineral-veins and in sedimentary rocks must have been deposited from an aqueous solution, probably resulting by the reduction of iron-vitriol. Of the numerous localities at which it is found, we will here only mention those which have yielded specially fine crystals or those at which the mineral occurs in large quantities.

Simple pentagonal-dodecahedra and "iron-cross" twins, either fresh or altered to goethite, are found embedded in the Keuper marl at Vlotho near Minden in Westphalia (plate 26, figs. 12 and 13). Distorted octahedral growths and nodules, the size of a man's head, often intergrown with marcasite, are met with in the Tertiary clay and lignite deposits at Gross-Almerode in Hesse-Nassau (plate 2, figs. 2 and 3); and delicate forms of growth in the clay-slate of Münsterappel near Kreuznach in Rhenish Prussia (plate 2, fig. 4). In the British Isles, the mineral is of common occurrence, and good, crystallized specimens have been found in many of the Cornish mines.

The largest and finest crystals are found at Brosso and Traversella in the Ivrea district of Piedmont and at Rio in the Island of Elba. The mines of iron-pyrites at Brosso have been worked since the time of the Romans; and at the present time 400 to 500 men raise 1000 tons of ore a day. The ore occurs here as lenticular masses, 4 to 40 metres in thickness, with bands of limestone in mica-schist; associated minerals are quartz, dolomite, haematite and various sulphur compounds. The crystals shown in plate 3, figs 6 and 7, are from this locality. At Traversella the magnetite ore (the magnetite shown in plate 29 *a*, fig. 1, is from here) occurs at the contact of diorite, and the fine crystals of iron-pyrites (plate 26, figs. 2, 3, 4, 5 and 10) are found in the ore or in the accompanying gangue minerals. On the Island of Elba magnificent crystals of iron-pyrites (plate 26, figs. 6, 7, 9, 11 and 14) occur in association with haematite in the iron mine of Rio, close to the village of Rio Marina on the east coast of the island.

Large deposits of massive iron-pyrites are mined at Rammelsberg, near Goslar in the Harz, where the ore is mixed with copper-pyrites, zinc-blende, galena and barytes (see under copper-pyrites, p. 103). Similar deposits at Meggen in Westphalia have, during the last thirty years, yielded two-thirds of the total amount of iron-pyrites mined in Germany. Of special importance are the enormous deposits of Rio Tinto and other places in the Spanish province of Huelva. The ore here is unusually pure, being mixed with only little quartz and silicates; and as it contains some copper-pyrites it

is at the same time a valuable ore of copper. The content of copper varies from 2.6 to 3.02 per cent., and during the year 1898 the mines yielded 54,000 tons of copper. During the eighties of last century the iron-pyrites mines of Huelva accounted for between one-fifth and one-quarter of the total copper production of the whole world; but since then this has decreased, owing to the increased production from the United States. In the year 1900 the Rio Tinto mines yielded 1,894,500 tons of pyrites, containing on the average 2.744 per cent. of copper; 1,189,701 tons of the ore were smelted in Spain, yielding 21,120 tons of copper, and the remainder was exported to Germany, England and America. Even when poor in copper, the ore is of value for the manufacture of sulphuric acid.

Somewhat similar deposits are also mined at Sulitjelma in Arctic Norway, where the ore consists of a fine-grained mixture of iron-pyrites with copper-pyrites, pyrrhotite and other sulphides, and containing usually a little over two per cent. of copper. During the year 1880 these mines yielded 890 tons of copper; and in 1890, 466 tons of copper were obtained and 60,000 tons of pyrites exported. Another important deposit of cupriferous pyrites, consisting of a mixture of iron-pyrites and copper-pyrites, is met with at Røros in the district of South Trondhjem, in Norway. The total export of pyrites from Norway amounts to over 100,000 tons per annum. The Norwegian ore contains 44—45% of sulphur and $\frac{1}{4}$ to 5% of copper, and it possesses the great advantage of being practically free from arsenic.

Of other localities for iron-pyrites, we may mention those represented by specimens figured on the plates: Tavistock in Devonshire (plate 26, fig. 1, and probably also plate 3, fig. 8); Beresovsk in the Urals (plate 3, fig. 9), where the mineral occurs in the veins of gold ore; the French Creek mines in Pennsylvania (plate 2, fig. 1); Pelican Point, Lake Utah (plate 26, fig. 8); and the coal mines at Sparta in Illinois (plate 26, fig. 15).

Uses of iron-pyrites. — Next to native sulphur, iron-pyrites is the most important material for the manufacture of sulphuric acid (oil of vitriol), and for this purpose it is being used in increasingly larger amounts. It is heated in specially constructed ovens in a current of air, and when ignition has been started the material burns by itself: the sulphur dioxide is conducted to the acid chambers, and the red iron oxide which remains behind is utilized as a colouring material or as an ore of iron. Sulphuric acid prepared from iron-pyrites usually contains some arsenic, whilst that prepared from native sulphur is free from this disadvantage.

Iron-pyrites, owing to its high degree of hardness, takes a good polish, and it is used to a certain extent in cheap jewellery, especially in France; the form of cutting adopted is often that of a flat rosette. Polished plates of iron-pyrites have been found in the graves of the ancient Incas of Peru; these are known as Inca-stones, and were probably used as mirrors.

Marcasite has the same chemical composition as iron-pyrites, but it crystallizes in the rhombic system, the compound FeS_2 being dimorphous. Whilst the crystals of iron-pyrites are often large and distinctly developed, those of marcasite, on the other hand, are usually quite small and their form generally obscured by twinning. According to the forms of aggregation assumed by the twinned crystals, various popular names are applied to the mineral; for instance, the aggregate may be spear-shaped, as in the variety called "spear-pyrites" (plate 27, figs. 1 and 2). Simple (i. e. untwinned) crystals are rare and are similar to those of mispickel (text-fig. 136); they are bounded by an obtuse brachy-dome r , the faces of which are deeply striated parallel to the brachy-axis, and the vertical prism M with an angle of 75° between its faces; often the faces of the prism are quite small, or they may be completely absent. The crystal shown in plate 27,

fig. 1, consists of a twin of two such simple individuals, the twin-plane being a face of the vertical prism; the differently directed striations on the brachy-dome faces of the two portions of the twin meet in the vertical line, which is the trace of the twin-plane and the junction between the two individuals. The re-entrant angles at the sides of the compound crystal are the result of parallel grouping.

A similar kind of twin grouping is shown in the "spear-pyrites" in fig. 2, but here the twinning is frequently repeated, as shown by the fact that the re-entrant angles at the sides are connected with a change in the direction of the striations. This repeated twinning is shown more clearly in text-fig. 135. Sometimes there is a regular intergrowth of these marcasite twins with crystals of iron-pyrites, so that on the same specimen we have together the two modifications of iron disulphide. The small square outlines seen in the lower part of fig. 1 are cubes of iron-pyrites.

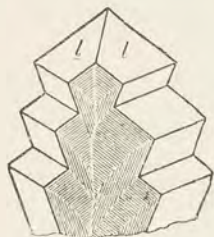


Fig. 135.
Twinned crystal of Mar-
casite (variety "Spear-
pyrites").

Another form of aggregation of marcasite crystals is that of a flattened plate with re-entrant angles along the edge, and bearing a close resemblance to a cock's comb; hence the name "cockscorn pyrites" for this variety. This is due to a repeated twinning on alternate faces of the prism, the prism planes forming the re-entrant angles, and the sides of the plate being a flat rounded brachy-dome. The crystals forming the group represented in fig. 3 show an approach to this form.

Globular (plate 27, fig. 4) and nodular aggregates with an internal radially fibrous structure are of common occurrence in marcasite. The form of the crystals is here obscured, and it is very difficult, or often impossible, to distinguish with certainty whether the material is marcasite or iron-pyrites.

The pale brass-yellow colour of marcasite is very similar to that of iron-pyrites, though perhaps it has a slightly more pronounced tinge of greenish-grey. The colour is, however, often masked by surface tarnish or alteration. The specific gravity of 4.8 is slightly less than that of iron-pyrites, whilst the hardness of the two minerals is about the same ($H. = 6$). The blowpipe reactions of marcasite are exactly the same as those of iron-pyrites, but as shown by careful researches there are certain differences in the chemical behaviour of the two substances. On some difference of this kind, no doubt, depends the greater readiness with which marcasite weathers to iron-vitriol. It has been suggested, however, that the greater surface presented by the thin and deeply striated marcasite crystals with their numerous re-entrant angles may favour atmospheric weathering to a greater extent than the more limited surface of crystals of iron-pyrites.

Marcasite is on the whole of rarer occurrence than iron-pyrites, but it is nevertheless of wide distribution, especially in mineral-veins, in clay and coal, and as a petrifying material. It is found in the mineral-veins of Clausthal in the Harz, of Freiberg in Saxony, and in Cornwall and Derbyshire; in the beds of zinc ore of Prussian Silesia; and in the deposits of lignite at Littnitz in Bohemia (plate 27, fig. 1). It is abundant in the chalk-marl of England and France, particularly between Dover and Folkestone in Kent (figs. 2 and 4).

When occurring in large amounts, marcasite is mined like iron-pyrites for the manufacture of sulphuric acid; and it is also used for making iron-vitriol.

Mispickel, arsenopyrite or arsenical pyrites, crystallizes in the rhombic system, and the crystals are usually bounded by a short vertical prism M and an obtuse, deeply striated brachy-dome r (text-fig. 136). The faces of the vertical prism ∞P are inclined at an angle of 112° (or 68° over the acute edge), and the obtuse dome $\frac{1}{4} P \infty$ has an



Marcasite Group and Pyrrhotite.

Fig.

1. **Marcasite** (variety "Spear-pyrites").
Littmitz, Bohemia.
2. **Marcasite** (variety "Spear-pyrites"), in grey chalk-marl.
Folkestone, Kent.
3. **Marcasite**, group of crystals.
Carterville, Missouri, U. S. A.
4. **Marcasite**, nodular group of crystals.
Folkestone, Kent.
5. **Mispickel** (Arsenopyrite), large crystals with black zinc-blende.
Mord mine, Freiberg, Saxony.
6. **Mispickel**, crystals with galena and black zinc-blende.
Freiberg, Saxony.
7. **Mispickel**, isolated crystal.
Freiberg, Saxony.
8. **Mispickel**, twinned crystal.
Deloro, Hastings Co., Ontario, Canada.
9. **Löllingite**, acicular crystals in serpentine.
Reichenstein, Prussian Silesia.
10. **Pyrrhotite**, tabular, hexagonal crystals.
Loben, St. Leonhard, Carinthia.
11. **Pyrrhotite**, massive.
Silberberg, Bodenmais, Bavarian Forest.



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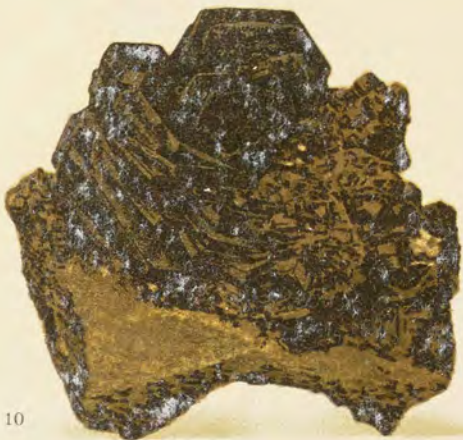
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11



angle 147° over its upper edge. Simple crystals with these forms are represented in plate 27, figs. 5, 6 and 7. Sometimes the crystals present a long prismatic habit and are terminated by an acute brachy-dome.



Fig. 136.
Crystal of Mispickel.

Interpenetration-twins of two crystals are of frequent occurrence, the two having a face of the macro-dome $P \infty$ in common (text-fig. 137); very often the two individuals differ in size, the smaller one projecting out of the larger. Twins with the vertical prism as twin-plane, as in marcasite, are also met with, as shown in plate 27, fig. 8; here the spear-like form of the upper portion of the twin is repeated in reversed position

in the lower portion, owing to the intercrossing of the individuals over the twin-plane.

Crystals of mispickel are often closely aggregated or confusedly crowded together on the matrix; and columnar and granular aggregates are not uncommon. They possess a metallic lustre with tin-white colour, but are often more or less tarnished on the surface. The hardness is 6, and the specific gravity 6.1.

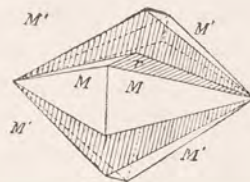
Not only in the form of the crystals is there a similarity between mispickel and marcasite, but also in the chemical composition. If we replace one of the atoms of sulphur of marcasite (FeS_2) by an atom of arsenic, we get the formula FeAsS of mispickel. Corresponding with this formula, the mineral contains 46 per cent. of arsenic. Small amounts of silver, gold, nickel and cobalt are sometimes present. When heated before the blowpipe, the mineral fuses to a magnetic bead and gives a strong garlic-like odour of arsenic. Heated in a bulb-tube, it first gives a red sublimate of arsenic sulphide and then a black lustrous sublimate of metallic arsenic.

Mispickel is principally found in metalliferous veins together with zinc-blende, galena and silver ores, or sometimes with tin-stone. The most important locality is Freiberg in Saxony (plate 27, figs. 5—7), where mispickel occurs in large amount in veins traversing gneiss. Large quantities are also found in many of the tin mines of Cornwall and Devonshire. Other localities are Munzig near Meissen, Marienberg, and Ehrenfriedersdorf in Saxony; Reichenstein in Prussian Silesia, here with löllingite in serpentine; the tin mines of La Villeder in Morbihan, France. Intercrossing twinned crystals (fig. 8) occur embedded in a quartzite in the Deloro mine in Ontario, Canada.

Like the following mineral, löllingite, mispickel is largely used for the preparation of white arsenic and other arsenic compounds. From some of the ores silver and gold are extracted.

Löllingite, or leucopyrite, consists of arsenic and iron with only a small amount of sulphur. The average content of arsenic is 67 per cent. and of sulphur 2 per cent.; and when free from sulphur the formula may be expressed as FeAs_2 , the two atoms of sulphur of marcasite being here replaced by arsenic. Small amounts of cobalt, nickel, copper, silver or gold are also frequently present. Distinctly developed crystals are rarely met with; these are rhombic with a form similar to that of mispickel; or more frequently they present the form of long needle-like prisms without terminal faces and are embedded in some other mineral, such as serpentine (plate 27, fig. 9). Usually, however, the mineral is met with as granular or columnar aggregates.

The colour is silver-white to steel-grey with a metallic lustre, and in external appearance the mineral has nothing to distinguish it from mispickel. The specific gravity of löllingite (7.4) is, however, considerably higher than that of mispickel (6.1). Before



the blowpipe, the mineral fuses only with difficulty, and the bead obtained is not magnetic; it gives a strong smell of arsenic and only a feeble reaction for sulphur.

A very extensive deposit of löllingite is met with in serpentine at Reichenstein in Prussian Silesia, which, it has been supposed, owes its origin to magmatic separation from the igneous rock from which the serpentine was derived. A similar occurrence, with zinc-blende and garnet is met with at Breitenbrunn in Saxony. The mineral also occurs in the deposits of chalybite on the Erzberg near Lölling in Carinthia; and in the Anniviers valley in Wallis, Switzerland.

Löllingite and mispickel are employed for the preparation of white arsenic (arsenious oxide) and other arsenic compounds. The ore is roasted in a current of air and the white arsenic condensed in long flues. The largest arsenic works are those at Reichenstein in Silesia, which date back to 1699. The annual production of löllingite amounts to 15,000 tons, from which white arsenic, arsenic sulphide (p. 139) and metallic arsenic are obtained, as well as 50—60 kilograms of gold (p. 78).

Pyrrhotite, or magnetic pyrites, is composed of the same elements as iron-pyrites and marcasite, but combined together in the proportion of approximately 1:1 instead of 1:2, the simplest formula being FeS . Usually, however, the mineral contains an excess of sulphur over that required by this simple formula and its actual composition varies from Fe_5S_6 to $\text{Fe}_{16}\text{S}_{17}$. Of impurities which may be present, nickel is the most frequent, and for this reason the mineral is often an important ore of nickel. In the Norwegian ores the nickel averages 3 per cent., and in the Canadian 5 per cent. The presence of nickel is, however, not essential, and many specimens are entirely free from it, so that the mineral is more appropriately described here than with the ores of nickel.

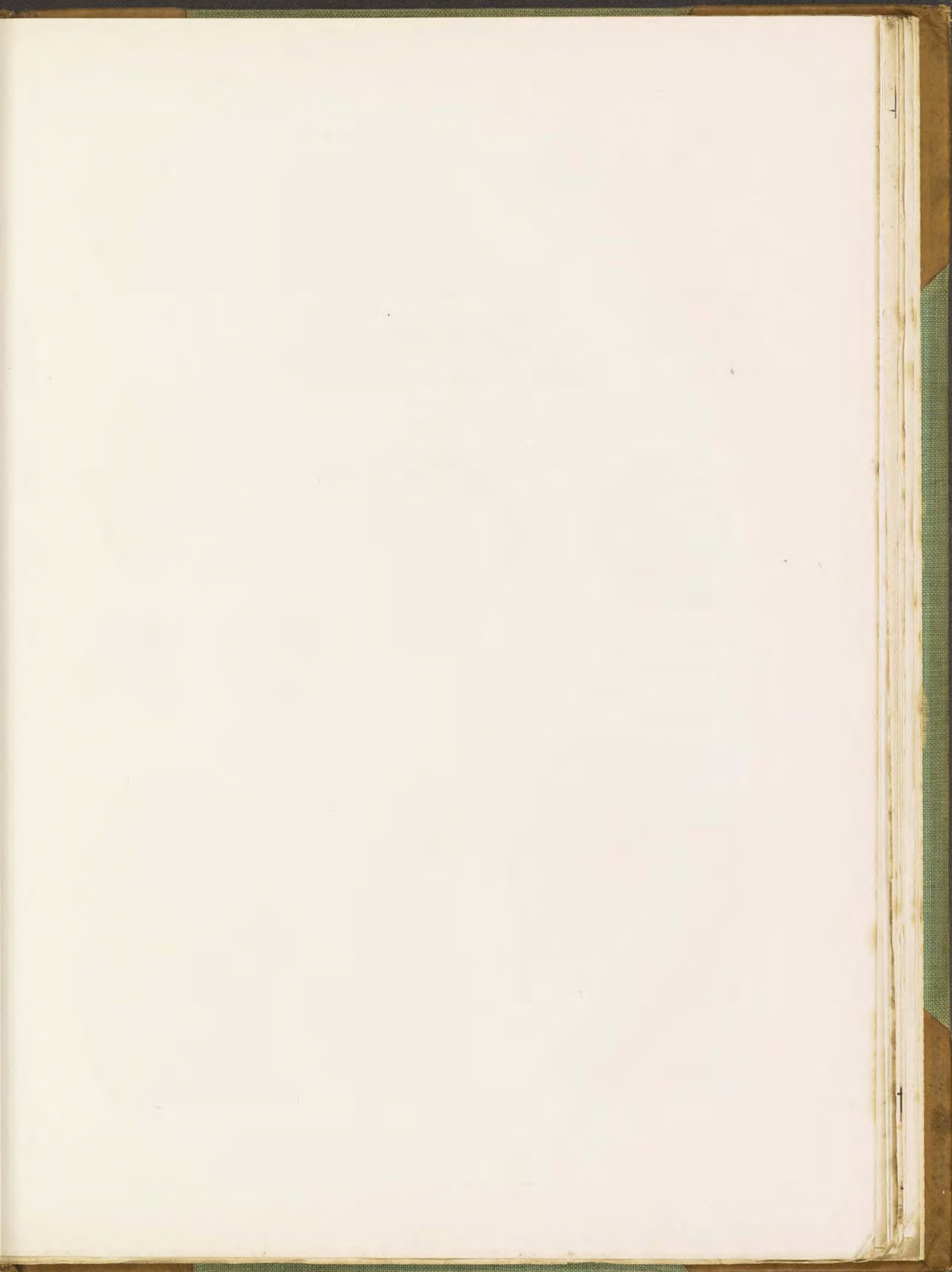
Crystals are hexagonal and tabular parallel to the basal plane (plate 27, fig. 10). More usually, the mineral is found as granular or lamellar masses (fig. 11). A characteristic feature is the bronze-yellow colour seen on a fresh fracture of the mineral; on the surface this soon tarnishes to a tombac-brown (tombac is a copper alloy, p. 114).

The name magnetic pyrites is applied to this mineral because of its magnetic character: small pieces are attracted by a magnet, and larger pieces will become magnetic with polarity when a magnet has been drawn across them. The hardness is 3—4, and the specific gravity 4.6. The mineral is soluble in hydrochloric acid with the evolution of hydrogen sulphide and the separation of some sulphur. When heated in the air it emits a strong smell of burning sulphur.

When subjected to special alteration processes, the mineral passes into iron-pyrites or marcasite, as proved by the frequent occurrence of pseudomorphs of these after pyrrhotite. By ordinary weathering it forms iron-vitriol.

Pyrrhotite is found in igneous rocks, such as gabbro and basalt, and it was probably formed as a separation from these while they were still in a molten condition. The large deposits occurring in connection with granite probably had a similar origin. It is also sometimes found embedded in crystalline limestone and in metalliferous veins.

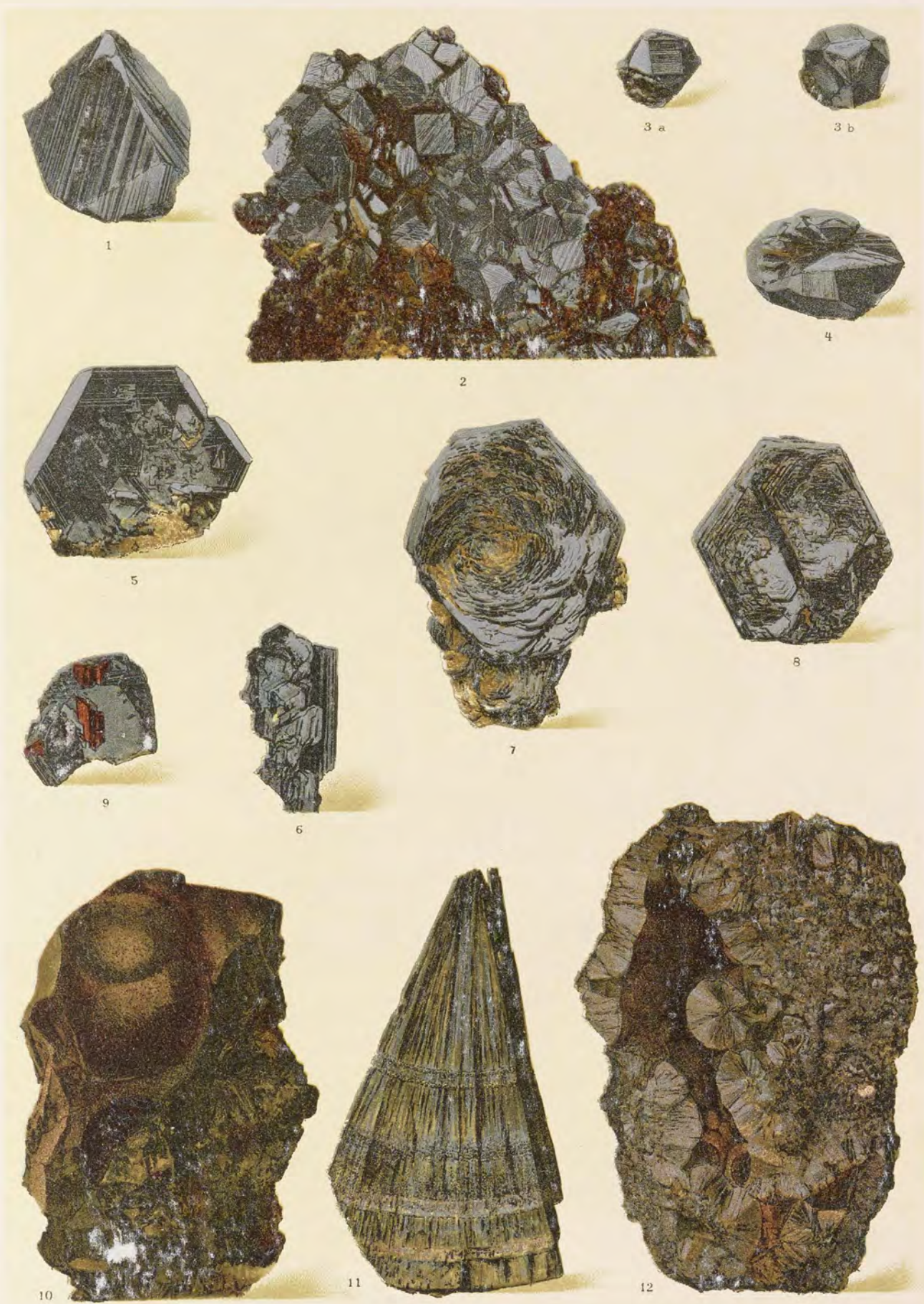
In Germany, the largest deposits of pyrrhotite are those on the Silberberg near Bodenmais in the Bavarian Forest (plate 27, fig. 11). The ore here forms lenticular masses interbedded in gneiss at the contact of this with granite, and consists of mixtures in variable proportions of pyrrhotite, iron-pyrites, copper-pyrites, zinc-blende and galena. Tabular crystals aggregated as rosettes are found at Leoben near St. Leonhardt in Carinthia (plate 27, fig. 10); and very similar crystals, altered to iron-pyrites, marcasite or mispickel, have been found in the mineral-veins of Freiberg in Saxony. Deposits, similar to those of Bodenmais, are met with at Sulitjelma in Arctic Norway and at Røros in central Norway; while small crystals occur with native silver at Kongsberg.



Iron Ores I.

Fig.

1. **Haematite** ("Iron-glance"), rhombohedron, with the faces striated parallel to their longer diagonal.
Achmatovsk, Ural Mountains.
2. **Haematite**, group of rhombohedra, with faces striated parallel to their longer diagonal.
Dognacska, Krasso, Hungary.
3. **Haematite**, *a* viewed from the side, *b* from above. Rhombohedron with hexagonal pyramid of the second order and a low rhombohedron.
Island of Elba, Italy.
4. **Haematite**, like the crystal shown in fig. 3, but with rounded edges.
Island of Elba, Italy.
5. **Haematite**, tabular crystal viewed from above; large basal plane with rhombohedron.
Tavetsch, Switzerland.
6. **Haematite**, thin, tabular crystals (sublimed on lava).
Porto da Sol, Madeira.
7. **Haematite** ("Iron-rose").
Fibbia, St. Gotthard, Switzerland.
8. **Haematite** ("Iron-rose").
Lago do Netto, Ouro Preto, Minas Geraes, Brazil.
9. **Rutile**, red prisms grown in regular position on haematite.
Cavaradi, Tavetsch, Switzerland.
10. **Haematite** ("Kidney-iron-ore").
Adorf, Waldeck, Germany.
11. **Haematite**, with fibrous and concentric structure.
Schwarzenberg, Saxony.
12. **Haematite** ("Kidney-iron-ore"), showing radial fibrous structure.
Eleonore mine, Bieber, Giessen, Hesse.





Very extensive deposits of nickeliferous pyrrhotite are mined at Sudbury in Ontario, Canada, and from these mines the larger part of the world's supply of nickel is obtained. Here again the ore occurs in connection with a basic igneous rock, from which it has probably separated in the molten condition.

Pyrrhotite is utilized for the manufacture of sulphuric acid, and when it contains nickel it is one of the most important ores of this metal.

Recent investigations have proved the identity of pyrrhotite with the meteoric mineral *troilite*. When fresh, this is bronze-yellow in colour, but it soon tarnishes steel-blue or tombac-brown. The larger nodular masses of troilite readily fall out or are decomposed when the surrounding iron becomes rusted: in this way were formed the rounded empty spaces in the meteoric iron shown in plate 32.

Iron Ores.

The compounds of iron which are useful as ores of the metal are all oxygen compounds, containing, besides iron, either oxygen alone or oxygen and water or carbonic acid. They include the following mineral species: —

Haematite, Fe_2O_3 .	Goethite, $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$.
Magnetite, Fe_3O_4 .	Limonite, $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$.
Chalybite, FeCO_3 .	

Several varieties of these minerals are distinguished, and they frequently occur mixed together, so that the ores themselves are often of the nature of rocks rather than of simple minerals. Indeed, such names as iron-stone, red-iron-stone, brown-iron-stone and clay-iron-stone suggest as much. The various impurities which may be present include clay, quartz, coal and iron phosphate.

One of the more important of iron ores, *minette*, is clearly not a mineral species, but a rock, being a highly ferruginous mixture of hydrated iron oxide, calcium carbonate, phosphates, and silica; it has the appearance of pisolitic iron ore (plate 30, fig. 6), but differs from this in the smaller size of its spherical concretions, which are never larger than a millet-seed. Minette occurs as beds in strata of Jurassic age, and its principal development is in Lorraine, Luxemburg and the neighbouring districts in France. The amount of ore available is estimated at 3435 million tons, and most of the iron produced in Germany and France is obtained from this class of ore.

Another iron ore, of much the same composite character and often with an oolitic structure, is known as *chamosite*. This occurs in the Silurian rocks of Bohemia and the Thuringian Forest, and in Bohemia it is of considerable importance as an ore of iron. Since, however, it is more of the nature of a rock than a simple mineral, it need not further engage our attention.

In addition to the simple minerals mentioned above, ilmenite and chromite are also rich in iron; the former will be considered with the compounds of titanium, and the latter will be mentioned in this place with the iron ores. In combination with silica, iron is also an important constituent of many other minerals, but these are of more importance as rock-forming minerals, which we shall consider together in their proper place.

Haematite. When crystallized, this mineral possesses a brilliant metallic lustre and black colour, and for this reason it has long been popularly known as *iron-glance*;

it differs, however, from other minerals to which the term glance is applied in containing no sulphur. On the other hand, the fibrous, compact, and earthy varieties of the mineral possess little lustre and are red in colour. It will therefore be convenient to distinguish the crystallized and massive varieties as iron-glance and red-iron-ore respectively.

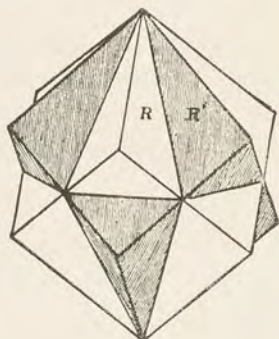


Fig. 138.
Twinned crystal of Haematite.

Crystals of haematite (plate 28) belong to the rhombohedral division of the hexagonal system, and are usually rhombohedral or tabular in habit. The angle between the faces of the primary rhombohedron is 86° , and the faces are often striated parallel to their longer diagonal. The unusually large rhombohedron represented in fig. 1 is of this form, and in addition it carries a narrow face of a more obtuse rhombohedron truncating an edge in the lower part of the figure. At the top of this crystal the edge of a smaller crystal is to be seen projecting from the large rhombohedral face to the left: this is the result of twinning on the basal plane, the two portions having this plane in common but placed in reversed position in respect to it. This twin intergrowth is shown more clearly in text-fig. 138, where the two interpenetrating rhombohedra are of equal size and of ideal development: the shaded rhombohedron R' may be brought into the position of the rhombohedron R by a rotation of 180° about the vertical axis, that is, an axis perpendicular to the basal plane which is here the twin-plane.

In the crystals from Dognacska, shown in fig. 2, the striated primary rhombohedron is also the predominating form, here in combination with the basal plane, which is to be seen as small triangular face. Crystals from the Island of Elba, figs. 3 and 4, show the same rhombohedron, but here with smooth faces, combined with a hexagonal pyramid of the second order $\frac{4}{3}P2$ and a flat rhombohedron; the faces of these forms are lettered r , r' and p respectively in text-fig. 139. The faces of the obtuse rhombohedron r' are often much rounded, as shown in fig. 4.

Crystals of tabular habit, owing to the large development of the basal plane, are characteristic of Alpine occurrences. The crystal shown in fig. 5 is set with up the base to the front, and the bright narrow faces at the edges are those of the primary rhombohedron. Often a number of tabular crystals of this kind are aggregated in not quite parallel position, giving rise to rosette-like groups, known as "iron-roses". An "iron-rose" from St. Gotthard is shown in fig. 7, and one from Ouro Preto, Brazil, in fig. 8. They contain, as a rule, a smaller or larger amount of titanium dioxide, which is often present as mechanically intermixed rutile, but sometimes it is in chemical combination.

Extremely delicate forms of crystallization are sometimes met with in the haematite formed by sublimation on the lava of volcanoes. The temperature of the lava is too low for the mineral to have been formed by direct sublimation, and it has resulted by the interaction of vapours of iron chloride and water. Thin plates of such sublimed haematite from Madeira are shown in fig. 6, and similar specimens are also found at Vesuvius.

The tabular crystals of haematite from the Alps often carry on their surface numerous minute crystals of rutile, with a definite crystallographic orientation between

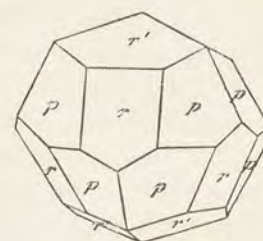


Fig. 139.
Crystal of Haematite.

the two minerals. As shown in text-fig. 140, the prism edges of the crystals of rutile are set perpendicularly to the adjacent edges of the haematite plate, so that over the whole surface of the latter the needles of rutile are arranged in three directions at angles of 60° . On the specimen shown in plate 28, fig. 9 the rutile prisms are much larger than is usually the case, and they follow only one of the three possible directions. This regular intergrowth of two totally distinct minerals is not readily accounted for, since there is neither a crystallographic nor a chemical relation existing between haematite and rutile, the latter being titanium dioxide with a tetragonal form of crystallization. Regular intergrowths of crystals of haematite and magnetite are also met with: here the octahedron faces of the magnetite coincide with the basal plane of the haematite, as shown in the upper left-hand corner of fig. 12, plate 19. These crystals of Alpine haematite sometimes show an alteration of a special kind, their whole substance being replaced more and more by rutile (plate 19, fig. 11 and 12), until at last the crystal with the external form of haematite consists solely of an interlacing network of rutile needles. The latter are arranged in the three directions at 60° explained above, as may be readily seen by the reflections from the surface as the crystal is turned about. In cases of this kind it is not always easy to decide whether we are dealing with an alteration pseudomorph or with an original intergrowth.

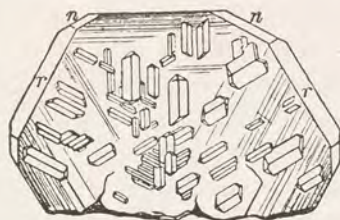


Fig. 140.
Rutile in regular growth on Haematite. (After Tschermak).

When haematite is finely powdered it loses its black or steel-grey colour, and the colour of the powder and of the streak is brownish-red. It is on account of this colour, like that of dried blood, that the mineral receives its name, the meaning of the Greek word haematite being blood-stone. In lamellae of extreme thinness, haematite is transparent with a deep red colour; and the lustre and colour of certain spangled minerals (sun-stone, aventurine quartz, carnallite) is due to the inclusion in them of microscopically small and thin plates of haematite.

When heated, haematite becomes magnetic, while in its unaltered natural state it is only feebly or not at all magnetic. The mineral is slowly dissolved by acids. Its hardness is 6, and its specific gravity 5.3. The pure material contains 70 per cent. of iron.

In addition to distinctly developed crystals, haematite also occurs as crystalline, granular, platy and scaly masses; the last being known as micaceous iron-ore. And when it is found in large quantity it is mined under the name of iron-glance or specular iron-ore. This variety of the mineral is not particularly susceptible to weathering, though when it takes up water into its constitution it passes to limonite.

Fine crystals of haematite are found in the deposits of granular and platy iron-glance on the east coast of the Island of Elba. The iron ores of this locality were known to the ancients, and at the present time the annual production amounts to 200,000 tons. The specimens shown in plate 28, figs. 3 and 4, are from here. Good crystals are also found at Traversella in Piedmont, in Sweden, and in other countries. The rich deposits in Sweden, yielding annually over two million tons of ore, are principally of magnetite, though there is also much iron-glance. Small, thin-tabular crystals are abundant in the deposits of red-iron-ore in Nassau.

Another mode of occurrence of crystals of haematite is in the crevices of silicate rocks. In the Swiss Alps, tabular crystals (plate 28, figs. 5, 7 and 9) are found in crevices in the gneissic rocks, and are associated with rock-crystal, adularia, rutile and several other crystallized minerals. Crystals of rhombohedral habit are met with in the veins

of tin ore at Altenberg in Saxony; and in metalliferous veins at Dognacska in Hungary (fig. 2), Achma'ovsk in the Urals (fig. 1), and other places.

Iron-glance of volcanic origin is found at Bertrich in the Eifel, on Vesuvius, Madeira (fig. 6), and elsewhere.

Red-iron-ore, or red haematite, when in a crystalline condition presents an internal radially fibrous structure and a nodular or reniform surface, being then known as kidney-iron-ore. The nodular surfaces of such masses are often smooth and polished, hence the German name "roter Glaskopf", for which there is no English equivalent. The nodular surface of kidney-iron-ore is shown in plate 28, fig. 10, and the fibrous structure on the fractured surfaces in fig. 12. In addition to the radially fibrous structure, there is often also a concentric shelly structure, as represented in fig. 11. Generally, however, red-iron-ore is quite compact and more or less impure owing to the admixture with it of quartz, clay (red clay-iron-stone or "ruddle"), or limestone. The presence of quartz increases the hardness of the ore, while clay diminishes it and the ore is then sometimes quite earthy. All varieties of red-iron-ore possess the red colour characteristic of powdered iron-glance, and in the mining districts where it is worked all the roads and the faces and clothes of the miners are of the same red colour.

Red-iron-ore usually occurs as beds in sedimentary rocks, and sometimes it has replaced limestones. This replacement process has already been described above in connection with a description of pseudomorphs of red-iron-ore after calcite (p. 50). The iron contained in the solutions which gradually replace the limestones may have been brought up from unknown depths in the earth's crust. Large deposits of this kind occur in connection with limestones in Cumberland, Nassau, Westphalia and the Harz. In other cases red-iron-ore may have been deposited directly from solution, or it may have been formed by the dehydration of the precipitates of chalybeate springs.

When occurring in the neighbourhood of igneous rock masses, red-iron-ore is not infrequently altered to magnetite; for instance, at the contact with diabase in the Dillenburg district in Nassau. In such cases the ore must have been deposited at a period prior to the intrusion of the igneous rock.

In Germany, beds of red-iron-ore occur in the Devonian rocks in the district of the Lahn and Dill, and at Elbingerode in the Harz Mountains. The important deposits in west Cumberland and the Ulverston district in north Lancashire fill large, irregularly-shaped cavities in the Carboniferous Limestone. Large deposits of earthy to compact red-iron-ore mixed with limonite and chalybite occur in the Chalk formation at Bilbao on the Bay of Biscay in Spain; the annual production of ore here being five million tons. A similar ore is also mined in north Africa. Brazil is also known to be rich in iron ores, but, owing to the lack of coal for smelting and to the difficulties of transport, they are but little exploited.

The principal use of iron-glance and red-iron-ore is of course as ores of iron. The more compact iron-glance and the finely fibrous red-iron-stone is often cut and engraved for ring-stones, pin-stones and other objects for personal ornament. The material takes a good polish, and is deep black with a brilliant metallic lustre. The finely fibrous material suitable for cutting comes mainly from Cleator Moor in Cumberland, and the compact variety is said to come from India; it is cut, under the name of blood-stone, mostly at Oberstein and Idar in Germany. Engraved cylinder-seals of haematite have been found in the ruins of Babylon and Troy, and in late Roman times the magic Abraxas gems were cut in the same material.

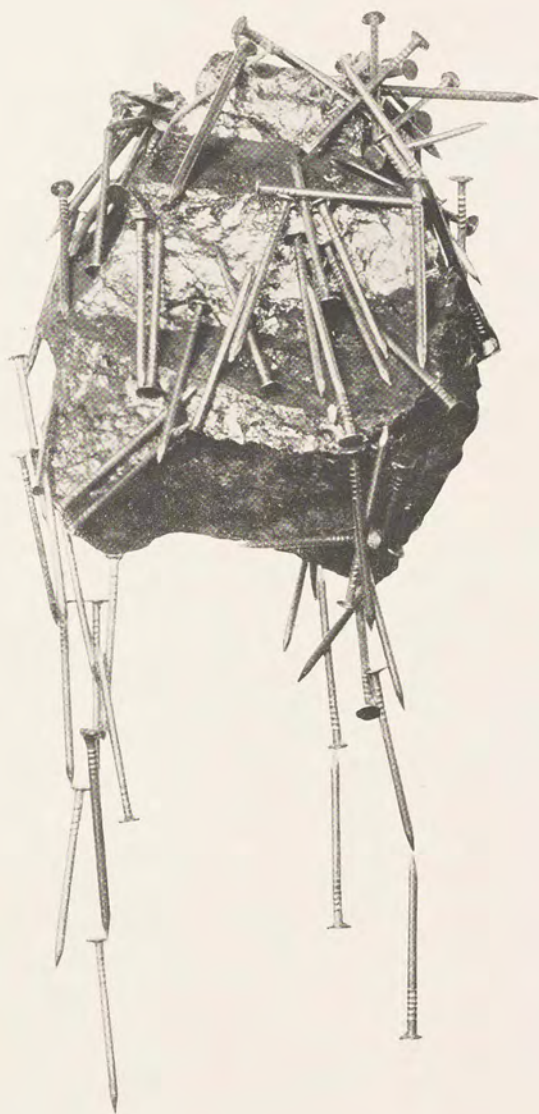
Tools made of polished haematite are used for burnishing gold and silver. Powdered haematite is used as a polishing material, and for making red paint and red pencils.



PLATE 28a.

Magnetite, as a natural magnet.
Magnet Cove, Arkansas, U. S. A.

PLATE 28a.





Magnetite, or magnetic iron-ore, occupies a unique position amongst minerals by reason of its very strong magnetic character. Some specimens of the mineral, especially massive pieces which are somewhat weathered, possess the property of attracting and holding to themselves small pieces of iron (plate 28*a*). In former times these natural magnets or lodestones were set in a suitable mount, and were the strongest magnets known; these are now no longer used, since much stronger and more conveniently shaped magnets can be made artificially by electrical means. Magnetite being a magnetic substance, any fragment of the mineral will be attracted by a magnet, or will affect a freely suspended magnetic needle, but every specimen of the mineral does not possess the power of attracting other magnetic substances; in other words, it is only particular fragments that are magnetic with polarity. It is probable that this polarity is not an original character of the mineral, but that it has been induced in it subsequent to its formation. Such a change may have been brought about by an electric current where magnetite exposed at the surface has been struck by lightning. Crystals found embedded in the solid rock are never magnetic with polarity. When heated to a high temperature ($575^{\circ}\text{C}.$) natural magnets, like artificial magnets, lose their magnetism.

Crystals of magnetite belong to the cubic system; their forms are illustrated in plates 29 and 29*a*. Fig. 1 of plate 29 shows a regular octahedron embedded in chlorite-schist, and fig. 2 of plate 29*a* shows crystals of the same form grown on the surface of mica-schist; an octahedron detached from the surface of the matrix is shown in plate 29, fig. 5. Octahedra of magnetite are frequently distorted in form, owing to the unequal size of the faces; in fig. 3, plate 29, alternate faces are smaller in size, and the crystal has the appearance of a combination of two tetrahedra. In fig. 4 the crystal is greatly elongated in the direction of one pair of parallel edges of the octahedron, so that it presents the appearance of a rhombic prism terminated by a brachy-dome. In these cases, however, the angle between the faces is the same ($109^{\circ} 28'$) as in a regularly developed octahedron. The edges of the octahedron are sometimes truncated by faces of the rhombic-dodecahedron (plate 29, figs. 2 and 6; plate 29*a*, fig. 1), but it is only rarely that faces of the cube are also present (fig. 7). Other crystals of magnetite are bounded by the rhombic-dodecahedron alone (fig. 8), or by this in combination with small faces of the octahedron; in the latter case the faces of the rhombic-dodecahedron are usually striated parallel to their longer diagonal (text-fig. 141).

The twinned crystal shown in plate 29, fig. 9, and text-fig. 142 is an octahedron twinned on an octahedron plane, and resembles the well-known twins of spinel (p. 45). These "spinel-twins" of magnetite usually occur embedded in chlorite-schist.

Delicate forms of growth are often assumed by magnetite, but only when the mineral is embedded in the solid rock; these are therefore only to be observed under the microscope in thin slices of the rock. Such a dendritic growth is shown under a magnification of ninety diameters in plate 59, fig. 1; here, numbers of tiny octahedra are arranged along branches at angles of 90° , parallel to the three cubic axes (as, on a much larger scale, in the specimen of native silver shown in plate 6, fig. 7).

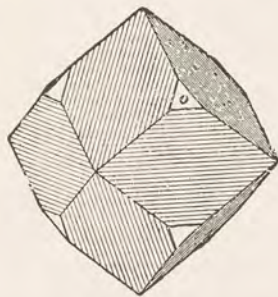


Fig. 141.
Crystal of Magnetite.

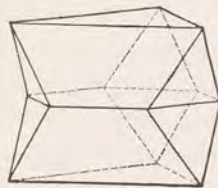


Fig. 142.
"Spinel-twin" of
Magnetite.

Magnetite is opaque and black, and sometimes exhibits a brilliant metallic lustre (as in plate 29*a*, fig. 2); often, however, the crystals are dull (plate 29, figs. 1, 3 and 4). The streak and powder are of the same black colour. The hardness is 6, and the specific gravity 5.

When pure, magnetite contains 72.4 per cent. of iron, and its formula is Fe_3O_4 or $\text{FeO} \cdot \text{Fe}_2\text{O}_3$. Titanium, chromium, manganese, magnesium, etc. are sometimes present. In its chemical formula, as well as in its crystalline form, magnetite shows a close relationship to the spinel group (see spinel). When subjected to weathering, magnetite passes into limonite or into haematite. When altered to haematite, the crystals are known as martite, this name having been given to a supposed cubic form of iron sesqui-oxide (Fe_2O_3), which is now recognized as haematite pseudomorphous after magnetite. Magnetite undergoes no alteration when heated to redness, but other iron ores when ignited pass into the more stable form of magnetite.

In addition to embedded and attached crystals, magnetite also occurs as granular and compact masses, which are often of very considerable extent. The mode of occurrence of such masses in the earth's crust varies according to their mode of origin. The mineral is of wide distribution as a constituent of igneous rocks (plate 59, fig. 1) and volcanic ashes: and it may be extracted from the powdered rock by means of a magnetized knife-blade. In such cases it usually occurs in only a finely divided condition and is present in greater quantity in the darker coloured rocks; but at times it has separated or accumulated in the igneous rock to form enormous masses, and even mountains are sometimes formed of almost pure magnetite. Rich deposits of this kind are met with and mined in the mountains of Vyssokaya Gora near Nizhni-Tagilsk and the Goroblagodot near Kushva in the Urals, the Kirunavara and the Luossavara and other mountains in Swedish province of Norrbotten, and the Taberg near Jönköping in Småland, Sweden. The richness in iron ore of Russia and Sweden is mainly accounted for by these magnetite deposits. The largest Scandinavian deposit of iron ore is that of Kirunavara and Luossavara in the north of Sweden, where between the surface and a depth of only a metre $1\frac{3}{4}$ million tons could be obtained, whilst the total amount of ore available is estimated at 750 million tons. The ore contains on an average 63 per cent. of iron together with about 2 per cent. of phosphorus.

Other deposits of magnetite have been formed by the heating action (contact metamorphism) of igneous rock masses on other ores of iron (chalybite, haematite or limonite), whereby these have been wholly or partially converted into magnetite. Thus, near Siegen in Westphalia a vein of chalybite in contact with basalt has been altered into earthy magnetite, and at Dillenburg in Nassau red-iron-ore has been converted by a diabase intrusion into hard, compact magnetite. These small occurrences in Germany illustrate the mode of formation of the rich deposits of magnetite at Gellivara in Swedish Lapland, and perhaps also those of Dannemora near Upsala and the beds of magnetite interlaminated in crystalline schists at Grängesberg in Sweden. The deposits at Arendal in southern Norway are well known to mineralogists because of the beautifully crystallized silicates (idocrase, epidote, augite, scapolite, garnet, etc.) which they have yielded. Similar, but poorer, deposits of magnetite are met with at Schmiedeberg in the Riesengebirge, at Dognacska in Hungary, and at Traversella in Piedmont.

Fine crystals have been found at several localities, for example: at Traversella in Piedmont, in cavities in the massive ore, in which the crystals of iron-pyrites already mentioned are also found, (plate 29, fig. 6 and plate 29*a*, fig. 1); in the Tyrolese Alps, embedded in chlorite-schist (plate 29, figs. 1 and 9, from the Pfitschthal): in the Binnenthal in Wallis, Switzerland, attached to the walls of crevices in gneiss and



Iron Ores II.

Fig.

1. **Magnetite**, octahedron embedded in chlorite-schist.
Pfitschthal, Tyrol.
2. **Magnetite**, octahedron with narrow faces of the rhombic-dodecahedron.
Mineville, Essex Co., New York, U. S. A.
3. **Magnetite**, irregularly developed octahedron presenting the appearance of a combination
of two tetrahedra.
Moriah, Essex Co., New York, U. S. A.
4. **Magnetite**, irregularly developed octahedron, elongated in the direction of one edge.
Mineville, Essex Co., New York, U. S. A.
5. **Magnetite**, octahedron with rounded edges.
Binnenthal, Wallis, Switzerland.
6. **Magnetite**, octahedron with rhombic-dodecahedron. The faces of the apparent rhombic-
dodecahedron are really built up of small octahedra.
Traversella, Piedmont Italy.
7. **Magnetite**, octahedron with rhombic-dodecahedron and cube.
Stura valley, Turin, Piedmont, Italy.
8. **Magnetite**, crystals on matrix; rhombic-dodecahedron with octahedron.
Nordmark, Wermland, Sweden.
9. **Magnetite**, octahedron twinned on an octahedral face.
Pfitschthal, Tyrol.
10. **Chalybite**, rhombohedra on quartz.
Neudorf, Harz Mountains, Germany.
11. **Chalybite**, group of rhombohedra.
Dörell, Lintorf, Hannover.
12. **Chalybite**, rhombohedron altered on the surface to limonite.
Viesch, Wallis, Switzerland.
13. **Chalybite** (variety "Sphaerosiderite"), globular on basalt.
Steinheim, Hanau, Germany.

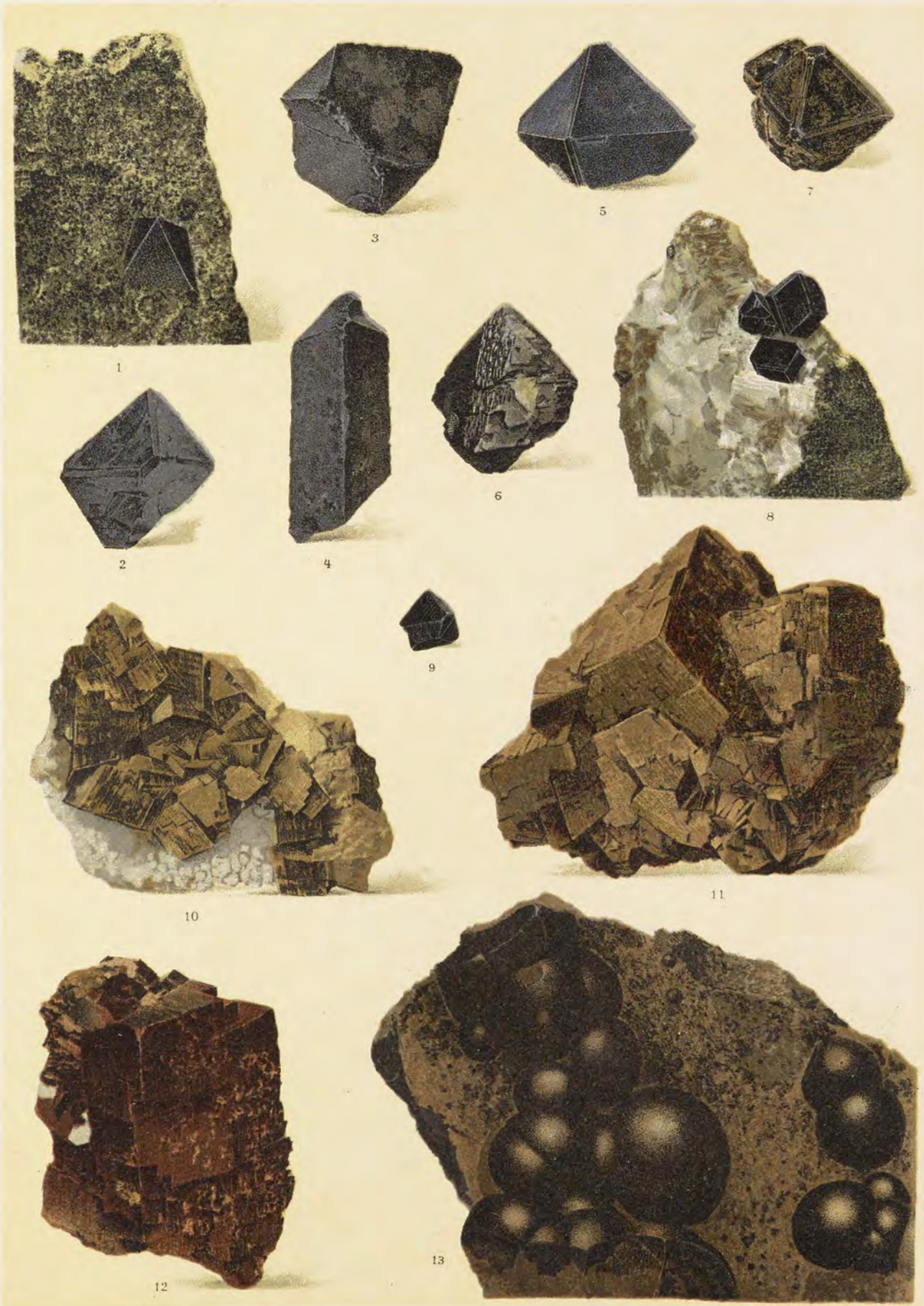






PLATE 29 a.

Iron Ores III.

Fig.

1. **Magnetite**, group of crystals; octahedron with rhombic-dodecahedron.
Traversella, Piedmont, Italy.
2. **Magnetite**, octahedra on mica-schist.
Binnenthal, Wallis, Switzerland.



1



2



mica-schist (plate 29, fig. 5, and plate 29*a*, fig. 2); in the Stura valley, north-west of Turin (fig. 7); at Nordmark in Sweden (fig. 8). The remaining crystals represented on plate 29 are from Mineville (figs. 2 and 4) and Moriah (fig. 3) in Essex Co., New York.

Magnetite finds an extensive application as one of the most important ores of iron. Suitable pieces are also used as natural magnets.

Chromite, or chromic iron-ore, is a mineral closely resembling granular magnetite in general appearance, but it may be distinguished from this by its brownish-black colour, brown streak and slightly greasy lustre. A ready and certain test for distinguishing these two minerals is by fusing fragments of them in borax beads: in both cases the bead is yellow while still hot, but when cold it is yellowish-green for chromite. This characteristic green coloration is due to chromium, which is an essential constituent of chromite. In a pure condition the mineral consists of 68 per cent. of chromic oxide and 32 per cent. of ferrous oxide, corresponding with the formula $\text{FeO} \cdot \text{Cr}_2\text{O}_3$. Often, however, the ferrous oxide is partly replaced by an equivalent amount of magnesia, and the chromic oxide by ferric oxide and alumina. Chromite is practically unattacked by acids. Its hardness is $5\frac{1}{2}$, and its specific gravity 4.8. The rarely occurring crystals are cubic, like those of the closely allied minerals magnetite and spinel.

Chromite occurs as granular masses, and has been formed as a separation from molten igneous rocks rich in olivine, thus having an origin similar to that of some magnetite deposits. These olivine rocks are particularly susceptible to weathering, and it is in the serpentines derived from them that deposits of chromite are usually met with.

Rich deposits of chromite occur in Asia Minor, and it is from here that the bulk of the world's production of this mineral is now obtained. The mines are situated in two districts: one is near the south-west coast of Anatolia not far from the island of Rhodes; and the other, in the north, at Chatalja-Dagh and Chardi to the south and south-west of Mount Olympus. The annual production of one of the richest mines amounts to 10,000 to 12,000 tons of the best ore, valued at about £50,000.

Considerable deposits are also found in North Carolina, between Ashe County and Clay County; the yield here in 1896 was 17,887 tons. In Russia, chromite is found only in the Urals, and in the government Perm there were, in the year 1893, twenty-five mines which produced 14,600 tons of ore; but since that date the production has fallen off. Chromite has been mined also at Kraubat in Upper Styria, at Hestmandö in Norway, and in some other localities.

Chromite is used for the preparation of chromium compounds, such as potassium chromate and bichromate, chromic acid and various chrome colours; and, more recently, metallic chromium has been extracted from it, this being added to steel to give the hard chromium-steel. Owing to the high melting point of chromium, it is only recently that the extraction of this metal has been possible on a commercial scale. The method now extensively in use was discovered by H. Goldschmidt and depends on the very high temperature produced by the burning of metallic aluminium. Chromium oxide is mixed with aluminium powder, and this surrounded by another mixture of aluminium powder and barium peroxide in which a magnesium ribbon is laid. The magnesium is ignited and this ignites the aluminium, which in the outer layer burns at the expense of the barium peroxide and so produces an extremely intense heat; at this high temperature the aluminium in the interior is oxidized at the expense of the chromic oxide, whereby alumina (corundum) and metallic chromium are produced.

Besides occurring as an essential constituent of chromite, chromium also occurs in crocoite (p. 123), in some garnets, and in a few other minerals; but none of these are used for the extraction of the metal or its compounds.

Chalybite, or spathic iron-ore. Whilst magnetite, the iron ore which we have just considered, owes its origin to the action of heat, another important ore, namely chalybite, has been deposited from aqueous solution. It is, however, not from solutions at the earth's surface that the mineral can be deposited, since in contact with the air and water it is not stable. Being ferrous carbonate, FeCO_3 , it is, like all other ferrous salts, readily oxidized, and at the earth's surface it soon becomes altered to the more stable compound limonite. For this reason, where beds or veins of chalybite outcrop at the surface, there is a gossany capping of limonite.

When chemically pure, chalybite contains 62 per cent. of ferrous oxide or 48.2 per cent. of iron; but the iron may be partly replaced isomorphously by equivalent amounts of manganese, magnesium or calcium, whilst the ores are often mechanically intermixed with clay, coal or other impurities. The mineral dissolves with effervescence (owing to the liberation of carbon dioxide) in warm hydrochloric acid, and the solution becomes yellow. When ignited it becomes black and magnetic. The hardness is 4, and the specific gravity 3.9.

Crystals (plate 29, figs. 10, 11, 12) have usually the form of a rhombohedron with angles of 107° between the faces. They are often very like crystals of dolomite in appearance, as may be seen from a comparison of plate 29, fig. 11, and plate 75, fig. 7; the crystals of both these minerals are frequently curved in saddle-shaped forms, and they possess perfect cleavages parallel to the faces of the rhombohedron. Both in crystalline form and chemical composition, chalybite and dolomite are closely related to the rhombohedral minerals calcite, magnesite, rhodochrosite and calamine, all of which are carbonates of chemically allied metals. Some of them exhibit characteristic differences in colour, depending on the metal they contain, which in some cases enables us to distinguish one mineral from another by inspection alone. The colour of fresh and unaltered chalybite is yellowish-grey, but usually it shows a rich brown colour owing to the partial alteration of the mineral. When weathered, the mineral passes into limonite, as shown in the pseudomorph of limonite after chalybite in fig. 12. Manganiferous chalybite becomes bluish-black on weathering, owing to the black colour of the separated manganese oxide; this is known as "blue ore", whilst fresh chalybite is "white ore", and the ordinary ore partially weathered to limonite is called "brown ore".

Chalybite also occurs as coarse or fine grained crystalline aggregates; and this massive material forms the ordinary type of ore. Intimately intermixed with clay it forms nodular masses in some sedimentary rocks, and is then known as clay-iron-stone or clayey sphaerosiderite; or when mixed with carbonaceous matter it is called black-band iron-stone. Pure chalybite also occurs in nodular masses with an internal radially fibrous structure and is then known as sphaerosiderite; in plate 29, fig. 13, this is seen in a cavity in basalt.

Chalybite occurs in veins and is then usually accompanied by quartz and copper-pyrites (plate 11, figs. 5 and 10); as, for example, in the Siegen district in Westphalia, in the Harz, in the mining district of Schmalkalden in the Thuringian Forest, and in Cornwall. Or again, it forms thick beds, one of the richest being that of the Erzberg near Eisenerz in Styria; this has been worked ever since the time of the Romans, and the annual production amounts to about one million tons of ore containing on the average 42 per cent. of iron. Similar deposits are mined at Hüttenberg in Carinthia and at Gyalar in Transylvania. The iron ore occurring as extensive beds in the Lias strata of the Cleveland district in Yorkshire consists mainly of chalybite in a pisolitic form; here about $5\frac{1}{2}$ million tons of ore are raised per annum. Of great importance are the clay-iron-stones and the black-band iron-stones found in the Coal-measures of England and

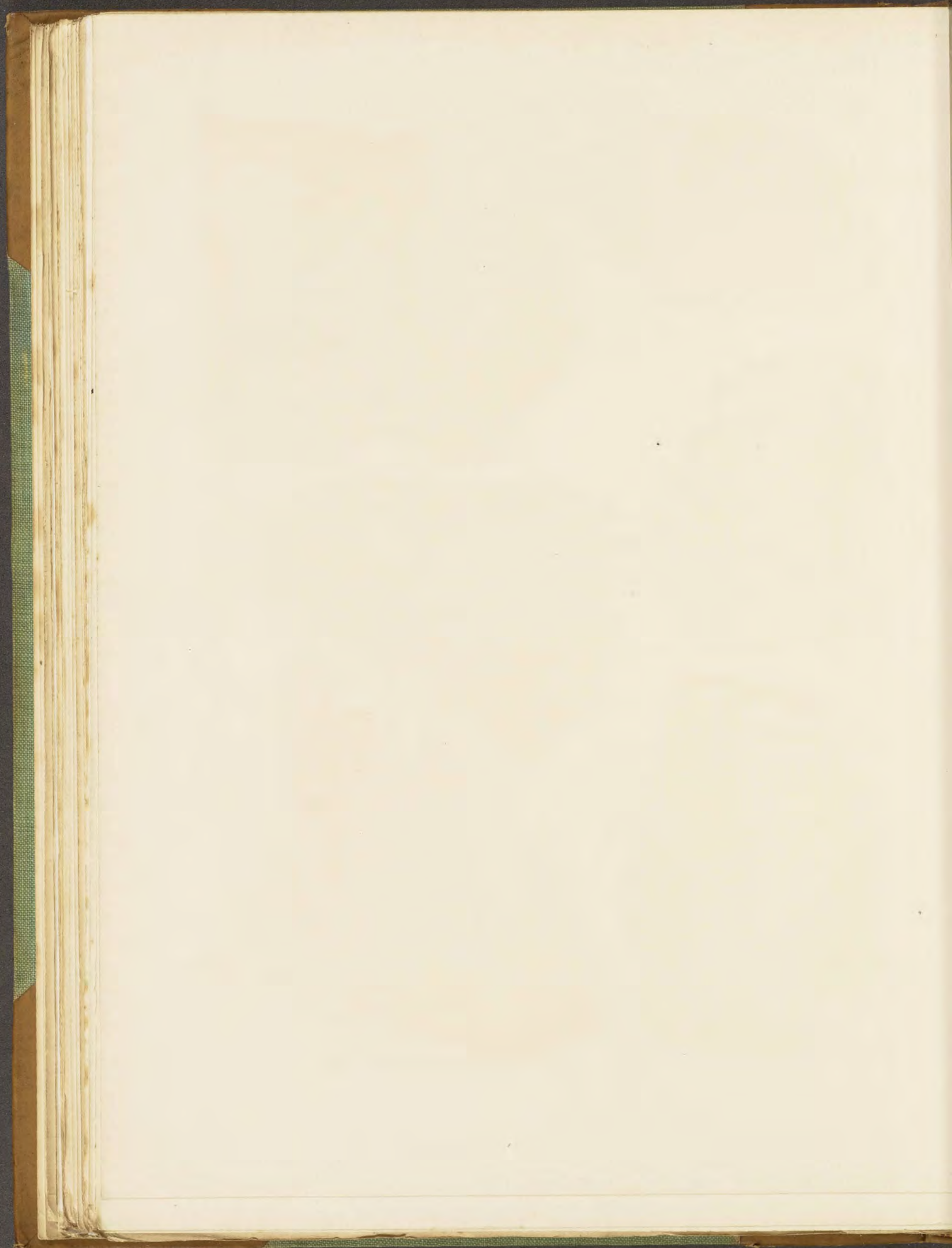


Iron Ores IV.

Fig.

1. **Goethite**, striated, columnar crystals forming radial aggregates.
Florissant, Colorado, U. S. A.
2. **Goethite** (variety "Lepidocrocite"), an aggregate of fine scales with an external nodular form.
Siegen, Westphalia.
3. **Limonite** ("Brown-iron-ore"), with radial and concentric structure.
Luise mine, Horhausen, Rhenish Prussia.
4. **Limonite**, tubular with internal radial structure.
Siegen, Westphalia.
5. **Limonite**, stalactitic with internal radial structure.
Rossbach mine, Puderbach, Westerwald, Germany.
6. **Limonite** (variety "Pisolitic iron-ore").
Auggen, southern Baden.





South Wales, and in the coal mining district of Ruhr in Prussian Silesia. Sphaerosiderite is found in basalt at Steinheim near Hanau (plate 29, fig. 13) and at several spots in the Vogelsberg. Localities for good crystals of chalybite are: Neudorf in the Harz (fig. 10); Lintorf in Hannover (fig. 11), these often with small scalenohedral faces; the Siegen district in Westphalia; and several of the Cornish mines.

Chalybite is one of the best ores of iron, and is of great importance for the production of the metal.

Limonite, or brown-iron-ore, is distinguished from the other ores of iron by the fact that it never occurs as crystals; pseudomorphous crystals of limonite after some other mineral are, however, by no means uncommon. Apart from these pseudomorphous crystals, the mineral itself forms fibrous aggregates or compact amorphous masses. The former are often stalactitic (plate 30, fig. 5), tubular (fig. 4), reniform or botryoidal on the exterior; in the interior these rounded forms are brown with a fibrous structure, whilst on the exterior they are often black and shining, hence the German name "brauner Glaskopf", for which there is no English equivalent. Sometimes the internal structure is very similar to that of red-iron-ore, suggesting that in some cases limonite may have been derived from haematite, though of course it is possible that the reverse transformation may also have taken place. Thus, for example, the radially fibrous and concentric shelly structure shown for limonite in plate 30, fig. 3, is very similar to that of red-iron-ore in plate 28, fig. 11. The bulk of the ore in a deposit of limonite usually consists of amorphous and compact or earthy material. Sometimes, a pisolitic structure is apparent throughout the whole mass of ore, which consists of small spherical concretions, with a concentric shelly structure, set in a cement of earthy limonite: this is known as pisolitic iron-ore or as bean-ore (plate 30, fig. 6). When the spherical concretions are much smaller, the structure is described as oolitic, an example of which is the ore known as "minette" (p. 151).

Pure limonite contains 59.9 per cent. of iron, corresponding with the formula $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$; but the compact masses of this mineral, as well as pisolitic iron-ore and "minette", are rendered impure by the admixture of clay, silica, calcium carbonate, phosphates, etc. The presence of calcium and manganese in the ore is rather an advantage, since less limestone need be used in the smelting, and less manganese added for making special kinds of steel. The hardness of fibrous limonite is 5—5 $\frac{1}{2}$, and the streak brown to ochre-yellow: the specific gravity is 4, though often lower than this when impurities are present. When a fragment of the mineral is heated in a bulb-tube, water is expelled and condenses as drops on the side of the tube, and the brown limonite is converted into red iron oxide.

At the earth's surface, limonite is the most stable compound of iron, and it results from the weathering of other iron ores and other minerals rich in iron. In the form of earthy iron-ochre it separates around chalybeate springs, in swampy places on moors and meadows (bog-iron-ore, marsh-ore, meadow-ore), and at the bottom of pools and lakes (lake-ore). The fibrous and more compact masses occur in the gossany capping of lodes and deposits of other minerals (see under chalybite and copper-pyrites). Pisolitic iron-ore occurs as a deposit from springs either directly or as a replacement of limestone.

In Germany, veins and beds of limonite occur in the Siegen district in Westphalia, in Nassau, on the borders of the Vogelsberg, in the Harz, and in the Thuringian Forest; rich deposits are met with at Peine in Hannover, at Salzgitter in the Harz, and in Prussian Silesia. Bean-ore occurs principally in fissures and cavities in limestone, for example in the Swabian Jura, and at Kandern in Baden (plate 30, fig. 6), as also

at Lauben in Switzerland. The localities for "minette" have already been mentioned on p. 151.

Bog-iron-ore is widely distributed over depressed areas in north Germany, in European Russia, and in Finland and Sweden. A typical occurrence in North America is that of the Three Rivers district in province Quebec. Deposits of bog-iron-ore, like those of peat, may be observed in their process of growth, and when such a deposit has been exhausted, it may again be worked after the lapse of some time. Owing to the never failing presence of phosphates in this ore, it was formerly of only little use as an ore of iron; it gave a very fluid metal especially suitable for castings, but these are very brittle ("cold-short"). Now, however, that iron can be readily freed from phosphorus by the Thomas-Gilchrist process, and as the Thomas slags are of value as fertilizers, these ores are of increased importance: and the same applies to "minette", which is the most important of iron ores in Germany.

Besides being used as an ore of iron, limonite in its ochreous variety is employed as a pigment (yellow ochre). The pigment known as umber is a mixture of limonite, manganese oxide and clay. (Cologne umber is an earthy lignite.)

Goethite is a mineral which receives its name from the poet Goethe, who added the study of minerals and rocks to his many-sided interests, and he not only collected minerals and gems but also published several of his observations relating to them. Such a name might very well have been associated with a more beautiful and interesting mineral than the one to be now described. This is a hydrated oxide of iron, containing the same constituents as limonite but combined in different proportions, the formula being $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$. The pure mineral contains 62.9 per cent. of iron.

Crystals of goethite belong to the rhombic system and are developed in two very different habits. In one, they are long-prismatic or acicular with a form similar to that of manganite (compare plate 34, figs. 5—7), and are usually closely aggregated in bundles (plate 30, fig. 1); this variety is sometimes known as needle-iron-ore. Other crystals have the form of very small and thin scales, which are transparent with a ruby-red colour; this is the variety called pyrrhosiderite. Nodular aggregates of very fine scales (plate 30, fig. 2) have received the name lepidocrocite. The mineral also occurs as compact masses, as in the pseudomorph after iron-pyrites shown in plate 3, fig. 8.

The crystals possess a perfect cleavage in one direction. Their hardness is 5—5½, and their specific gravity 5.3.

Most frequently, goethite occurs in association with limonite, either as strings of lepidocrocite or crystallized in glittering scales in the cavities. Under these conditions it is found in the Siegen district in Westphalia, at Bieber near Giessen in Hesse, and some other places. Amethyst with enclosed needles of goethite is found at Oberstein on the Rhine, on Wolf's Island in Lake Onega, Russia, and in Brazil. The best crystals are from the Restormel iron mines at Lostwithiel and the Botallack mine near St. Just in Cornwall; these are prismatic in habit and have a brilliant lustre. Crystallized material is also found at Florissant in El Paso Co., Colorado (plate 30, fig. 1).

Metallurgy of Iron. — The metallic iron obtained by smelting iron ores in blast-furnaces is not a chemically pure iron, but always contains other elements, principally carbon, in combination: pure iron is not used for technical purposes. The furnace is charged with alternating layers of iron ore and coke, and when necessary some limestone is also added. The latter combines with any silica which may be present in the ore and with the ash of the fuel to form an easily fusible slag. With certain classes of ore, such as the German "minette", which contain the necessary amount of calcium this addition of limestone is not necessary. The lowest layer of coke is ignited and a strong

blast of hot air is forced into the furnace. In this way the upper layers of ore become gradually heated, water and carbon dioxide are expelled (if the ore has not been previously treated in special roasting ovens) and iron oxide is formed. Carbonic oxide, formed by the burning coke, rises in the furnace and gradually reduces the heated iron oxide to a spongy mass of metallic iron rich in carbon. Lower down, where the temperature is greater, this fuses and dissolves more carbon, and owing to its great weight it flows down and collects in the bed of the furnace. From here the metallic product is drawn off from time to time, whilst the lighter slag flows almost uninterruptedly from a higher opening. The slag is utilized for road-metal, or for the manufacture of cement or compressed artificial stone. The process is a continuous one, for fresh materials are constantly being charged into the top of the furnace, and the products continuously drawn out from the bottom.

The raw iron, or pig-iron, so obtained contains about 4 per cent. of carbon, together with small and variable amounts of silicon, phosphorus, sulphur and manganese. Being fusible at a comparatively low temperature, it is used for castings. White cast-iron contains the carbon in chemical combination, and since the presence of manganese favours the formation of carbides, ores rich in manganese are used for smelting; the product, which may contain up to 15 per cent. of manganese, is very brittle and hard, and has a distinctly crystalline structure with large, silver-white surfaces of fracture; it is principally used for the manufacture of steel and wrought iron. Grey cast-iron, on the other hand, contains a portion of the carbon as free graphite; it is less hard and less brittle, has a finely granular structure and grey colour, and is more suited for castings than is white cast-iron.

The brittleness of cast-iron is due to its high content of carbon, and when deprived of a portion of this the iron is less brittle. At the present time the decarbonization of iron is usually effected by the Bessemer process. The molten iron is transferred direct from the blast-furnace to a large pear-shaped vessel, supported on trunnions and known as a converter, and hot air under pressure is blown through the molten mass. By this means the various impurities, carbon, sulphur, silicon and phosphorus, are oxidized and burn off, forming gases and slag, while the phosphoric acid combines with the lining of lime in the converter (thus forming the Thomas-Gilchrist basic slag, which, owing to the calcium phosphate it contains, is of considerable value as a fertilizer). When the amount of carbon has been reduced to about 2 per cent. (as may be determined by a spectroscopic analysis of the flame from the converter) the blast of air is shut off, and the product, now converted into steel, is poured out.

Steel is a variety of iron containing 0.8 to 2.5 per cent. of carbon in chemical combination, which as iron carbide is alloyed with the remainder of the metallic iron. Steel melts at a temperature of 1400° C.; it can be cast, hammered, welded, and hardened; and in rolling-mills it is made into rails, girders, armour-plates, sheets and wire. The use of steel on a large scale for various purposes has been rendered possible only since the introduction of the much more efficient Bessemer process. When steel is raised to a red-heat and quickly cooled it becomes brittle and very hard: hardened steel of good quality is capable of scratching window-glass, or even quartz. When hardened steel is again heated and allowed to cool slowly it becomes softer, or annealed, and the longer and more intense the heating the softer does it become. It is thus possible by these means, together by the addition of other metals (chromium, nickel, tungsten, manganese, titanium), to produce steel of any desired degree of hardness and suited to the varied purposes to which it is put. All these processes naturally add considerably to the cost of production; for instance, the fine quality

of steel used for the escapement pins in the best chronometers is worth many times as much as pig-iron.

Iron containing still less carbon than steel is a malleable iron; and this can also be produced directly from pig-iron by the Bessemer process, or from white cast-iron by the puddling process. This variety of iron is tough and not very hard; it fuses only with difficulty, but softens at a red-heat and can then be shaped by hammering and welded. Its numerous applications are well known, from the simple bars of garden fences to the most intricate hammered iron work with delicate rosettes and tendrils.

Production of Pig-iron in the year 1900.

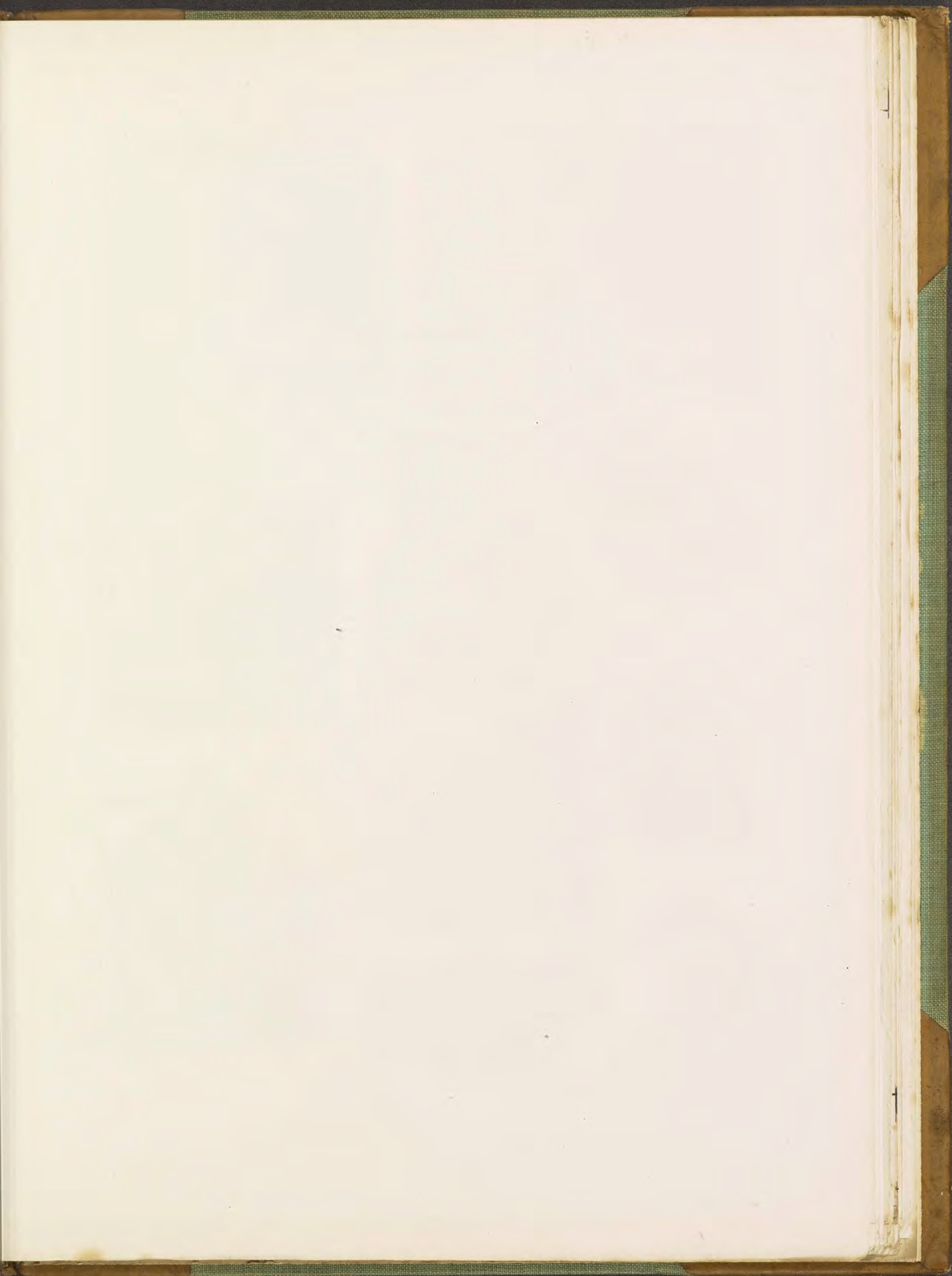
Country.	Tons.	Percentage of the total.
<i>United States</i>	14 099 870	34·4
<i>United Kingdom</i>	9 052 107	22·1
<i>Germany</i>	8 351 742	20·4
<i>Russia</i>	2 850 000	6·9
<i>France</i>	2 699 424	6·6
<i>Austria-Hungary</i>	1 350 000	3·3
<i>Belgium</i>	1 018 507	2·5
<i>Sweden</i>	520 606	1·3
<i>Spain</i>	294 118	0·7
<i>Other countries</i>	731 397	1·8

Appendix to the Iron Ores.

Meteoric Irons and Meteoric Stones.

Iron readily combines with other elements, and especially with oxygen; for this reason metallic iron never takes its origin at the earth's surface, and any pieces which become exposed to weathering are soon rusted and destroyed. Native iron is, in fact, a mineral of the greatest rarity. It is found as large masses, weighing as much as 50,000 pounds, in a basalt at Ovifak on the island of Disko, off the west coast of Greenland. The basalt at this place has been erupted through beds of coal, and it is possible that a reduction of the iron compounds in the basaltic magma has been effected by the coal, in much the same way that iron ores are reduced in a blast-furnace. All other known occurrences of terrestrial iron are of little importance.

On the other hand, masses of metallic iron of greater or less size, occasionally found on the earth's surface, are known to have fallen from outer space. These consist mainly of metallic iron, and are known as meteoric irons; whilst other meteorites, composed largely of stony material (i. e. silicates), are distinguished as meteoric stones. These bodies are quite unattractive in appearance, and the extraordinary interest they possess depends solely on their extra-terrestrial origin and comparative rarity.



Meteorites.

Fig.

1. **Meteorite Iron**, an artificially cut and etched surface showing Widmanstätten figures.
The long grey bands of kamacite are edged with very narrow reddish bands of taenite, and the interspaces are filled with plessite. The bands intercross at angles of 60° , indicating that the mass of iron has been cut parallel to an octahedral face.
Roebourne (200 miles south-east of), Western Australia. Found in 1892.
2. **Meteorite Iron**, showing Widmanstätten figures.
Descubridora, Catorce, San Luis Potosi, Mexico. Found before 1780.
3. **Meteorite Iron**, showing Widmanstätten figures.
Staunton, Augusta Co., Virginia, U. S. A. Found about 1858—59.
4. **Meteorite Iron**, showing Widmanstätten figures. The bands of kamacite are here very narrow.
Carlton, Hamilton Co., Texas, U. S. A. Found in 1887—88.
5. **Meteorite Iron**, a breccia of grains with hexahedral structure.
Kendall County, Texas, U. S. A. Found before 1887.
6. **Meteorite Iron**, showing the natural form and surface.
Cañon Diablo, Arizona, U. S. A. Found in 1891.
7. **Meteorite Iron**, with olivine. "Pallasite."
Eagle Station, Carroll Co., Kentucky, U. S. A. Found in 1880.
8. **Meteorite Stone**, showing natural form and surface. The black crust is broken in two places.
Pultusk, Poland. Fell January 30, 1868.
- 9a. **Meteorite Stone**, showing natural form and surface. Weight, 56.5 grams.
Hungen, Giessen, Hesse. Fell May 17, 1877.
- 9b. **Meteorite Stone**, end-view of the same stone, showing an artificially cut surface speckled with metallic iron.



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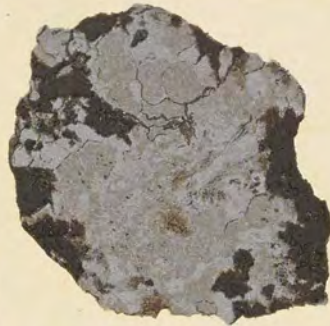
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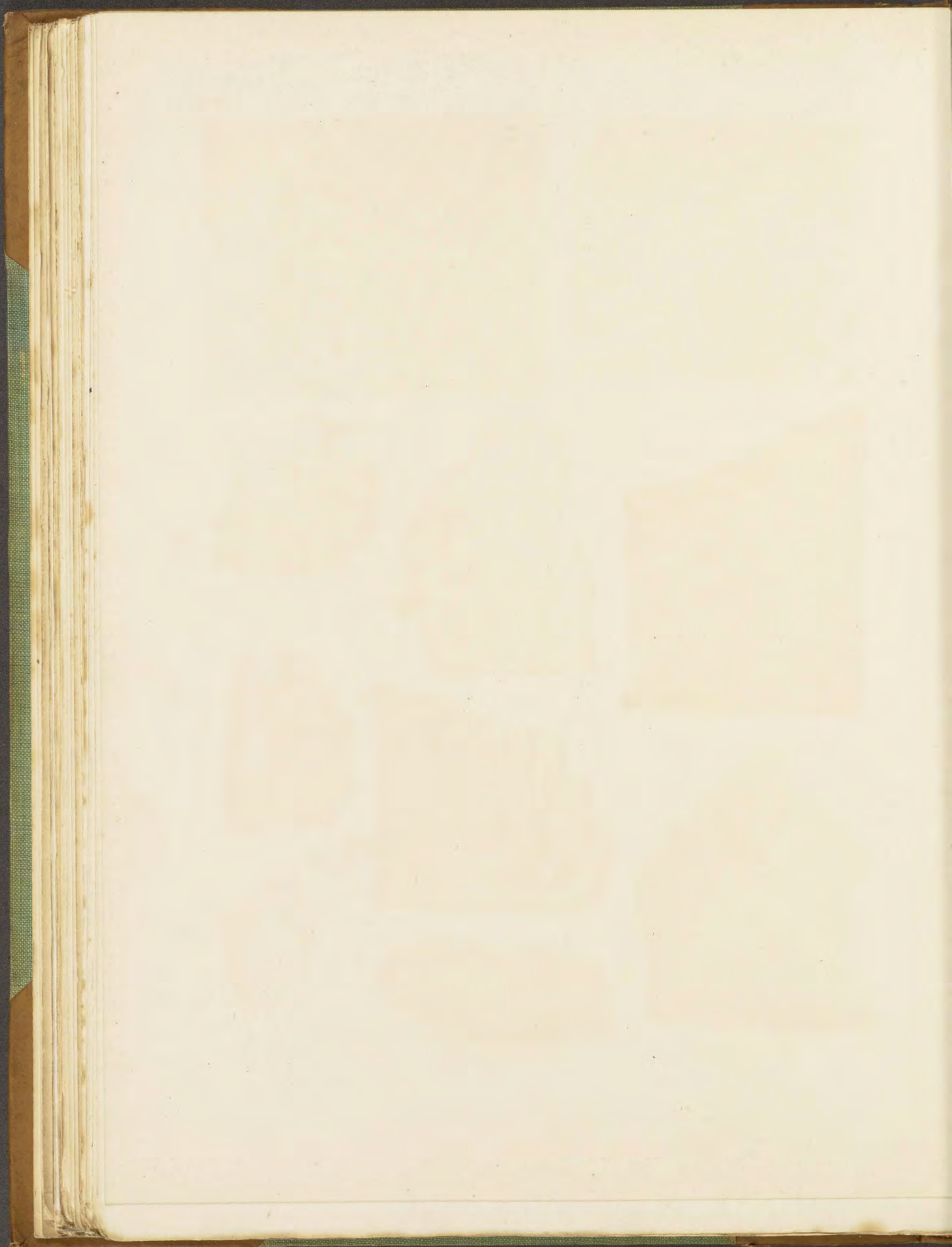
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9 a



9 b



The fall of a meteorite to the earth's surface is accompanied by a display of brilliant light and by loud explosions: owing to the great height and velocity of the moving meteor, its advent is often made manifest over a very wide area. When these solid bodies, travelling through space with an enormous velocity, come near enough to our earth to pass through the upper rarified strata of the atmosphere, the friction of the air acts as a check to the velocity and the energy of motion is largely transformed into heat. The air in front of the body becomes suddenly compressed and consequently heated, while the meteor itself is raised to a glowing temperature on the surface. The rapid motion through the air drives the molten particles on the surface to the rear of the moving mass, giving rise to the characteristic valleys and ridges radiating from the back of meteorites (plate 32*a*, fig. 1). Many of the particles will, however, be completely separated from the main mass, and these give rise to the tail of fire of a meteor or shooting star. The velocity of meteors when they reach our atmosphere is several miles per second, being that of the planets and comets, but this velocity rapidly diminishes, and for an instant the meteor appears to stand still and ceases to glow; frequently the mass then breaks up with a loud and far-reaching report, similar to that of a cannon, and with the accompaniment of thunder-claps and rumblings the fragments fall to the ground. The loud and sharp report is usually attributed to the bursting of the meteor, and the subsequent thunder-claps to the rushing of the air into the vacuous space behind the moving mass, while the rumblings are due to the reflection of these sound waves from different strata of the air or from clouds. Since, however, the report is also heard when only a single meteorite reaches the earth, it is held by other authorities that the report is not caused by the bursting of the mass, but by the intense compression of the air in the front of the moving body.

Usually only a single meteorite falls, but sometimes there may be two or three or several, while in a very few instances, for example, at L'Aigle in Normandy in the year 1803, some thousands have been picked up after a fall. On reaching the earth, a meteorite may be hot on the surface, but in the interior it is more often cold, and temperatures as low as -50° C. have been reported. This is not surprising when we remember that the meteorite has only just arrived from the extremely cold regions of outer space, and that during its short and rapid flight through our atmosphere there has not been sufficient time for the heat thereby generated to be conducted into the interior of the mass. The sudden heating may, too, be the cause of the breaking of the mass into fragments, and this would explain the irregular angular form of most meteorites. In some instances the several fragments belonging to the same meteoritic fall may be fitted together and the original mass re-constructed. For example, after the fall at Butsura in India on the 12th of May 1861, there were picked up three stones at distances of 4—5 kilometres apart; these fitted together exactly and showed, with the exception of one corner, the original shape and size of the whole mass. The shallow cup-shaped depressions or "thumb markings" so characteristic of the surface of meteorites are doubtless due to the chipping away of fragments from the heated surface, these being subsequently rounded by the friction of the air and the new surface covered by a skin of fused material. Following this brief description of meteorites in general, we shall now more particularly consider the meteoric irons and then pass on to the meteoric stones.

Meteoric irons, or siderites, are always covered on their natural surfaces by a thin, dark coating of oxide (plate 31, fig. 6), like that to be seen on iron which has been strongly heated. When fresh, this has the character of hammer-slag and the composition of magnetite; when weathered it passes into hydrated oxide of iron. In external form

the masses are irregular with angular edges and corners, and the surfaces are often rounded and marked with shallow concave depressions or pittings.

Internally, the material is crystalline, with a structure corresponding to that of the cubic system; and this may often be recognized on the exterior by the presence of cleavages parallel to the faces of the cube. In order to display more clearly the internal structure, meteoric irons are sawn through, and the section faces polished and etched with dilute nitric acid or bromine water. Most meteoric irons when so treated exhibit on their etched surfaces a system of lines of greater or less fineness intercrossing at different angles, which are known, after their discoverer, as *Widmanstätten figures* (plate 31, figs. 1—4). These consist of long grey bands of *kamacite* surrounded by narrow reddish bands of *taenite* (plate 31, fig. 1), whilst the remaining space is filled up with *plessite*, which may, however, consist mainly of kamacite (plate 31, fig. 2) or of taenite (fig. 1). Some meteoric irons, for example that of Braunau, consist wholly of kamacite, and these do not show the figures just described. That *Widmanstätten figures* can be developed by etching therefore depends on the fact that the meteoric iron is, as a rule, built up of different constituents which are differently attacked by acids; and further, the regularity of the figures shows that these constituents are arranged together in a perfectly definite manner in the mass. A specially characteristic feature of meteoric iron is the invariable presence of nickel in alloy with the iron; together with 89—95 per cent. of iron there is 4—10 per cent., or rarely as much as 10—15 per cent., of nickel. Other chemical elements present in small amounts are cobalt, sulphur, phosphorus, carbon and chromium. Kamacite and taenite are both alloys of iron and nickel, the former containing less, and the latter more nickel; kamacite isolated from the meteoric iron of La Caille in France contains 91.9 per cent. of iron and 7 per cent. of nickel; while the taenite from the same iron contains 85 per cent. of iron and 15 per cent. of nickel. Taenite is more difficultly attacked by acids than kamacite.

The angle at which the different bands intersect depends on the orientation of the section with respect to the crystalline structure of the mass of the iron. When the section is parallel to a face of the octahedron, the bands will be at 60° (plate 31, fig. 1, and plate 32); when parallel to a face of the cube, at 90° (plate 32, fig. 2); and when the section has neither of these directions, the angles will be different. Since the bands are sections of lamellae, it follows that these lamellae are arranged parallel to the faces of the octahedron, and meteoric irons possessing this structure are known as *octahedral irons*. As may be seen from plate 31, the lamellae are very variable in width; the iron of Carlton (fig. 4) has fine lamellae, those of Descubridora (fig. 2), Staunton (fig. 3) and Toluca (plate 32) have lamellae of medium width, while in some others the width may exceed 2 mm. This arrangement of the lamellae indicates a zonal structure of the iron parallel to the faces of the octahedron, and the lamellae pass uninterruptedly throughout the whole mass, forming a single crystalline individual often of considerable dimensions. Thus the two masses of meteoric iron found at Chupaderos in Mexico, when placed together to form the original mass, measure nearly 5 metres in length, $2\frac{1}{2}$ in breadth and $\frac{1}{2}$ m. in height; usually, however, the masses are much smaller.

In other meteoric irons the lamellated structure parallel to the octahedron faces is not present and the mass is homogeneous in composition; but these still clearly show the cleavage parallel to the faces of the cube, and they are consequently known as *hexahedral irons* (hexahedron being another name for the cube). Irons of this type are often traversed by twin-lamellae ("Neumann" lines) parallel to the octahedral faces, but they show no *Widmanstätten figures* when a polished surface is etched. The best example of this type of structure in meteoric iron is afforded by the meteorite which fell at



PLATE 32.

Meteoric Iron.

Figs.

1 and 2. **Meteoric Iron**, an etched slice showing Widmanstätten figures.

Toluca, Mexico. Known before 1776.

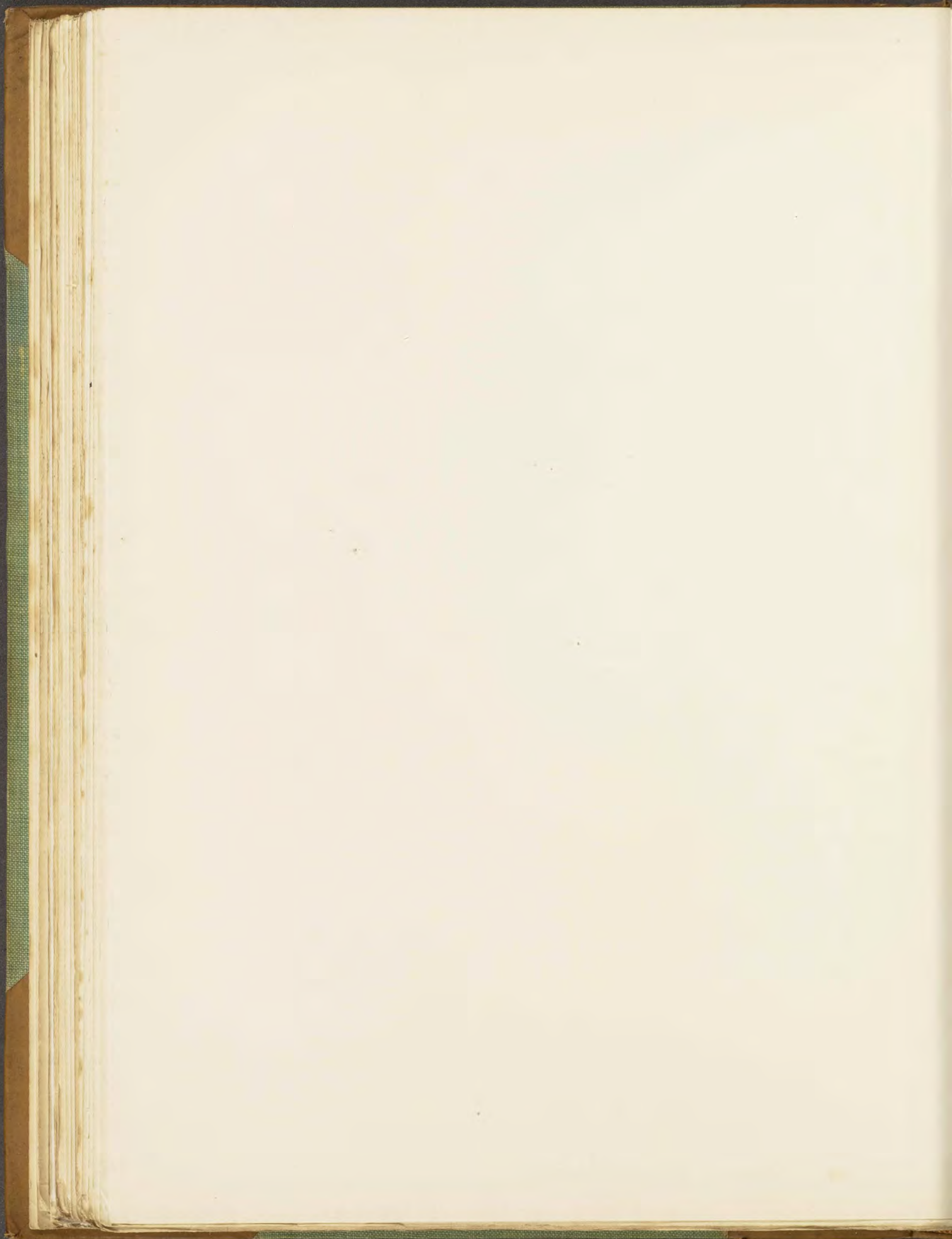
- (1.) Cut parallel to a face of the octahedron: the bands of kamacite intercross at angles of 60° . The slice here represented on a slightly reduced scale measures 33 by 25 centimetres and weighs 21.30 kilograms.
- (2.) Cut parallel to a face of the cube: the bands of kamacite intercross at angles of 90° . Natural size.



2



1



Braunau in Bohemia. In a third type, the mass consists of smaller or larger irregular fragments of hexahedral iron forming a breccia; this is known as a *brecciated hexahedral iron*. An example of this is seen in the Kendall County meteorite (plate 31, fig. 5), which consists of an aggregate of small grains of iron, with some dark grains of troilite. Another example with much larger grains is the Mount Joy meteoric iron (plate 32*a*, fig. 4) the original mass of which weighed 348 kilograms; here the Neumann lines due to lamellar twinning are to be seen in some of the grains.

The specific gravity of meteoric irons varies between 7.80 and 7.88. Most irons readily acquire permanent magnetism.

Of the chemical constituents of meteoric iron mentioned above, the cobalt is alloyed with the iron and nickel of the kamacite, etc.; and the sulphur is combined with iron to form another constituent, namely *troilite* (FeS, see 151). This is usually present as rounded grains or nodules embedded in the nickel-iron (plate 31, fig. 5), and being liable to weathering they sometimes fall out, leaving rounded spaces (plate 32, fig. 4). In many meteoric irons the troilite takes the form of thin plates arranged parallel to the cube faces, which, on the polished sections, appear as very fine lines (0.1—0.2 mm. in thickness), and are called "*Reichenbach*" lamellae, after their first observer. The phosphorus is present as a phosphide of iron and nickel called *schreibersite*, (Fe, Ni, Co)₃P; which forms metallic white laths embedded in the kamacite. The carbon occurs in combination with iron as carbide (Fe₃C, called *cohenite*), and also in the free state as *graphite* or as *diamond*. The presence of diamond has been detected in the meteoric irons of Cañon Diablo in Arizona and Magura in Hungary, and in a few others.

With the exception of troilite, all the meteoric minerals just mentioned are scarcely ever visible to the unaided eye. But in another group of meteoric irons large grains of olivine are plentifully distributed through a network of metallic nickel-iron (plate 31, fig. 7). The earliest known example of this type is the large block weighing 700 kilograms discovered near Krasnojarsk in Siberia by the traveller Pallas, and for this reason known as the Pallas iron; the name *pallasite* being also extended to the whole group. The olivine possesses characters — chemical composition and angles between the crystal faces — identical with those of the olivine of terrestrial rocks, but the crystals of the former are sometimes much richer in faces than those of the latter. In addition to olivine, other silicates (bronzite and plagioclase) are also sometimes present. Meteorites of this group are of comparatively rare occurrence, and they form a connecting link between the two main groups, the meteoric irons and the meteoric stones; and for this reason they are called *mesosiderites* or *siderolites*.

The **Meteoric stones**, or *aerolites*, also contain some metallic nickel-iron, but only as grains or particles scattered through the mass of silicates; the latter include olivine, bronzite, augite, plagioclase and glassy matter. In addition, there is often some gas (hydrogen, etc.), and rarely diamond.

Meteoric stones, which have not been broken during their flight through the air, possess certain peculiarities in their external form, which are dependant on their direction when falling. As shown in plate 32*a*, figs. 1—3, the front of the stone, which encountered all the resistance of the air, is rounded, while the back is flatter and puckered. The whole surface is covered with a thin, dark brown or black skin (plate 31, figs. 8 and 9*a*), caused by fusion on the surface during the flight through the air; and the minute characters on the surface of this skin also indicate the direction of flight. Thus in fig. 1 (plate 32*a*) minute furrows and ridges radiate from the apex to the sides of the stone; this being due to the backward flow of molten particles on the surface, which streamed round the sides and collected in ridges and projections on the back

(figs. 2 and 3). The stone here figured (plate 32*a*, figs. 1—3) fell at Guča in Servia on 28 November 1891, and is now at Belgrade.

In their interior, meteoric stones present much the appearance of certain terrestrial rocks which have consolidated from fusion, or of certain compact tuffs, with the addition of the glitter of the metallic particles (plate 31, fig. 9*a*). But, in most cases, they present a certain peculiarity of structure not met with in terrestrial rocks; this consists in the presence of numerous rounded crystalline grains, usually only of microscopic size, called chondrules by G. Rose; this structure being described as chondritic, and the stones exhibiting it as *chondrites*. The origin of this structure has not been satisfactorily explained; F. Berwerth considers such stones to have been formed by the partial fusing together of a meteoric ash or dust.

A noteworthy feature of freshly-fallen meteoric stones is the absence of any alteration of their material which might be attributed to the presence of water and weathering.

Only exceptionally are meteorites of any considerable size, and even the heaviest irons are of moderate dimensions owing to their high specific gravity. The large mass of meteoric iron found near Melbourne in Australia in 1854, and now to be seen in the Mineral Gallery of the British Museum, weighs about 3½ tons (3731 kilograms); that of Bendegó in Brazil, now in the Rio de Janeiro Museum, weighs 5360 kilograms; while a still larger mass, weighing 36½ tons, has been transported from Melville Bay in Western Greenland to New York. The largest known mass is that which still remains at Bacubirito in Mexico; it measures about 13 × 6 × 5 feet and has been estimated to weigh 50 tons. These are, however, quite exceptional, and the number of specimens weighing over 50 kilograms (i. e. about 1 cwt.) preserved in meteorite collections is limited to a few dozen. For instance, the Vienna collection in 1902 possessed ten irons exceeding this weight, but only one stone; and in the British Museum there is also only a single stone weighing more than 50 kilograms.

The descriptions of the meteorites given on the sheets accompanying plates 31, 32 and 32*a* require, perhaps, some explanation. The one or more masses belonging to each meteoritic fall are named after the locality where they were observed to fall or were found: thus the Roebourne meteoric iron (plate 31, fig. 1) was found in 1892 at a spot 200 miles to the south-east of Roebourne in the north of Western Australia; the specimen here represented is a slice weighing 444 grams cut from a mass which when found weighed 86·8 kilograms.

Historical. — Being bodies which have descended from the heavens, meteorites have at all times been regarded with reverence and awe; in early times they were thought to have fallen from the stars and to have been sent by the gods. Temples were built for them, and they are represented on numerous Roman and Grecian coins (betyl coins). Thus a stone worshipped in the temple at Emisa as the sun-god Elagabalus, and afterwards taken to Rome by the Emperor Elagabal, a priest of the sun-god, was represented on numerous coins. The Venus of Paphos in Cyprus was described as a rough triangular stone; and the statue of Ceres, the earliest image of Pallas at Athens, and the stone at Delphi were also meteorites. "Iron from heaven" was known to the Egyptians as far back as 4000 B. C.

A stone built into the Kaaba at Mecca has been known before the seventh century; it is said to have fallen red from heaven and turned black through the sins of men. Mohammed at the taking of Mecca did not venture to destroy the stone, but walked around it seven times and kissed it; since then it has been an object of the greatest veneration to all Mohammedans.

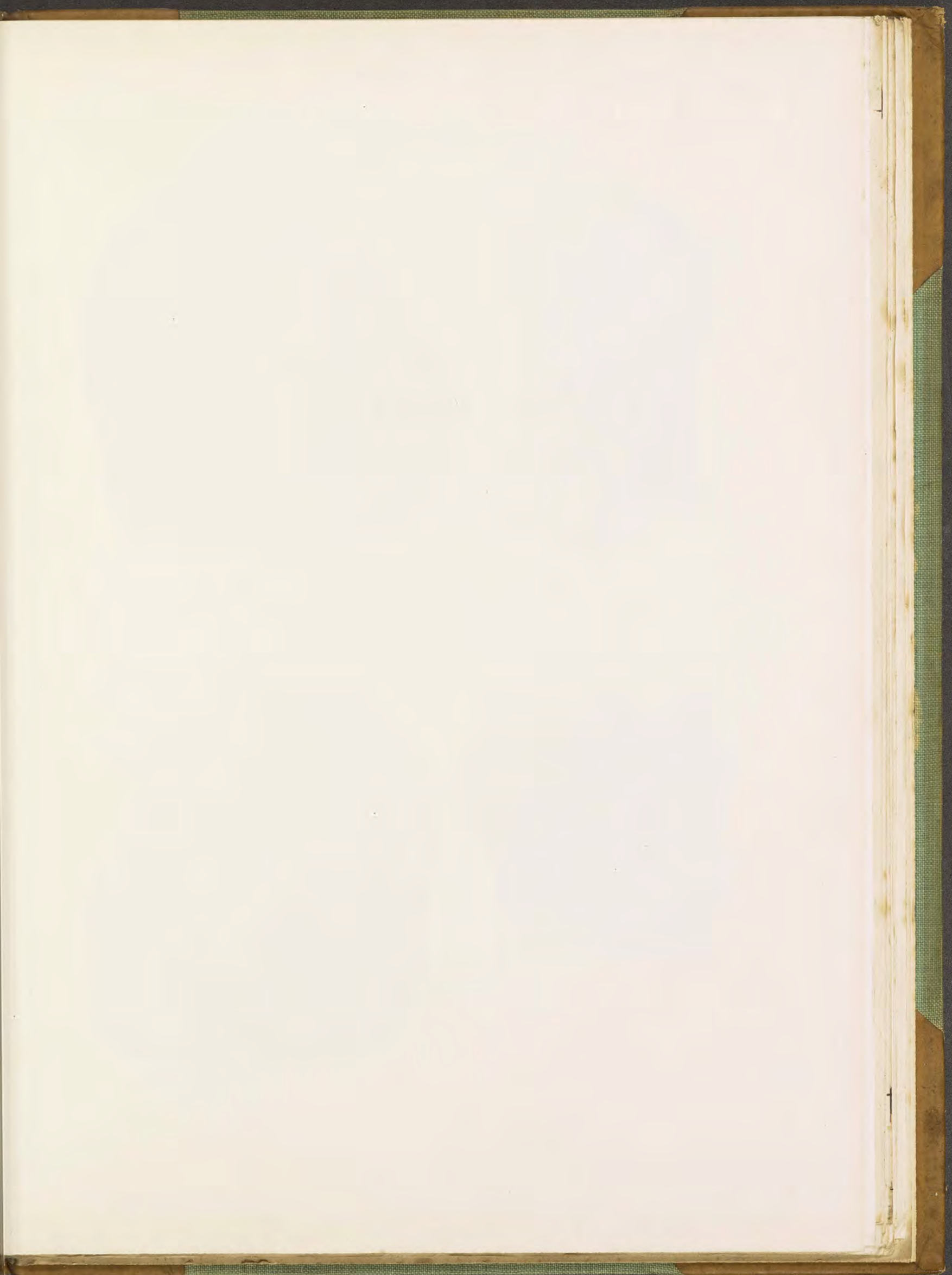


PLATE 32 a.

Meteorites.

Figs.

- 1—3. **Meteoric Stone**, three views of the stone which fell at
Guča, Cačak, Servia, on November 28, 1891.
4. **Meteoric Iron**, a brecciated hexahedral iron.
Mount Joy, Adams Co., Pennsylvania, U. S. A. Found in 1887.

PLATE 32a.



1.



3.



2.



4.



Several meteorites have been found in the prehistoric barrows of the Ohiotales in North America; some of them as loose pieces of an olivine-bearing pallasite laid upon an altar (the pallasite shown in plate 31, fig. 7, was found at a distance of only 100 kilometres from these graves); while the so-called ear-plugs made of copper were plated with meteoric iron. In Japan, until recent times, meteorites were regarded as household gods; and in Duruma, East Africa, a stone which fell in the year 1853 was thought by the Wanikas to be sent by god, until at the time of defeat they lost all faith in it and sold it to the missionaries. A stone which recently fell in Sabetmahet in India was bedecked with flowers and sprinkled with sandal-wood powder, and was so carefully guarded that only the smallest fragments could be obtained for scientific investigation. The famous meteoric iron found by Pallas at Krasnojarsk in Siberia had been regarded by the Tartars as a holy relic. And one of the two stones which fell on 10 September 1886 in the neighbourhood of the village of Novo-Urei in the Karasnoslobod district, government Pensa, is said to have been broken up and powdered by the peasants, since they attributed a magic power to this stone from the heavens. This stone is of interest in being the first meteorite in which diamonds were detected.

The meteoric stone which fell at Ensisheim in Elsass in the year 1492 is of particular interest as being the earliest authentic meteorite still preserved; for years it remained suspended by a chain from the roof of the church and it is now kept in the Rathhaus of the town. The following is a translated extract*) from a document preserved in the church: —

“On the 16th of November, 1492, a singular miracle happened: for between 11 and 12 in the forenoon, with a loud crash of thunder and a prolonged noise heard afar off, there fell in the town of Ensisheim a stone weighing 260 pounds. It was seen by a child to strike the ground in a field near the canton called Gisgaud, where it made a hole more than five feet deep. It was taken to the church as being a miraculous object. The noise was heard so distinctly at Lucerne, Villing, and many other places, that in each of them it was thought that some houses had fallen. King Maximilian, who was then at Ensisheim, had the stone carried to the castle: after breaking off two pieces, one for the Duke Sigismund of Austria and the other for himself, he forbade further damage, and ordered the stone to be suspended in the parish church.”

All unprejudiced persons believed from this and other similar accounts that the stones had in fact fallen from the sky; but in the latter half of the eighteenth century the scientific men of the time threw doubts on the origin of these supposed sky-stones and looked upon the reports of their fall as merely fables. When, in July 1790, a shower of stones fell at Barbotan (dep. Landes) in Gascogne a full report of the occurrence was prepared from the statements of several observers and signed by the mayor for presentation to the Paris Academy of Sciences. This report was received unfavourably, and Bertholon in his remarks upon it in the *Journal des Sciences* added: “How must we grieve to-day to see an entire municipality join in giving serious credence to popular tales which can but excite the pity, not only of physicists, but of all reasonable people.”

Four years later Chladni, the discoverer of sound figures, concluded, from the observations respecting the Pallas iron and other meteorites: firstly, that stones and masses of iron have fallen from the sky and the historical accounts relating to them must be accepted; secondly, that the phenomena are identical with those presented

*) Taken from “An introduction to the study of meteorites, with a list of the meteorites represented in the [British Museum] collection”. By L. Fletcher, 10th edition, 1908. A piece weighing 458 grams of the Ensisheim meteorite is exhibited in the British Museum.

by fire-balls, and that meteorites themselves are nothing other than such burning masses; thirdly, that these masses are of cosmic origin, having come to the earth from outer space. The subject still remained controversial until the undoubted falls at Siena in Tuscany on 16 June 1794, Wold Cottage in Yorkshire on 13 December 1795, Krakhut in India on 19 December 1798, and especially at L'Aigle in Normandy on 26 April 1803. After the last of these occurrences the celebrated physicist Biot was instructed by the French Minister of the Interior to make an inquiry on the spot, and he was able to completely confirm the statements that a shower of stones had actually fallen from the sky.

At the present time the extra-terrestrial origin of meteorites is universally recognized as an undoubted fact; and while in former times collectors were ashamed to include in their collections a stone supposed to be of celestial origin, to-day these form the most valuable portions of the large mineral collections in London, Vienna, Berlin, Paris, Tübingen, Budapest, New Haven, Washington, New York, and other cities, the rarer pieces being valued at their weight in gold.

Manganese Ores.

The manganese ores are compounds of manganese with oxygen, with oxygen and water, or with carbonic acid. Whilst the compound of iron with carbonic acid is of great importance as an ore, the corresponding manganese compound is practically only of interest as a mineral. To make the list of manganese minerals more complete we must also mention two compounds with sulphur, namely the disulphide MnS_2 , which as the mineral hauerite is related not only chemically but also crystallographically to iron-pyrites, and the monosulphide MnS (alabandite) possessing a similar relation to zinc-blende. Finally, there are several silicates and phosphates containing manganese, but these are of little or no importance as ores. The more important manganese minerals may then be listed as follows: —

Pyrolusite and Polianite, MnO_2 .	Rhodo-chrosite, $MnCO_3$.
Hausmannite, Mn_3O_4 .	Hauerite, MnS_2 .
Braunite, Mn_2O_3 .	Alabandite, MnS .
Manganite, $Mn_2O_3 \cdot H_2O$.	Rhodonite, $MnSiO_3$.
Psilomelane and Wad.	

All of these minerals, with the exception of polianite and braunite, are represented on plates 33, 34 and 35.

Pyrolusite and Polianite. Pyrolusite (plate 33, figs. 1 and 2) forms radially fibrous masses, or less often granular masses, which are grey with a metallic lustre. It is very soft ($H. = 2$) and soils the fingers, and for this reason is known as soft manganese ore. The powder is black. In appearance it sometimes shows a certain resemblance to the totally distinct mineral stibnite, but the two may be readily distinguished by their fusibility; stibnite being readily fusible and pyrolusite infusible. With warm hydrochloric acid it liberates the greenish-yellow gas chlorine; and in a blowpipe bead of microcosmic salt it produces a violet colour. These reactions are, however, also the same for the other oxides of manganese.

Pyrolusite frequently results from the alteration of manganite and it is often stated that all pyrolusite has been derived from other ores of manganese; in any case it is, together with psilomelane, the most stable compound of manganese at the earth's

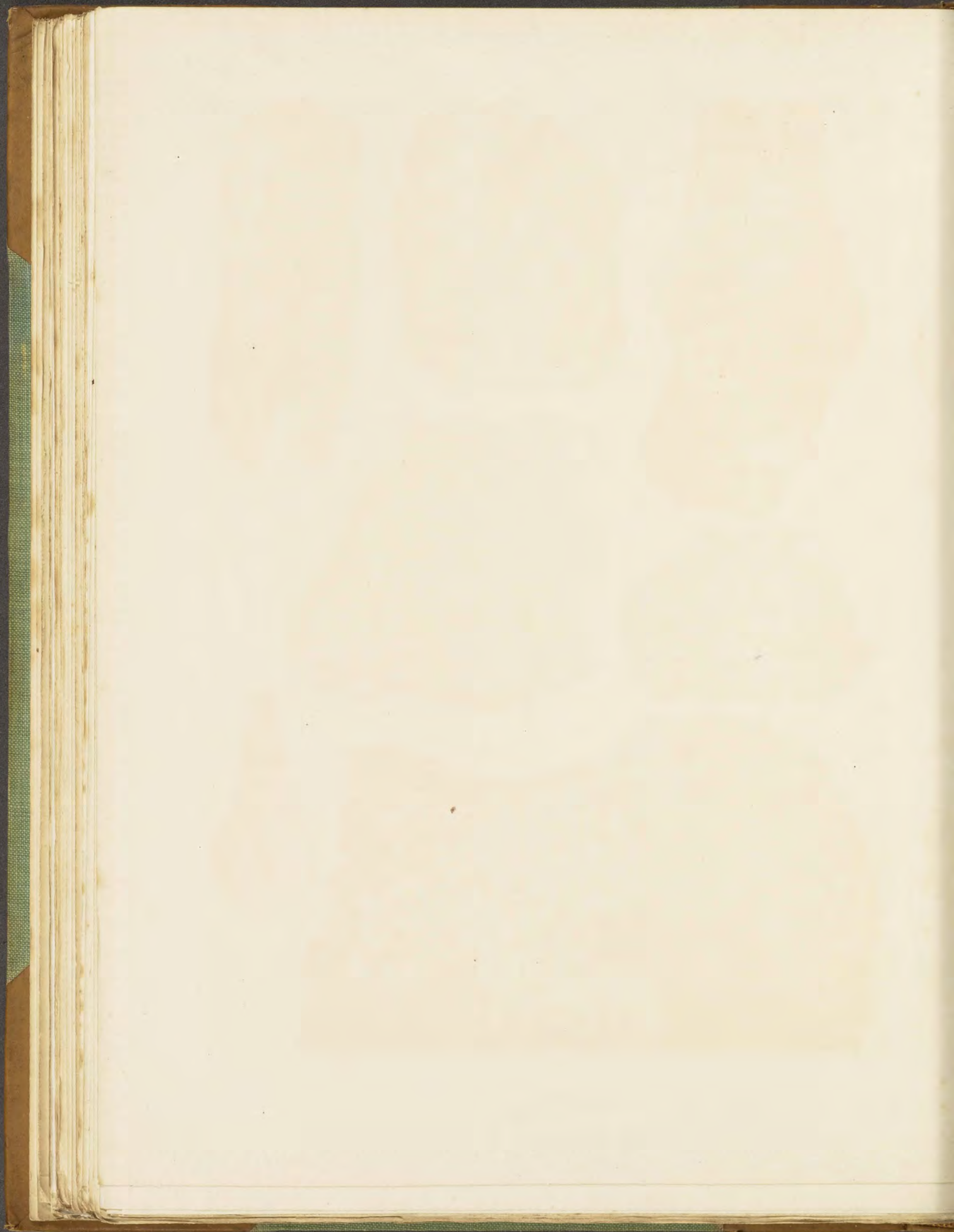


Manganese Ores I.

Fig.

1. **Pyrolusite**, radially fibrous aggregate.
Lindener Mark, Giessen, Hesse.
2. **Pyrolusite**.
Rossbach mine, Puderbach, Westerwald, Germany.
3. **Psilomelane**, stalactitic.
Hollerter Zug, Siegen, Westphalia.
4. **Psilomelane**, reniform.
Schmalkalden, Prussia.
5. **Psilomelane**, nodular with concentric structure.
Rossbach mine, Puderbach, Westerwald, Germany.
6. **Psilomelane**, club-shaped.
Bayreuth, Bavaria.
7. **Wad**, coating psilomelane, with iridescent tarnish.
Lindener Mark, Giessen, Hesse.





surface, and for this reason it is the most widely distributed. It also occurs as replacement-pseudomorphs after calcite and dolomite.

Localities for pyrolusite are: the Lindener Mark near Giessen (fig. 1), Puderbach in the Westerwald (fig. 2), Roszbach near Friedberg, Waldmichelbach in the Odenwald, Laisa near Battenberg, and the districts of Schmalkalden and Siegen, all of these being in Germany. Further, in the Chiaturi district in the Caucasus and many others; in fact at all the localities which will be mentioned below for manganese ores.

Polianite is another mineral with the same chemical composition as pyrolusite, the formula for both being MnO_2 , corresponding to 63.2% of manganese and 36.8% of oxygen. This mineral is, however, much harder ($H. = 6$), for it scratches glass and does not soil the fingers. Crystals of polianite are tetragonal, but are of rare occurrence and usually very indistinct. Like pyrolusite, the colour is also grey with a metallic lustre, but the aggregates of the mineral are usually more granular and on the exterior they present a faceted crystalline appearance. Polianite is quite a rare mineral and is found only at Platten in Bohemia.

Psilomelane, like wad, differs from the other ores of manganese in being amorphous without any indications of crystalline structure. It sometimes has a concentric shelly structure (plate 33, fig. 5), and the external surface may be stalactitic (figs. 3 and 5), reniform (fig. 4), mamillated or botryoidal. In the interior it is dark iron-grey and dull, but on the exterior rounded surfaces it is black and often with a brilliant polish, hence the German name "schwarzer Glaskopf" (fig. 4). The hardness is rather high ($H. = 5\frac{1}{2}-6$), and the mineral is consequently sometimes known as hard manganese ore; the specific gravity is 4.2—4.3.

The chemical composition of psilomelane is very variable and cannot be satisfactorily expressed by a formula. Manganese dioxide, MnO_2 , is the principal constituent, together with some manganous oxide, MnO ; and there are also several other oxides, the presence of which would scarcely be expected in this mineral, namely oxides of barium, potassium, copper, cobalt, silicon and lithium, whilst all contain a variable amount of water. The chemical reactions of psilomelane are the same as those for pyrolusite, but in addition the mineral gives off water when heated in a bulb-tube.

Psilomelane is found in association with limonite in the Siegen district in Westphalia and at many other localities, and with manganese ores at all the places mentioned above for pyrolusite.

Wad is another manganese ore of very variable chemical composition, but it is readily distinguished from psilomelane by its softness and porous character. The porosity is such that the mineral floats on water, and owing to its softness and looseness of texture it soils the fingers. It occurs as earthy and reniform masses of a dull black colour, and sometimes forms a coating on psilomelane (plate 33, fig. 7, here with an iridescent tarnish). The localities are the same as for pyrolusite.

Manganite. The manganese ores so far considered possess either no crystalline form or are very indistinctly crystallized; manganite, on the other hand, frequently occurs as well-developed crystals, which are rhombic with a prismatic habit. In plate 34, fig. 5, the sharply-developed rhombic prisms are terminated by a smooth base; in fig. 6 the prisms are deeply striated vertically and have drusy basal planes; and in fig. 7 the prisms are terminated by faces of a dome in addition to the drusy basal planes. Smaller crystals are often rich in terminal faces. The crystals possess a perfect cleavage in one direction parallel to the brachy-pinacoid.

The colour of manganite is dark steel-grey to iron-black, but the streak is brown, and this affords an easy means of distinguishing the mineral from other manganese

oxides. The hardness is $3\frac{1}{2}$ —4, and the specific gravity 4.3. In addition to crystals, fibrous and columnar aggregates are common.

Manganite is a hydrated oxide of manganese with the formula $Mn_2O_3 \cdot H_2O$; or it is probably more correctly to be considered as a manganese hydroxide $MnO \cdot OH$, since the water it contains is expelled only at temperatures above $200^\circ C$. When subjected to weathering the mineral alters to pyrolusite; it loses water and becomes softer, and the streak is then black.

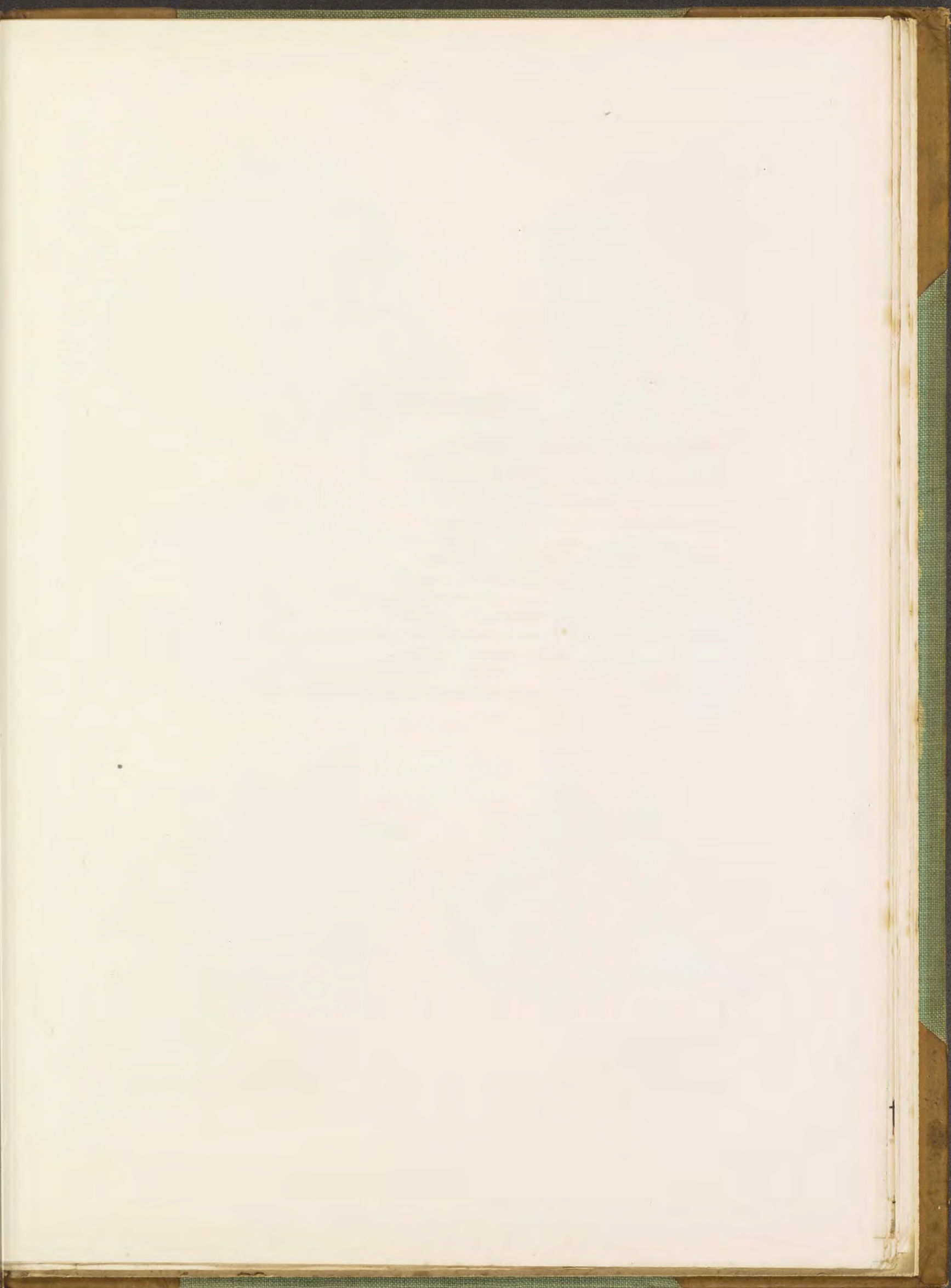
A very common associate of manganite is barytes (shown in fig. 5), and these two minerals form veins in porphyrite at Ilfeld in the Harz; at which locality the best crystallized specimens are found (plate 34, figs. 5—7). Other localities for crystals are Ilmenau and Oehrenstock in the Thuringian Forest, Upton Pyne near Exeter, Botallack mine in Cornwall, Granam in Aberdeenshire, Böhlet in Sweden, Negaunee in Michigan, Pictou in Nova Scotia. Massive material with a columnar structure occurs at these and other localities together with various ores of manganese.

Hausmannite forms small, acute tetragonal pyramids (plate 34, fig. 4), which are often grown together in twin position. Their colour is black and the lustre sub-metallic; the hardness is $5\frac{1}{2}$, and the specific gravity 4.8. The chemical formula of this oxide of manganese is Mn_3O_4 , or perhaps more correctly $MnO \cdot Mn_2O_3$. The chemical reactions are the same as for pyrolusite, and this mineral is best recognized by its crystalline form. It is found at Oehrenstock near Ilmenau in the Thuringian Forest (fig. 4); and in large amounts at Långban to the north of Filipstad in Wermland, at Pajsberg near Nordmark, and at Jakobsberg in Örebro; at all these Swedish localities the manganese ore occurs in connection with dolomite. Crystals are also found in a haematite mine at Bigrigg near Egremont in Cumberland.

Braunite also crystallizes in the tetragonal system, forming very small pyramids with angles not much different from those of the regular octahedron. The crystals are black, and are, as a rule, quite small and rough. The chemical composition can be expressed by the formula Mn_2O_3 , but the compound is not simply manganese sesquioxide, being rather a manganous salt of manganic acid $MnMnO_3$. This mineral is found in Thuringia and at the Swedish localities mentioned above for hausmannite.

Rhodo-chrosite or manganese-spar. All the manganese ores dealt with above are black in colour, but in rhodo-chrosite and rhodonite the colour is a beautiful rose-red.

In crystalline form and chemical composition, rhodo-chrosite is closely related to chalybite and calcite, belonging to the same isomorphous group of rhombohedral carbonates. The crystals have the form of the primary rhombohedron (plate 34, fig. 3) with angles of 107° between the faces, or of the scalenohedron (fig. 1); those represented in the figures are more sharply developed and larger in size than the crystals commonly to be met with. Often the rhombohedral crystals show a saddle-like curvature and are confusedly aggregated. More frequently the mineral occurs in globular or botryoidal forms with an internal granular structure, and it is then sometimes known as raspberry-spar (fig. 2). Being a carbonate ($MnCO_3$), rhodo-chrosite effervesces in warm hydrochloric acid with the liberation of carbon dioxide. The presence of manganese is readily shown by the violet colour which the mineral imparts to a blowpipe bead of microcosmic salt. When weathered, the mineral becomes black and passes into manganese oxides. Owing to this instability, rhodo-chrosite is a mineral of quite rare occurrence, whilst fine crystals are still rarer. The latter are found in cavities in limonite at Sayn-Altenkirchen (fig. 1) and Horhausen in Rhenish Prussia; in the metalliferous veins of Freiberg in Saxony and Kapnik in Hungary. Massive material occurs as beds in limestone at Vielle and Las Cabesse (dep. Ariège) in the Pyrenees, and in province Huelva in Spain. Large

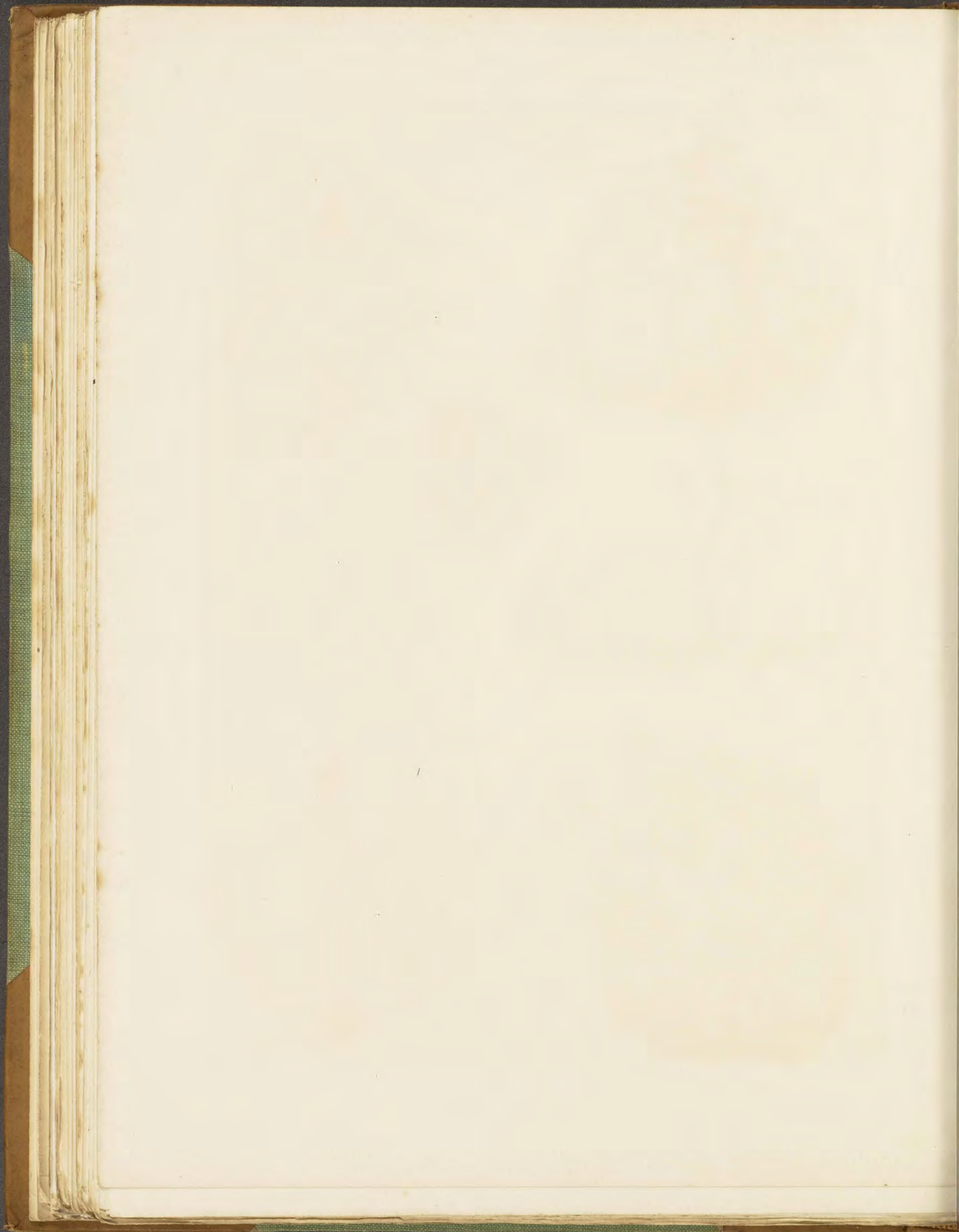


Manganese Ores II.

Fig.

1. **Rhodochrosite**, scalenohedra on limonite.
Biersdorf, Altenkirchen, Rhenish Prussia.
2. **Rhodochrosite**, botryoidal.
Oberneisen, Nassau.
3. **Rhodochrosite**, rhombohedra.
John Reed mine, Alicante, Lake Co., Colorado, U. S. A.
4. **Hausmannite**, small tetragonal pyramids.
Oehrenstock, Ilmenau, Thuringia.
5. **Manganite**, rhombic prisms with smooth basal planes, with barytes.
Ilfeld, Harz Mountains, Germany.
6. **Manganite**, rounded prismatic crystals with drusy basal planes.
Ilfeld, Harz Mountains, Germany.
7. **Manganite**, thick prismatic crystals, with barytes.
Ilfeld, Harz Mountains, Germany.





rhombohedra (fig. 3) are found with iron-pyrites at Alicante in Lake County and at other places in Colorado.

Rhodonite is a silicate of manganese with the formula $MnSiO_3$. In crystalline form and chemical composition it is related to the pyroxenes, and in the scientific classification of minerals it is placed in the pyroxene group. Here we consider it with the ores of manganese, since by weathering it gives rise to these, and it is itself occasionally mined as an ore; at the same time, however, we might place it with the precious stones, since the mineral has a certain application in this direction. Crystals are triclinic, and all the faces and edges are inclined at oblique angles. In plate 35, fig. 5, the large crystal is bounded by the base (the large face above), large faces of the vertical prisms (to the front and right) and narrow faces of the macro- and brachy-pinacoids; on the smaller crystals on the same specimen small pyramid faces truncate the edges between the base and the prism. Other crystals are more pointed in habit and much smaller. Like the pyroxenes, this mineral possesses two directions of good cleavage parallel to the faces of the prisms, the angle between which is $87\frac{1}{2}^\circ$.

The characteristic rose-pink colour of the mineral is shown in the imperfect crystal in fig. 4, and on the fractured surface to the left in fig. 5 (the colour being elsewhere obscured by a grey coating on the faces of the crystals). The hardness is $5\frac{1}{2}$ — $6\frac{1}{2}$, and the specific gravity 3.5—3.6. The mineral is only slightly attacked by hydrochloric acid; it is not readily fusible, and in a bead of microcosmic salt gives the usual violet colour due to manganese. More frequent than crystals are compact granular masses, which are almost invariably marked with black veins and patches; these are due to the alteration of the mineral along cracks by weathering, with the production first of a hydrated manganese silicate and then of black oxide.

Small, but very perfect crystals are found in the iron mines at Pajsberg in Sweden; and large, rough crystals are met with in the zinc mines of Franklin Furnace in New Jersey. The latter contain 5— $7\frac{1}{2}$ per cent. of zinc oxide and are known as fowlerite.

Massive rhodonite is found at Elbingerode in the Harz, at Långban in Sweden; and especially at Ssedelnikova near Ekaterinburg in the Urals, where it is quarried and cut in Ekaterinburg into various small articles and ornaments. Large masses occur together with massive rhodochrosite in the deposits of manganese ore in province Huelva in Spain.

Hauerite is one of the two sulphides of manganese which occur rarely as minerals, this being the disulphide with a formula MnS_2 and corresponding to iron-pyrites. Crystals are cubic and usually have the form of the regular octahedron (plate 35, fig. 1) or of the octahedron in combination with the cube (fig. 2). Sometimes on small crystals the faces of a pentagonal-dodecahedron may be present; the mineral thus being hemihedral with parallel faces like iron-pyrites. Crystals are found in a sulphur mine at Raddusa in province Catania in Sicily, where they occur with gypsum embedded in clay: a similar occurrence is met with at Kalinka in Hungary.

Alabandite is the monosulphide of manganese, MnS , and this also crystallizes in the cubic system, but with tetrahedral hemihedrism: in its chemical formula and crystalline form it thus shows a relation to zinc-blende. The exceptionally large crystals shown in plate 35, fig. 3, though apparently a combination of the octahedron with the cube, are really a combination of the two tetrahedra with the cube. Twin-crystals also occur (one is shown to the left of the large simple crystal in fig. 3), the twin-plane being a tetrahedron face as in text-fig. 142. The mineral possesses perfect cleavages parallel to the faces of the cube (in zinc-blende the cleavage is dodecahedral); its colour is black, but the streak

is dark-green. Alabandite is a rare mineral; it is found at Nagyag and Offenbanya in Transylvania, at Kapnik in Hungary, and a few other places.

Occurrence of manganese ores. — Only the black oxides are of any importance as ores of manganese, and usually several of these occur together in the same deposit. Thus pyrolusite, psilomelane and wad, or hausmannite and braunite, are found together in beds in connection with limestone or dolomite. On the other hand, manganite more frequently occurs in veins, though it is never altogether absent in the bedded deposits. The largest deposit in Germany is that of the Lindener Mark near Giessen, where the ore consists of pyrolusite, psilomelane, wad (plate 33) and an earthy manganese ore rich in iron; polianite and manganite are here rare. These form beds of very varying thickness on Devonian limestone and are overlain by clay, so that they can be worked in open quarries. The annual production amounts to 100,000 tons of ore. Beds of manganese ore with a similar mode of occurrence are also found at Friedberg and in the Odenwald, though here the limestone is of Permian age (Zechstein). The Swedish ores are also associated in the same way with limestone or dolomite, but here the manganese minerals are principally hausmannite and braunite. The invariable association of limestones with such beds of manganese ore can scarcely be accidental, but the exact relations are not quite clear: either the manganese was contained as traces in the limestones and concentrated by the weathering and solution of the rock; or the limestone may have caused the precipitation of the manganese from springs (p. 70). The most extensive manganese mines are those of Russia where new deposits are continually being opened up. The ore, consisting mainly of pyrolusite, is at present won in the governments of Kutais and Tiflis in Caucasus, in governments Perm and Orenburg in the Urals, in government Ekaterinoslav in South Russia, and in the government of Semipalatinsk in Siberia. The richest deposits are those of Chiaturi in the Shavpan district in the western Caucasus; here, in the year 1901, the production amounted to 800,000 tons of ore. Rich manganese deposits are also met with in Brazil, Greece, Chile, Spain and Japan.

Applications. — Manganese is used in large quantities in the manufacture of iron (white pig-iron); its presence favours the chemical combination of carbon with the iron, and a manganiferous iron can be more readily freed from impurities by the Bessemer process than one not containing manganese. The bulk of manganese ores is used in the smelting of iron, and the demands in this direction have led to a continued increase in the production. Pyrolusite is also used for many other purposes: for example, for the manufacture of chlorine and bleaching powder, though not so much as formerly, since at the present time chlorine is largely obtained by the electrolysis of alkali chlorides. In the manufacture of glass, pyrolusite is used for obtaining a colourless product: the cheaper qualities of glass always contain some iron, which imparts a yellow or green colour, and by the addition of pyrolusite to the molten glass this colour is neutralized. In the potteries, pyrolusite is used to give a violet-coloured glaze, and pyrolusite and iron to give a brown glaze. Earthy pyrolusite is used in the manufacture of black mosaic tiles, for making galvanic cells, and in the preparation of potassium manganate and permanganate.

Most of the manganese ore imported into England comes from Russia, Brazil, Greece, Chile and Madras; while the quantity from Spain, European Turkey and Japan has considerably fallen off.

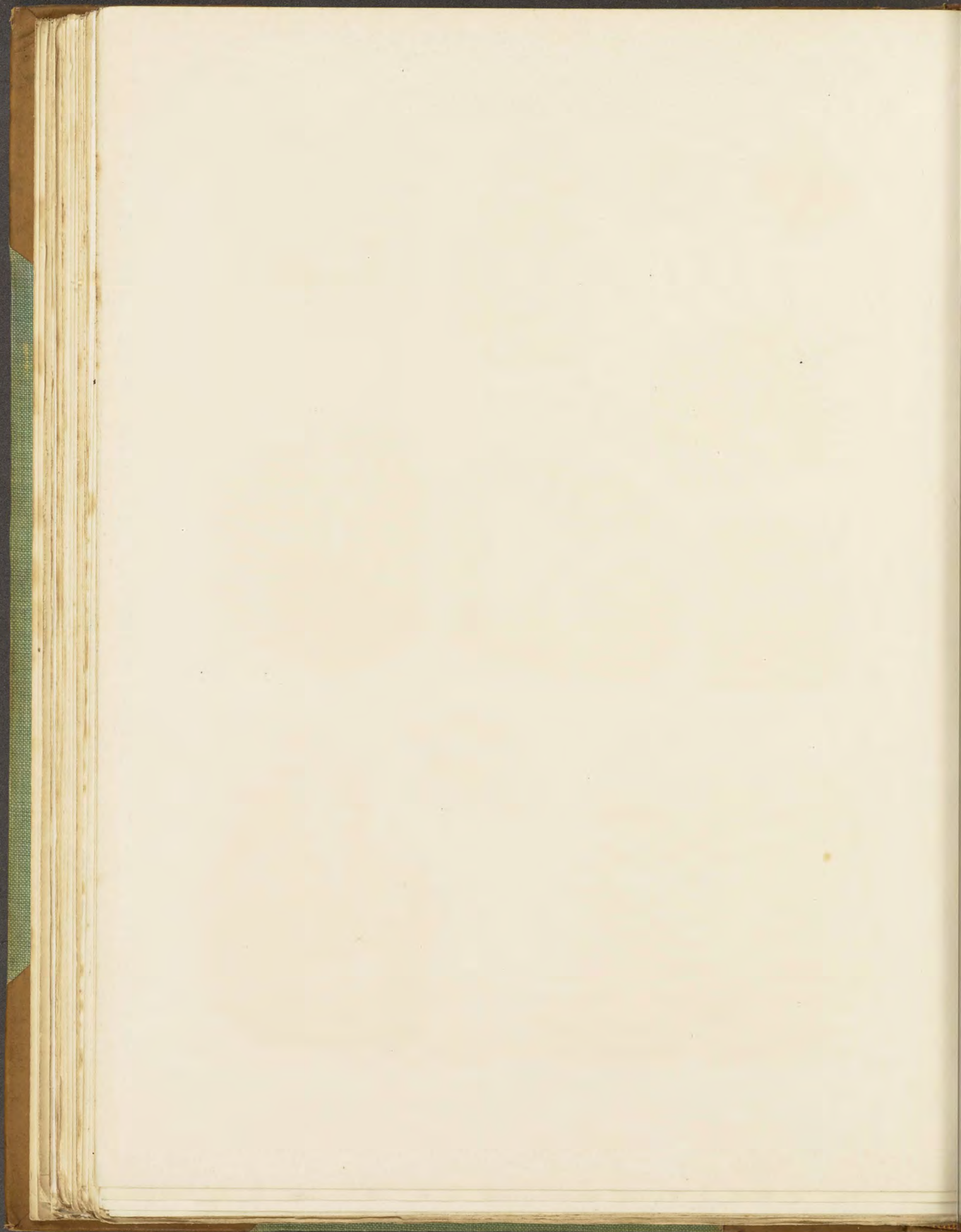


Manganese Ores III and Nickel Ores.

Fig.

1. **Hauerite** (MnS_2), isolated octahedron.
Raddusa, Catania, Sicily.
2. **Hauerite**, octahedron with cube.
Raddusa, Catania, Sicily.
3. **Alabandite** (MnS), octahedra, simple crystals and twin-crystals (twinned on an octahedral face).
Nagyag, Transylvania, Hungary.
4. **Rhodonite** (variety "Fowlerite"), triclinic crystal of prismatic habit.
Franklin Furnace, Sussex Co., New Jersey, U. S. A.
5. **Rhodonite**, (variety "Fowlerite"), tabular crystals.
Franklin Furnace, Sussex Co., New Jersey, U. S. A.
6. **Rhodonite**, cut and polished.
Ekaterinburg district, Ural Mountains.
7. **Niccolite** (NiAs), with barytes.
Richelsdorf, Rotenburg, Hesse.
8. **Millerite** (NiS), acicular crystals on matrix.
Hilfe Gottes mine, Nanzenbach, Dillenburg, Nassau.
9. **Millerite**, a bundle of acicular crystals.
Hilfe Gottes mine, Nanzenbach, Dillenburg, Nassau.
10. **Gersdorffite** (NiAsS), octahedra on chalybite.
Lobenstein, Saxon Vogtland.
11. **Chloanthite** (NiAs_2), cubes with octahedral faces.
Schneeberg, Saxony.
12. **Garnierite**, massive.
New Caledonia.





Nickel Ores.

The number of minerals from which nickel is obtained in any quantity is only small, being in fact limited at the present day to nickeliferous pyrrhotite (p. 150) and garnierite, a hydrated nickel silicate. Some few others have formerly been of importance as ores, and for this reason they will receive mention here. Nickel is always present in meteoric iron. The more important nickel minerals are the following: —

Pyrrhotite, $\text{FeS} + \text{NiS}$.	Gersdorffite, NiAsS .
Millerite, NiS .	Chloanthite, NiAs_2 .
Niccolite, NiAs .	Annabergite, $\text{Ni}_3\text{As}_2\text{O}_8 \cdot 8\text{H}_2\text{O}$.
Breithauptite, NiSb .	Garnierite.

The metals nickel and cobalt are very closely allied to one another and in a lesser degree to iron, and the compounds they form are very similar. Their minerals fall into isomorphous groups (p. 143) and frequently contain more than one of the metals replacing each other in equivalent amounts.

Millerite forms very thin, hair-like or needle-like crystals, with a brass-yellow colour and metallic lustre, which are frequently aggregated into divergent tufts (plate 35, figs. 8 and 9). These crystals are very long and slender hexagonal prisms, and sometimes have a helical twist about their length. Owing to the delicate form of the crystals, this mineral is also sometimes known as hair-nickel or capillary pyrites. It has been suggested that in all cases millerite has been formed by a molecular transformation of beyrichite, a rare mineral with a grey metallic colour. The two minerals are identical in chemical composition, NiS , and have the same prismatic form, so that the change only affects the internal structure and the colour. Beyrichite has a specific gravity of 4.7 and millerite 5.9. The mineral is dissolved by nitric acid giving a green solution of nickel nitrate.

Millerite occurs with copper-pyrites in the Hilfe Gottes mine at Nanzenbach near Dillenburg in Nassau (plate 35, figs. 8 and 9); and also in the Friedrich mine at Wissen, and at Gladenbach in Rhenish Prussia, where formerly the mineral was mined. Very fine, acicular crystals are found in crevices in nodules of clay-iron-stone at Neunkirchen in the Saar coal mining district, and at Merthyr-Tydvil in South Wales. Other localities are: Johanngeorgenstadt in Saxony; the Gap mine in Lancaster Co., Pennsylvania; St. Louis in Missouri; the Sterling mine at Antwerp, New York; and abundantly in quartz at Benton in Saline Co., Arkansas.

Niccolite differs chemically from millerite in containing arsenic instead of sulphur, it being nickel arsenide NiAs . In their external appearance these two minerals are quite different, niccolite having a metallic copper-red colour and usually occurring in compact masses (plate 35, fig. 7). On account of its characteristic copper-red colour, this mineral was very early known in Germany as "Kupfernickel" (i. e. copper-nickel), although it contains no copper. The names nickel and cobalt are themselves rather names of disgrace: the former means in German 'worthless', and was applied to this mineral because it was useless as a copper ore; and the latter is from Kobold, the demon of the German mines. An old mineralogical treatise dated 1759 remarks: "Kupfernickel is a cobaltic copper degeneracy" and "Kupfernickel is not only an indication of cobalt, but is itself a cobalt though more stupid". The present mineral could scarcely be mistaken for native copper, since it is hard ($H. = 5\frac{1}{2}$) and brittle, whilst copper is soft and malleable; its streak is black, that of copper being red. Niccolite is soluble in warm nitric acid giving a green solution, which on cooling deposits brilliant, colourless

octahedra of arsenic trioxide. When heated before the blowpipe on charcoal, it emits arsenical fumes with the well-known garlic-like odour.

Crystals are of rare occurrence, and are always indistinctly developed; they belong to the hexagonal system, and are usually seen as the tips of hexagonal pyramids closely clustered together. Usually the mineral occurs as compact masses, which on weathered surfaces are coated with green, earthy annabergite. This is the hydrated nickel arsenate, $\text{Ni}_3\text{As}_2\text{O}_8 \cdot 8\text{H}_2\text{O}$, which is always present as a product of weathering on arsenical nickel ores; its colour somewhat resembles that of garnierite (fig. 12), but is a paler apple-green.

Niccolite occurs in association with silver ores in veins traversing crystalline schists at Schneeberg, Annaberg and other places in Saxony; at Joachimsthal in Bohemia; and with cobalt ores and barytes in veins in the Kupferschiefer district of Sangerhausen, Mansfeld and Richelsdorf in Germany. It has also been found in some of the Cornish mines. The mineral has been used for the extraction of nickel and for the preparation of white arsenic.

Very similar to niccolite is the species *breithauptite*, which contains antimony in place of arsenic, its chemical formula being NiSb . It is found embedded in calcite at Andreasberg in the Harz. Isomorphous mixtures of these two compounds are also known.

Gersdorffite, or nickel-glance, crystallizes in regular octahedra (plate 35, fig. 10), with sometimes small faces of the cube and the rhombic-dodecahedron, and rarely of the pentagonal-dodecahedron; the mineral is therefore cubic with pentagonal hemihedrism, having the same symmetry as the more common mineral cobalt-glance. These two minerals are also closely related chemically, nickel-glance being NiAsS , and cobalt-glance the corresponding cobalt compound CoAsS . Crystals of nickel-glance are dull and greyish-black on their exterior, but freshly fractured surfaces are steel-grey with a metallic lustre. The hardness is 5–5½. The mineral is readily decomposed by weathering and becomes coated with a green crust of annabergite and nickel-vitriol.

The specimen with large crystals and associated chalybite represented in fig. 10 is from Lobenstein in Thuringia; smaller crystals and massive material are found in the mineral-veins of the Rhenish district and of the Harz, but the mineral is one of rare occurrence.

Chloanthite and the very similar mineral smaltite show more than any others the close relation which exists between nickel and cobalt. Ideally, chloanthite is a diarsenide of nickel, NiAs_2 , and should contain 28.1 per cent. of nickel and 71.9 per cent. of arsenic; whilst smaltite is the corresponding cobalt compound, CoAs_2 . As a matter of fact, however, neither of these compounds is ever found in the pure state, but they always contain cobalt, nickel and iron isomorphously replacing one another. There is thus no hard and fast line between chloanthite and smaltite, and they pass insensibly one into the other. The members of the series which are richer in nickel and on weathering consequently become encrusted with green annabergite are placed with chloanthite.

The crystals are cubic, usually with faces of the cube and the octahedron (plate 35, fig. 11), and have a metallic lustre with tin-white or steel-grey colour, but frequently a greyish tarnish. The mode of occurrence and the applications of chloanthite are the same as for smaltite, and will be mentioned under the latter mineral.

Garnierite is one of the most important of the ores of nickel. It occurs in compact or earthy masses which are quite soft and greasy to the touch, while the fine green colour is a feature which attracts the eye (plate 35, fig. 12). The colour varies in shade and is not always so rich as represented in the figure; it is usual to distinguish the darker green varieties as *noumeite* (after the locality, Noumea in New Caledonia), and the paler green varieties as *garnierite* (after Jules Garnier, the discoverer of the New

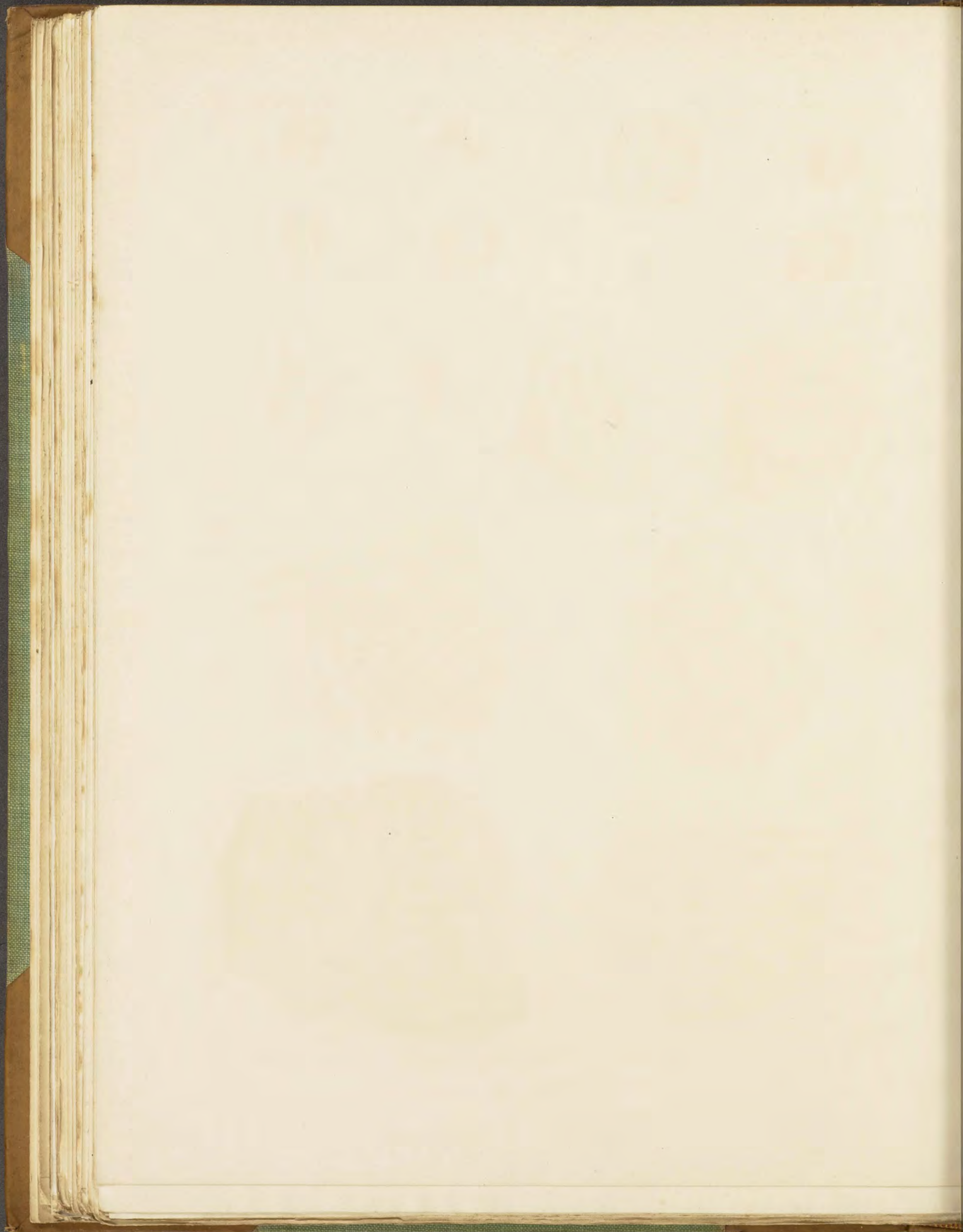


Cobalt Ores.

Fig.

1. **Cobaltite** (CoAsS), isolated crystal, pentagonal-dodecahedron.
Tunaberg, Sweden.
2. **Cobaltite**, pentagonal-dodecahedron with small cube faces.
Håkansboda, Westmanland, Sweden.
3. **Cobaltite**, cube with pentagonal-dodecahedron.
Tunaberg, Sweden.
4. **Cobaltite**, octahedron.
Tunaberg, Sweden.
5. **Cobaltite**, octahedron.
Tunaberg, Sweden.
6. **Cobaltite**, crystal with smooth octahedron faces, striated pentagonal-dodecahedron faces and small cube faces.
Tunaberg, Sweden.
7. **Cobaltite**, octahedron with pentagonal-dodecahedron, so-called icosahedron.
Tunaberg, Sweden.
8. **Cobaltite**, octahedron with pentagonal-dodecahedron.
Skutterud, Modum parish, Norway.
9. **Cobaltite**, crystal in copper-pyrites.
Tunaberg, Sweden.
10. **Cobaltite**, crystals in mica-schist.
Skutterud, Modum parish, Norway.
11. **Glaucodote** (CoAsS), isolated crystal, prism with brachy-dome.
Håkansboda, Westmanland, Sweden.
12. **Glaucodote**, interpenetrating twin with an ortho-dome as twin-plane.
Håkansboda, Westmanland, Sweden.
13. **Smaltite** (CoAs₂), indistinct crystals, cube with octahedron.
Richelsdorf, Rotenburg, Hesse.
14. **Smaltite**, cubes with octahedron and rhombic-dodecahedron.
Richelsdorf, Rotenburg, Hesse.
15. **Smaltite**, with shelly structure and a thin coating of earthy erythrite.
Richelsdorf, Rotenburg, Hesse.
16. **Erythrite**, radial groups of acicular crystals.
Rappold mine, Schneeberg, Saxony.





Caledonian nickel ores). This distinction is, however, of little importance, for the material is not a definite chemical compound and consequently not a distinct mineral species, but only a mixture. It contains silica, magnesia, nickel oxide and water in variable proportions, and may be considered as a nickel-bearing hydrated magnesium silicate allied to serpentine; the amount of nickel oxide contained in pure selected samples varies from 3 to 30 per cent. The mineral occurs in veins traversing a serpentine-rock, and like this it has been derived by the weathering of an olivine-rock, the olivine of which contained nickel. With the weathering of the olivine the nickel was set free and was deposited in crevices as a concretionary layer on blocks of the weathered rock.

The largest and richest deposits of garnierite are those near Noumea in New Caledonia, and beds up to ten metres in thickness also occur in Douglas County, Oregon. Of less importance is the occurrence at Gläsendorf and Kosemütz near Frankenstein in Prussian Silesia, where the mineral, containing 2—3½ per cent. of nickel, has recently been mined. Pure nickel can be more readily extracted from garnierite than from ores which contain their nickel in combination with sulphur and arsenic, and it is therefore only since discovery of the garnierite deposits in New Caledonia that the nickel industry has attained its present importance.

Applications of nickel. — At the present time nickel ores are mined only in New Caledonia, Canada and the United States. During the year 1901 the New Caledonian ores treated in England, France and Germany yielded 5000 metric tons of metallic nickel, while Canada and the United States produced 3600 tons. The price of nickel is about three shillings per kilogram.

Nickel is used for the construction of a variety of household vessels and utensils, and for nickel-plating. Steel with an addition of nickel is greatly increased in toughness, and on this account nickel-steel has recently been used for the armour plates of battleships. An alloy of copper, zinc and nickel is known as German silver (p. 114). The nickel coins of Germany contain 25 parts of nickel and 75 parts of copper; those of other countries (Switzerland and Austria) contain more nickel.

Cobalt Ores.

The cobalt ores are analogous in composition to the ores of nickel, though the simplest compounds, corresponding to millerite and niccolite, are not known in nature. On the other hand, the rare mineral skutterudite, consisting of cobalt triarsenide, CoAs_3 , has no nickel analogue. With these exceptions, the cobalt minerals correspond with the nickel minerals, and we have the following pairs: cobalt-glance and nickel-glance, smaltite and chloanthite, erythrite and annabergite. Oxide of cobalt occurs mixed with oxides of manganese and iron, forming a cobaltiferous wad known as black earthy cobalt or asbolite. The arseno-sulphide of cobalt, CoAsS , is dimorphous, occurring as the pyritohedral-cubic cobalt-glance and as the rhombic glaucodote. The more important cobalt minerals are thus the following: —

Cobalt-glance and Glaucodote, CoAsS .	Erythrite, $\text{Co}_3\text{As}_2\text{O}_8 \cdot 8\text{H}_2\text{O}$.
Smaltite, CoAs_2 , and Skutterudite, CoAs_3 .	Asbolite (a mixture).

The best test for cobalt is given by the blue colour which it imparts to a blowpipe bead of microcosmic salt or borax, and cobalt ores may always be detected by this characteristic reaction.

Cobalt-glance, or cobaltite, is a mineral which can always be recognized by the form and colour of its crystals. These are cubic with pentagonal hemihedrism exactly

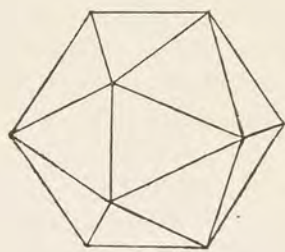


Fig. 143.
Crystal of Cobaltite.

like those of iron-pyrites in form, the two minerals cobaltite and iron-pyrites being isomorphous. Several isolated crystals are represented in plate 36: fig. 1 shows the pentagonal-dodecahedron, and fig. 2 the same with small faces of the cube; fig. 4 the cube in combination with the pentagonal-dodecahedron; figs. 4 and 5 the octahedron; and figs. 6, 7 and 8 the combination of the octahedron and the pentagonal-dodecahedron developed to the same extent, giving the so-called icosahedron. The accompanying text-fig. 143 shows this combination drawn with ideal regularity; the octahedron

faces are equilateral triangles, and those of the pentagonal-dodecahedron are isosceles triangles. In the natural crystals these two sets of faces are physically quite different, and may be readily distinguished; the octahedron faces being bright and smooth, and the pentagonal-dodecahedron faces striated or dull.

The colour of the crystals is silver-white with a tinge of red, or steel-grey with a tinge of violet, and the streak is greyish-black. There are distinct cleavages parallel to the faces of the cube. The hardness is $5\frac{1}{2}$, and the specific gravity a little over 6. Corresponding to the formula CoAsS , the mineral, when pure, contains 35.4 per cent. of cobalt, but owing to the partial replacement of cobalt by iron the former may be as low as 30 per cent. Crystals of cobaltite are readily recognized, and the massive ore is easily determined before the blowpipe; it gives an arsenical odour, with soda the hepatic reaction, and in the microcosmic bead a blue colour.

Crystals of cobaltite are found together with copper-pyrites (plate 36, fig. 9) in veins in gneiss at Tunaberg in Sweden (figs. 1, 3—7 and 9); embedded in a quartzose mica-schist at Skutterud in the parish of Modum in Norway (figs. 8 and 10); and at Håkansboda in Westmanland, Sweden (fig. 2). At Dashkessan in government Tiflis in Caucasia there is a bed of pure cobaltite with an average thickness of 0.2 metre.

Glaucodote has the same chemical composition as cobaltite, though here a larger proportion of the cobalt is replaced by iron, and in most instances iron predominates. Crystals from Håkansboda contain 15 per cent. of cobalt and 19 per cent. of iron, so that the formula must be written as $(\text{Fe,Co})\text{AsS}$, and the mineral may be considered to be a richly cobaltiferous mispickel (p. 148). The crystals are rhombic with angles very close to those of mispickel. In plate 36, fig. 11 shows a simple crystal and fig. 12 an intercrossing twinned crystal. The crystals here represented are prismatic in habit, but it is usual to take the long faces in fig. 11 and the striated faces in fig. 12 as the brachy-dome, and the small terminal faces as the vertical prism, the twin-plane then being a face of the macro-dome. The hardness is 5, and the specific gravity 6.0.

The finest crystals are those from Håkansboda in Sweden, where they occur with crystals of cobaltite embedded in copper-pyrites. Crystals in gneiss from Franconia, in New Hampshire, approach more nearly to mispickel in composition, and are called danaite.

Smaltite. This, the the most important ore of cobalt, is a compound of cobalt and arsenic CoAs_2 , but a portion of the cobalt is invariably replaced by equivalent amounts of nickel and iron. Theoretically, the percentage of cobalt should be 28.1, but it scarcely ever reaches as much as 20, and is often less than this.

Crystals are cubic and are usually rather roughly developed; thus the large crystal shown in plate 36, fig. 13, is a combination of the cube and octahedron (the large surface to the front being a cube face), and the crystals in fig. 14 are bounded

by the cube, octahedron and rhombic-dodecahedron. The crystal in fig. 15 has been broken across and shows, in the interior, shelly lines of growth, so that we see here a zonal structure in an opaque mineral. The reddish colour seen on these crystals is due to a partial alteration of the material by weathering with the formation of earthy erythrite. Dendritic and rod-like forms of growth are also met with, while compact, granular masses of the mineral are of common occurrence.

Smaltite occurs in association with native bismuth, niccolite, silver ores and quartz in veins traversing granite and gneiss at Schneeberg in Saxony and at Wittichen in Baden; and under very similar conditions, together with large amounts of native silver, near Lake Temiskaming in northern Ontario in Canada. With barytes, niccolite and asbolite it occurs in veins in the Kupferschiefer (copper-shale) at Richelsdorf and Bieber in Hesse, and at Glücksbrunn and Kamsdorf in Thuringia. The beds of the Zechstein formation, of which the Kupferschiefer (p. 104) forms a part, are intersected by planes of faulting with downthrows of 10 to 20 metres, and along the crevices the various minerals have been deposited; the cobalt and nickel ores are collected mainly against the downthrown Kupferschiefer, and these portions of the veins are called "backs", and the ores "cobalt backs".

Erythrite, or cobalt-bloom. This is a hydrated arsenate of cobalt with the formula $\text{Co}_3\text{As}_2\text{O}_8 \cdot 8\text{H}_2\text{O}$, corresponding to the hydrated arsenate of nickel, annabergite or nickel-bloom. The former is of a beautiful crimson or peach-red, while the latter is of an equally characteristic pale apple-green colour. Annabergite is found only in an earthy and massive form, whilst erythrite is sometimes found as acicular crystals, of a fine red colour, aggregated in radiating tufts or stellate groups (plate 36, fig. 15); more frequently, however, it occurs as an earthy encrustation on smaltite, to the weathering of which it owes its origin.

Specimens of crystallized erythrite come from Schneeberg in Saxony, while the earthy mineral occurs at all the localities at which smaltite is known. Sometimes the earthy erythrite is encrusted with small, white, spherical masses with a radially-fibrous structure and very like spots of mould in appearance: this is the mineral pharmacolite, a hydrated calcium arsenate, which has been formed by the action of the weathering products of smaltite on the neighbouring limestone.

Applications of cobalt. — Attempts have recently been made to use metallic cobalt for the same purposes as metallic nickel, but apart from this almost the only application of cobalt depends on its property of imparting a fine blue colour to glass and porcelain. This use of cobalt has been known since very early times, for blue cobalt glass has been found in the tombs of the ancient Egyptians and in the ruins of Troy. In the preparation of blue glass, the cobalt ore, after roasting, is simply added to the molten glass. The blue glass so obtained, when powdered and the finer particles collected by washing in water, gives smalt or cobalt-blue, which owing to its resistance to heat and solutions, is much used as a pigment. The blue colour of porcelain is produced by black cobalt oxide, which is taken up by the glaze during the burning.

Since olden times the cobalt industry has been centred in the Saxon Erzgebirge, and the smalt is there manufactured in colour works belonging both to the state and to private firms. Now, however, a sufficient quantity of ore cannot be mined on the spot, and the ore is imported from Sweden, Russia and New Caledonia. The New Caledonian ore is an earthy mixture of limonite with manganese oxides and about 4 per cent. of cobalt oxide; this is known as black earthy cobalt (asbolite). Important deposits of cobalt ore (smaltite) have recently been discovered in northern Ontario.

Tungsten Compounds.

Of the few tungsten compounds occurring in nature, only one is of any importance as an ore; this is wolframite, a tungstate of iron and manganese $(\text{Fe,Mn})\text{WO}_4$. Scheelite, a tungstate of calcium CaWO_4 , is of importance as a mineral, but the others (stolzite PbWO_4 and hübnerite MnWO_4) are of quite rare occurrence.

Scheelite, a mineral named in honour of the Swedish chemist Scheele, the discoverer of the metal tungsten, is of especial interest to crystallographers. The

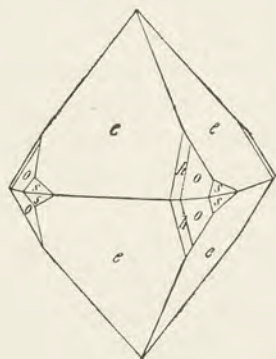


Fig. 144.
Crystal of Scheelite.

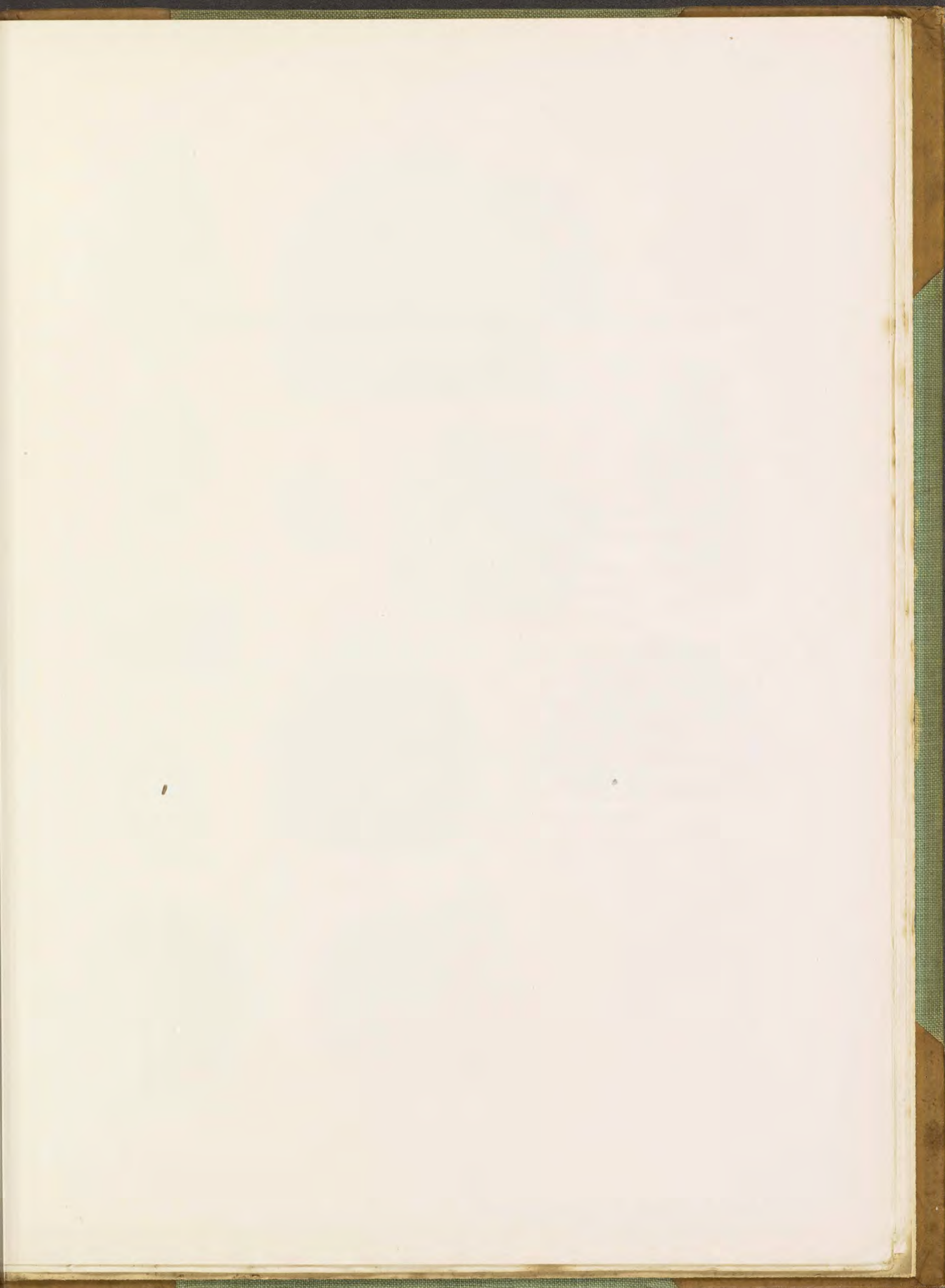
crystals belong to the tetragonal system and are usually bounded by a single square pyramid, which even in combinations predominates and gives rise to the characteristic pyramidal habit of the mineral (plate 37): tabular crystals are rare, whilst a prismatic habit is not known. When the pyramidal crystals are examined closely other small faces may sometimes be detected on their corners. In text-fig. 144 the predominating pyramid e is taken as a pyramid of the second order P_∞ ; the faces marked o belong to the primary pyramid P of the first order; and the faces h and s occupy the positions of eight-sided pyramids, but each of them have only half the full number of faces developed, these forms being hemihedral with parallel faces and having the symbols $\frac{3P3}{2}$ and $\frac{P3}{2}$ respectively. Scheelite

is thus tetragonal with pyramidal-hemihedrism, and it affords the best example of this type of symmetry.

The crystals are usually yellow of various shades (plate 39, figs. 1—5), but sometimes grey or white (fig. 6); they are transparent to translucent, and may be bright or dull and rough. The hardness is $4\frac{1}{2}$ —5, and the specific gravity 6.0. Parallel to the faces of the primary pyramid o there are good cleavages. The pure mineral contains 19.44% of lime (CaO) and 80.56 of tungstic oxide (WO_3), corresponding with the formula CaWO_4 ; often, however, a small proportion of the tungsten is isomorphously replaced by an equivalent amount of the closely allied metal molybdenum. The mineral is decomposed by hydrochloric acid, the calcium passing into solution and the tungstic oxide remaining behind as a yellow powder.

Scheelite only rarely shows any signs of alteration by weathering, nevertheless it does sometimes undergo a change, as proved by the occurrence of pseudomorphs of wolframite after scheelite (fig. 7).

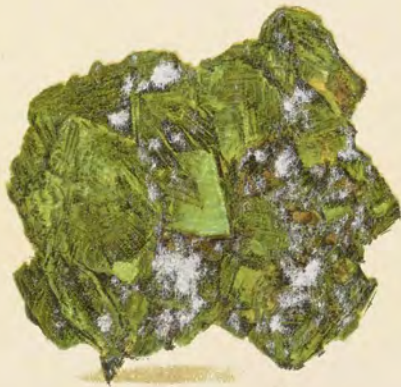
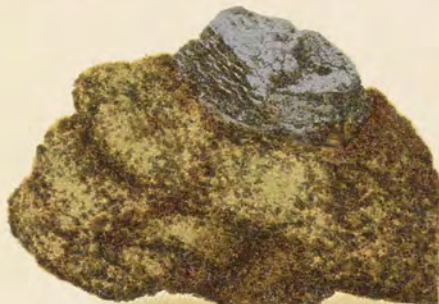
The mineral is generally found in veins in granitic rocks and is then a common associate of tin-stone, but it may be unassociated with this and also tin-stone may occur without scheelite. Crystals are found in the tin-stone veins at Schlaggenwald (plate 37, fig. 6) and Zinnwald in Bohemia, at Ehrenfriedersdorf in Saxony, and in Devon and Cornwall. In other veins it is associated with flour-spar, as at the Riesengrund in the Riesengebirge in Bohemia (fig. 2), and at Fürstenberg in Saxony (fig. 1). Crystals also occur in crevices in hornblende-schist on the Little Mutschen in the Etzli-thal, and at Kamegg near Guttannen above Meiringen (fig. 4), in Switzerland; in the magnetite deposits at Traversella in Piedmont (fig. 5); at Dragoon in Arizona; and at Carrock Fell in Cumberland. Pseudomorphs of wolframite after scheelite (fig. 7) are from Lane's mine at Monroe in Connecticut.



Tungsten, Molybdenum and Uranium Compounds.

Fig.

1. **Scheelite**, yellow pyramidal crystals on quartz.
Fürstenberg, Schwarzenberg, Erzgebirge, Saxony.
2. **Scheelite**, large pyramidal crystals with fluor-spar.
Riesengrund, on the southern slopes of the Schneekoppe in the Riesengebirge (Bohemia).
3. **Scheelite**, dark amber-yellow pyramid.
Dragoon, Arizona, U. S. A.
4. **Scheelite**, pyramid with dull, rough faces.
Guttannen, Meiringen, Switzerland.
5. **Scheelite**, pyramidal crystal on matrix.
Traversella, Piedmont, Italy.
6. **Scheelite**, pyramidal crystals on quartz.
Schlaggenwald, Bohemia.
7. **Scheelite**, altered to wolframite.
Lane's mine, Monroe, Connecticut, U. S. A.
8. **Wolframite**, simple (i. e. untwinned) crystal.
Zinnwald, Bohemia.
- 9a and b. **Wolframite**, two views of a twinned crystal.
Zinnwald, Bohemia.
10. **Pitchblende**, botryoidal.
Joachimsthal, Bohemia.
11. **Cuprouranite**, group of thin-tabular crystals.
Redruth, Cornwall.
12. **Molybdenite**, hexagonal tabular crystal in peridotite rock.
Aldfield, Pontiac Co., Quebec, Canada.
13. **Molybdenite**, hexagonal tabular crystal, viewed from above.
Aldfield, Pontiac Co., Quebec, Canada.





Wolframite consists of an isomorphous mixture of tungstate of iron and tungstate of manganese in very variable proportions, $(\text{Fe, Mn})\text{WO}_4$, sometimes the iron and sometimes the manganese predominating. With this variation in composition there is a corresponding variation in colour from brownish-black (containing more manganese) to pitch-black; the mineral is opaque with a semi-metallic lustre; the streak is reddish-brown to blackish-brown. The specific gravity is very high, varying with the chemical composition from 7.1 to 7.5.

Crystals are monoclinic, often with a rhombic habit, the mineral having been in fact formerly considered to be rhombic in crystallization. In plate 37, fig. 8, the large face to the front is the ortho-pinacoid (r in text-fig. 145), the vertically striated faces at the sides the vertical prism (M), while above are an ortho-dome (P) and one face of a clino-dome (u). The Naumannian symbols of the forms present on the crystal shown in text-fig. 145 are: —

$$r = \infty P\infty, b = \infty P^2, M = \infty P, P = -\frac{1}{2}P\infty, n = \frac{1}{2}P\infty, u = P\infty, a = -P, s = -2P^2.$$

Figs. 9a and b show two views of a crystal twinned on the ortho-pinacoid; in the first the striated ortho-pinacoid and prism faces are set up vertically (as in fig. 8), while in the second the crystal is turned round to show more clearly the re-entrant angle at the top. Crystals of wolframite possess a very perfect cleavage parallel to the plane of symmetry, that is parallel to the clino-pinacoid, although this is not developed as a crystal face on any of the crystals here shown.

Crystals of wolframite are of comparatively rare occurrence, the mineral being more often met with as granular, columnar or fibrous masses. These may usually be recognized by the perfect cleavage with dark blackish-brown colour and sub-metallic lustre, and by the high specific gravity; and the determination may be confirmed by the following tests. When heated before the blowpipe for some time a fused globule of the mineral becomes magnetic, proving the presence of iron; the powdered mineral when fused with sodium carbonate and potassium nitrate gives a green colour characteristic of manganese; and in warm hydrochloric acid the mineral is decomposed leaving a yellow residue of tungstic acid.

Wolframite is a frequent associate of tin-stone, but it also occurs without this. Large crystals are met with in the veins of tin ore in the Erzgebirge of Saxony and Bohemia, and in many of the Cornish tin mines; the large crystal shown in fig. 8 is from Zinnwald in Bohemia. Finely fibrous masses, with occasionally minute crystals, are mined in Spain, which is the chief wolfram-producing country. The production of ore in the year 1900 amounted to 1958 tons in Spain, 188 tons in Queensland (at Wolfram Camp in the Hodgkinson mining field), 43 tons in Saxony, and 36 tons in Austria.

The metal tungsten finds an application in the manufacture of steel (tungsten-steel), and the greater the amount of tungsten added the harder and tougher is the product. An alloy of tungsten and aluminium, known as partinum, is used in the construction of automobiles. The pure metal is fusible only with great difficulty, but it can now be obtained by the Goldschmidt process, which has been described above under chromium. It is a very hard and heavy metal (sp. gr. 16), and would be suitable for projectiles if only it could be more easily worked. Quite recently, it has been employed as the metallic filament of incandescent electric lamps.

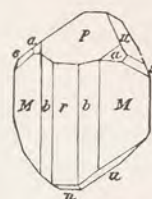


Fig. 145.
Crystal
of Wolframite.

Molybdenum Compounds.

One of the native compounds of molybdenum has already been considered with the lead ores, namely wulfenite, the molybdate of lead PbMoO_4 . There only remains to be mentioned here the sulphide MoS_2 .

Molybdenite, or molybdenum-glance, forms tabular hexagonal crystals with narrow and deeply striated prism faces at the edges (plate 37, figs. 12 and 13), but more frequently it occurs as thin plates without definite outline embedded in the matrix. It is lead-grey with a metallic lustre and is opaque. Owing to its low degree of hardness ($H. = 1$) it readily marks paper. The crystals and scales possess a perfect cleavage parallel to their large surface, i. e. the cleavage is basal. Molybdenite resembles graphite more or less closely in appearance, but it may be distinguished from this by its lead-grey colour, much higher specific gravity (4.8), and by its chemical reactions. It is a compound of molybdenum and sulphur with the formula MoS_2 ; the presence of sulphur is best detected by the hepatic reaction.

Molybdenite is found together with tin ores at Altenberg in Saxony, Zinnwald and Schlaggenwald in Bohemia, and in Cornwall. It is also found in the neighbourhood of granite and other plutonic rocks at Auerbach in Saxony, at Carrock Fell in Cumberland, and in Nerchinsk in Siberia. Large crystals occur at Aldfield, Quebec, and at Kingsgate, New South Wales; and masses of some size in the Hodgkinson mining field in Queensland.

Molybdenite never forms extensive deposits, though it is practically the only source of molybdenum. It is used for the preparation of molybdenum compounds, which are mainly employed as chemical reagents; and recently it has been employed, like tungsten, in the manufacture of certain varieties of steel.

Uranium Compounds.

Pitchblende, or uraninite, though in itself a mineral of most unattractive appearance, is of special interest on account of the remarkable and mysterious properties possessed by some of its constituents. The rays emitted by these constituents cause the air to become a conductor of electricity, so that under their influence an electroscope or other electrically charged body is discharged; they are capable of passing through certain opaque substances, and acting in the dark on a photographic plate; and further, they cause barium platinocyanide to phosphoresce with a bright light. To what source of energy these phenomena are due is not quite clear, but they may possibly be caused by the projection of extremely minute particles of the substance itself from the main mass. This radio-activity of salts of uranium was first observed by the late Professor Henri Becquerel in 1896, and the rays have on this account been known as Becquerel rays; they are also known as uranium rays or radium rays. It has since then been found that the rays are not emitted by the uranium itself, but by other substances which are mixed with it in extremely minute quantities. One of these has been isolated and named radium, a chemical element which in the crystalline forms of its salts shows a close relation to barium. The other, known as radio-active bismuth or polonium, has not yet been isolated in a pure condition; and it is still questionable whether a second radio-active substance is present in pitchblende, or whether the radio-activity of bismuth may not be due to the presence of traces of radium.

The rays emitted by radium also cause diamond to phosphoresce brightly in the dark. We are thus furnished with an easy and certain means of testing the genuineness of a diamond, for neither glass nor rock-crystal display any appreciable phosphorescence when placed close to radium; ruby, sapphire and emerald are likewise not affected. Another, and still more remarkable feature presented by radium is its slow transformation into helium, as recently observed by Sir William Ramsay. The search of the alchemists for the philosopher's stone and the transmutation of the elements has thus been vindicated, and the very foundations of modern chemistry have been shaken. It is, however, not yet proved beyond doubt that radium is an element; its properties have not yet been completely investigated by physicists and chemists, and it may possibly prove to be a compound or a mixture.

The mineral pitchblende, in which this magic substance is contained, usually occurs as compact, opaque masses of a greenish-black or pitch-black colour and greasy lustre; the free surface of the masses is mamillated or reniform (plate 37, fig. 10). The mineral crystallizes in the cubic system, but crystals are small and of extremely rare occurrence. Like other minerals which occur in compact masses, pitchblende is not a pure chemical compound, but rather of the nature of a mixture. It consists mainly of uranium oxides, which may be present to the extent of 80 per cent., the remainder consisting of lead, iron, bismuth, antimony, thorium, lanthanum, yttrium, and traces of radium.

In order to demonstrate the presence of uranium, a little of the powdered pitchblende is dissolved in nitric acid, and the solution evaporated to dryness. Water and sodium carbonate are then added and a drop of the filtered solution is placed on a microscope slide together with a drop of acetic acid and allowed to evaporate. Small regular tetrahedra of sodium uranyl acetate are thereby formed and these are readily recognized under the microscope.

Corresponding with the variation in chemical composition of the mineral, there is a wide variation in the specific gravity, which ranges from 8.0 to 9.7. The hardness is 5-6. Before the blowpipe the mineral is infusible.

The principal locality for pitchblende is Joachimsthal in Bohemia, where it is found in the mineral-veins with ores of silver, bismuth, nickel and cobalt. Until ten years ago about 22 tons of uranium ore were obtained annually from these mines, but since the discovery of radium the output has been greatly increased. The mineral is also found in the Saxon Erzgebirge at Marienberg, Annaberg and Johanngeorgenstadt, also in Cornwall and Colorado, and as crystals in the felspar quarries of Norway, but never in more than small amounts.

Pitchblende is the crude material or ore from which all uranium compounds are prepared. Amongst other purposes, these are used for the manufacture of the green fluorescent uranium glass and for pigments used in painting on porcelain. In recent times they have acquired considerable importance by reason of their radio-active properties: besides being used in physical investigations, radium is extensively used for medical purposes. It possesses all the advantages of the Röntgen rays without their injurious effects, and the rays it emits can be applied directly and conveniently at all times without the use of any accessory apparatus. A small glass tube no thicker than a quill containing only a little more than a milligram of the radium salt has been found to be just as effective as an expensive and cumbersome electrical apparatus; and in the treatment of cancer better results have been obtained than with the Röntgen rays, whilst in its local application, for example in the nose or throat, it possesses an enormous advantage in addition to that of simplicity.

The fact that radium gives out both light and heat and is also capable of causing other substances to become luminous holds out the hope that this material may in the future play an important part in lighting. A very small quantity of radium causes a screen coated with hexagonal zinc sulphide to become brilliantly luminous, and since this phosphorescent light is unaccompanied by the production of heat, there is no dissipation of a large proportion of the energy in this form, as in other methods of lighting. Were it not for the dangerous property it possesses of producing severe burns in the human skin, one would wish that this remarkable substance might be produced at a lower cost. Owing to its excessive rarity, its price is correspondingly high; in 1904 it was quoted at £400 per gram, while at the present time, with a demand greater than the supply, it is far higher.

The "Uranium Micæ". Whilst pitchblende is dull black and unattractive in appearance, many of the other compounds of uranium are brilliantly coloured and lustrous; their appearance is, in fact, rather suggestive of the phosphorescent colours which are induced in other substances by the Röntgen rays and the rays of radium. The most frequent of the naturally occurring compounds of uranium are platy in form and possess a perfect cleavage in one direction, so that they have a certain resemblance to the micæ, and on this account they are referred to collectively as the "uranium micæ". These minerals are hydrated compounds of uranium oxide with phosphoric or arsenic acid and in addition either calcium or copper: the more important are given below with their respective chemical formulæ:

Cuprouranite, $\text{CuO} \cdot 2\text{UO}_3 \cdot \text{P}_2\text{O}_5 + 8\text{H}_2\text{O}$. Zeunerite, $\text{CuO} \cdot 2\text{UO}_3 \cdot \text{As}_2\text{O}_5 + 8\text{H}_2\text{O}$.
 Calcouranite, $\text{CaO} \cdot 2\text{UO}_3 \cdot \text{P}_2\text{O}_5 + 8\text{H}_2\text{O}$. Uranospinite, $\text{CaO} \cdot 2\text{UO}_3 \cdot \text{As}_2\text{O}_5 + 8\text{H}_2\text{O}$.

Cuprouranite, or torbernite (plate 37, fig. 11) may be here briefly described as the typical representative of this group of somewhat rare minerals. It invariably has the form of thin square plates with a bright grass-green or emerald-green colour and a pearly lustre on the tabular face. A number of crystals are often closely and irregularly grouped together on the surface of the matrix. In their external form and in their optical characters the crystals conform with tetragonal symmetry: the large face with a square outline is the basal plane, at the edges of which are narrow faces of the square prism and pyramids. Parallel to the base there is perfect cleavage, and thin flakes can readily be separated from the crystals; when examined in convergent polarized light these show a uniaxial interference-figure (plate 4, fig. 1). The mineral is not harder than gypsum, and its specific gravity is 3.5. The presence of copper can readily be demonstrated by moistening a fragment with hydrochloric acid and holding it in the flame of a Bunsen-burner, when a green coloration is imparted to the flame.

Cuprouranite is found at Johanngeorgenstadt in Saxony and Joachimsthal in Bohemia, but the best and largest crystals come from Gunnislake, Redruth (plate 37, fig. 11) and Grampond Road in Cornwall.

Calcouranite, or autunite, is sulphur-yellow in colour, and, although its crystals are very similar in habit and appearance to those of cuprouranite, it crystallizes in the rhombic system. The same is also true of the siskin-green uranospinite, whilst the emerald-green zeunerite is tetragonal like cuprouranite. In all these uranium minerals, as well as in a few others, are there traces of radio-active substances.

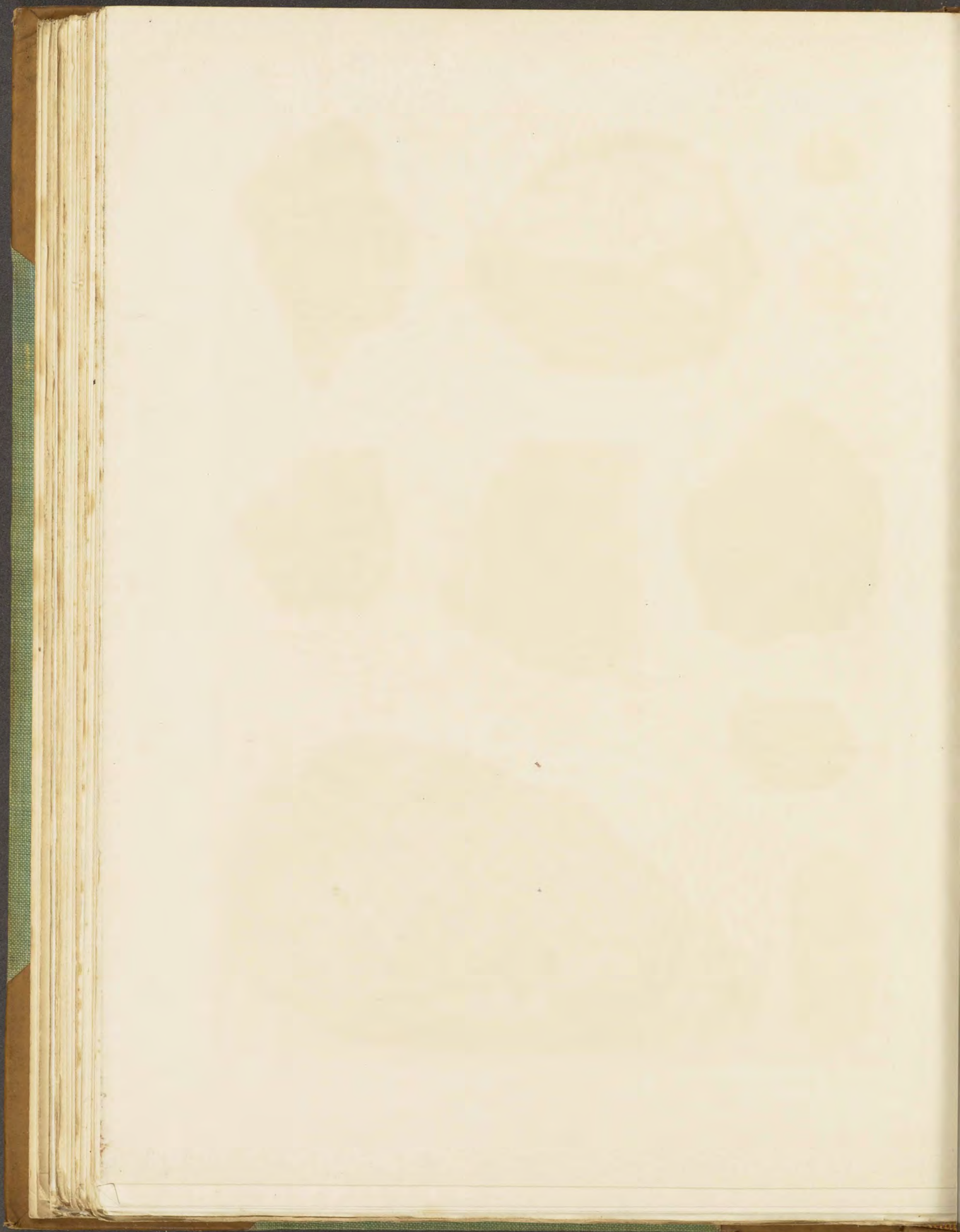


Tin Ores.

Fig.

1. **Cassiterite** (Tin-stone), simple (i. e. untwinned) crystal; prisms of the first and second orders with pyramids of the first and second orders. ∞P , $\infty P\infty$, P , $P\infty$.
La Villeder, depart. Morbihan, France.
2. **Cassiterite**, simple crystal with the same forms as in fig. 1, but with the pyramid of the first order small and that of the second order large.
Selangor, Malay Peninsula.
3. **Cassiterite**, large twinned crystal, twinned on a face of the pyramid of the second order $P\infty$. The large faces are those of the prism of the first order, and the faces forming the re-entrant angle are those of the pyramid of the first order. This is the so-called visor-shaped twin.
Schlaggenwald, Bohemia.
4. **Cassiterite**, three crystals twinned together; a trilling.
Zinnwald, Bohemia.
5. **Cassiterite**, twin-crystal as in fig. 3 viewed from the front.
Ehrenfriedersdorf, Saxony.
6. **Cassiterite**, the twinning is repeated on several faces of the pyramid of the second order $P\infty$, and the pyramid faces are grown up to the twin-plane without any re-entrant angle. This is the so-called knee-shaped twin.
La Villeder, depart. Morbihan, France.
7. **Cassiterite**, group of twin-crystals on quartz.
Schlaggenwald, Bohemia.
8. **Cassiterite**, group of twin-crystals with re-entrant angles.
Schlaggenwald, Bohemia.
9. **Cassiterite**, pseudomorph after felspar.
Wheal Coates, St. Agnes, Cornwall.
10. **Cassiterite** (variety "wood-tin"), with fine radially fibrous structure and reniform surface.
Cerro de Potosi, Bolivia.





Tin Ores.

Bronze, which is an alloy of copper and tin (p. 113), has been known since very early times, and in fact is closely connected with the development of the human race, for the bronze-age following after the stone-age preceded the age of iron. It is therefore clear that tin ore was known at this early period, but whether the bronze was obtained directly by smelting together ores of copper and tin or by alloying the metals is not known. When we consider the abundance of tin ore in the streams of certain districts and the ease with which it can be smelted it is not improbable that metallic tin also was known. In the Swiss lake-dwellings there have been found earthenware vessels, knobs and other articles coated with strips of tin-foil; and in the ancient graves on the island of Amrum off the coast of Schleswig-Holstein various objects made of tin have been discovered.

The rarity of objects of tin belonging to ancient times is, however, not surprising when we remember that metallic tin is subject to a remarkable kind of alteration or a disease of the metal itself. In a fresh condition tin is white and lustrous, and being

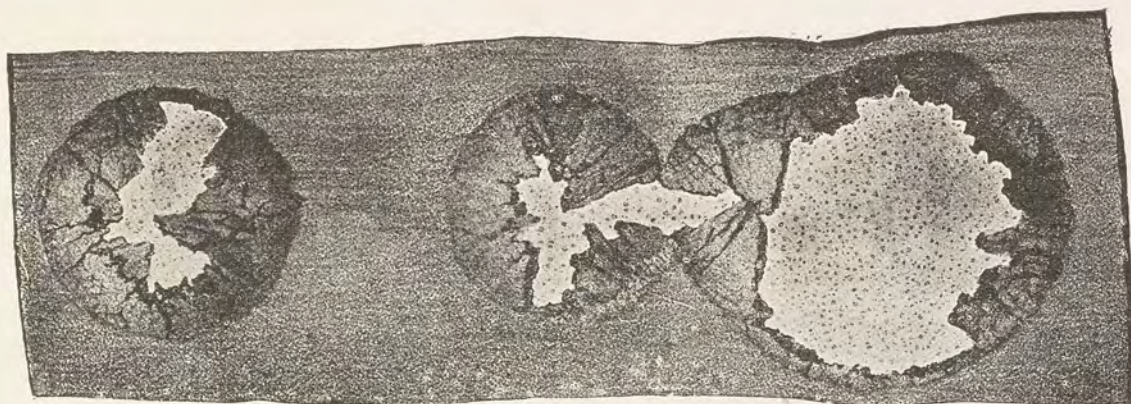


Fig. 146.

Strip of metallic tin attacked by the "tin pest". (After J. Fritsche).

malleable it can be hammered out into thin sheets (tin-foil). These characters are, however, not permanent, but the change that takes place is not the same as with other metals. Iron and copper chemically combine with the oxygen of the air and with water with the production of new compounds, iron passing into hydroxide of iron, and copper into malachite. On the other hand, tin undergoes no chemical change; it still remains metallic tin, but it gradually becomes grey and dull and falls to powder. This change is favoured by extreme cold and by dampness, but it also takes place in the dry. A tin vessel attacked by the "tin pest" cannot be saved, the alteration spreads and the tin becomes brittle and finally falls to powder. This powder is capable of infecting or inducing the change in other masses of tin, so that disease spreads until all the objects of tin in the immediate neighbourhood are destroyed. In text-fig. 146 is shown a strip of tin in which the alteration has spread outwards from three infected centres. Many instances of this destruction of tin even in recent times are known. Thus, in the year 1868 blocks of Banka tin in a store room in the custom-house at St. Petersburg were found to have been broken up by decay; and in a Russian imperial magazine in place of the tin uniform buttons little heaps of powder were found. During the winter of 1877 a consignment of Banka tin, sent on the railway from Rotterdam to

Moscow, arrived in the form of powder. The organ pipes in churches in Finland have been destroyed, and quite recently a large tin plate on the roof of the post-office at Rothenburg in Bavaria has been attacked by the "tin pest".

This alteration in tin is due to a change in the internal crystalline structure of the metal and is accompanied by an appreciable increase in volume, it is of the same nature as the gradual transformation of monoclinic sulphur to rhombic sulphur (p. 141), only in tin the change takes place much more slowly. By the action of heat the grey tin can be again converted into white tin, in the same way that rhombic sulphur can be again changed into monoclinic sulphur. Ordinary white tin which we use in everyday life is thus unstable at the ordinary temperature (about 20° C.), and is liable to alteration, more especially when subjected to a low temperature or when in contact with grey tin or a solution of a salt of tin.

In striking contrast with the universal application of metallic tin and bronze is the fact that these are obtained from a single ore of tin and further that this is quite limited in its distribution, being found at only a few spots in sufficient quantity for mining. This ore is tin-stone or cassiterite; the few other minerals which contain tin as an essential constituent are of rare occurrence and of no importance as ores. These include stannite ($\text{Cu}_2\text{FeSnS}_4$), franckeite ($\text{Pb}_5\text{FeSn}_3\text{Sb}_2\text{S}_{14}$), cylindrite ($\text{Pb}_3\text{FeSn}_4\text{Sb}_2\text{S}_{14}$), teallite (PbSnS_2), canfieldite (Ag_3SnS_6), and stokesite ($\text{H}_4\text{CaSnSi}_3\text{O}_{11}$).

Cassiterite, or tin-stone, is a compound of tin and oxygen, SnO_2 , containing when pure 78.6% of tin; usually, however, it contains some intermixed iron oxide causing a corresponding decrease in the amount of tin. When a fragment of the mineral is finely powdered and strongly heated on charcoal with sodium carbonate or potassium cyanide, beads of metallic tin are obtained, which are readily recognizable by their colour and lustre. The mineral is scarcely attacked by acids. The appearance of cassiterite does not at all suggest that it contains a large amount of a white metal: it is usually almost black, and only on splinters and fractured surfaces does it show a colophony-brown colour with translucency (plate 38, fig. 5). Less frequently the crystals are pale yellowish-brown (fig. 2), and exceptionally they are quite colourless. The faces of crystals often display a brilliant adamantine lustre. Since the mineral contains a heavy metal its specific gravity is correspondingly high, being 6.8–7. The hardness is 6–7.

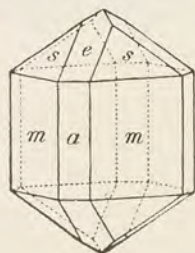


Fig. 147.
Crystal of Cassiterite.

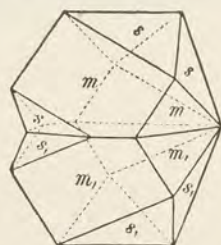


Fig. 148.
Twinned crystal of Cassiterite.

Well-crystallized specimens are not uncommon; the crystals belong to the tetragonal system, and the rarely occurring simple crystals (text-fig. 147) are bounded by prisms of the first and second orders, $m = \infty P$ and $a = \infty P \infty$, and pyramids of the two orders $s = P$ and $e = P \infty$. The isolated crystals shown in plate 38, figs. 1 and 2, have the same forms; in fig. 2 the pyramid $P \infty$ being larger than P . The faces of the pyramid P are inclined to one another at angles of $121\frac{3}{4}^\circ$. The faces of the crystals may be either smooth or marked with more or less regular hillocks (fig. 3); a parquered pattern on a prism face is represented in plate 19, fig. 8.

Almost invariably, crystals of cassiterite are twinned; and the twin-crystals present a certain resemblance in their shape to an upturned visor, and they are known to the Saxon miners as "Visiergrauen" or "Zinngrauen". This very characteristic form of cassiterite is represented in plate 38, figs. 3, 4 and 5, and in text-fig. 148. The twin-plane, which is the plane common to the two individuals of the twin, is a face of the

pyramid $P\infty$, being in text-fig. 148 a face which would truncate the upper edge of the pyramid s . The re-entrant angles on the outwardly bent portion of the twin are formed by the pyramid faces, which may be larger or smaller in size, giving a correspondingly larger or smaller cleft in the crystal; when these pyramid faces are altogether absent the prism faces meet across the twin junction, and the form more closely resembles a bent knee, as is more commonly met with in rutile. A knee-shaped twin of this kind is represented in fig. 6, where the crystal is placed with the twin-plane vertical and the narrow face of the prism of the second order to the front; standing up on the right is a third individual in twinned position to the portion immediately below. Repeated twinning, together with irregular grouping of crystals, gives rise to the kind of aggregates shown in figs 7 and 8.

Large crystals such as represented on plate 38 are not very common, the majority of crystals being smaller and less distinct, or the ore occurs as grains, often of microscopic size, scattered through the rock. Less frequently, the mineral forms compact, radially-fibrous aggregates with a concentric, shelly structure and a rough, nodular or reniform surface (fig. 10); such masses, with their brown colour and markings, possess a certain resemblance to fossil wood, and are known as *wood-tin*. This has, however, nothing to do with fossil wood, but is only a special form of structure, similar to that seen in limonite, malachite, etc.

An example of pseudomorphous cassiterite is shown in fig. 9; here a mixture of cassiterite and quartz has replaced a crystal of orthoclase felspar.

Cassiterite usually occurs in conjunction with ancient granitic rocks, either as small veins traversing the granite and the surrounding rocks or disseminated through the granite itself in the neighbourhood of these veins. Associated minerals are quartz (plate 52, fig. 2), wolframite (plate 37, figs. 8 and 9), fluor-spar (plate 71, fig. 4), topaz, lithia-mica, tourmaline, scheelite, native bismuth, molybdenite, etc. The felspar crystals in the granite near the veins may, as seen in the pseudomorphs mentioned above, be altered into a mixture of quartz, cassiterite, topaz and lithia-mica, and the rock itself may be transformed into a mixture of quartz and mica known as greisen. To account for these associations and alterations it is assumed that, after the injection of the granitic magma, hot vapours arising from the earth's interior or emanating from the magma itself penetrated the mass along numerous fissures, bringing with them the materials for the tin-stone and the associated minerals. This assumption is supported by the experiment of Daubrée, in which he prepared cassiterite artificially from vapours of tin chloride and super-heated water. Since many of the minerals associated with cassiterite contain fluorine, it may be concluded that in nature cassiterite has been formed by the interaction of tin fluoride and water vapour, and that the powerfully acting fluorine compounds have produced the alteration of the granite to greisen. Further support to this theory is given by the fact that the siliceous sinter deposited by the hot spring of Ajer Panas in Selangor contains half a per cent. of tin oxide.

With a mode of occurrence of this kind, cassiterite is found at several places in the Erzgebirge (plate 38, figs. 3, 4, 5, 7 and 8), namely at Altenberg and Ehrenfriedersdorf in Saxony, and at Zinnwald, Graupen and Schlaggenwald in Bohemia; in Cornwall and Devonshire; at La Villeder in the French department of Morbihan (fig. 1 and 6); in the Malay islands of Banka and Billiton and the Malay Peninsula; and in New South Wales and Tasmania. The tin ore occurring in these original deposits is known as *vein-tin*, to distinguish it from the more important stream tin to be mentioned presently.

Original deposits of another type are met with on the Bolivian tableland in the neighbourhood of Oruro and Potosi. Here the veins are not in ancient granitic rocks,

but in newer, acid volcanic rocks of the trachyte and andesite class, and the associated minerals are stannite, wolframite, and ores of silver, copper and bismuth. The fluorine-bearing minerals, fluor-spar, apatite and tourmaline, are here of rare occurrence, and it is only quite recently that their presence has been recognized, whilst topaz has not yet been found. Moreover the cassiterite itself is quite different in appearance to the cassiterite of other localities; crystals of any appreciable size are rare, and the mineral usually forms compact, fine-grained masses, often intimately intermixed with sulphides, and frequently with pseudomorphous impressions of other minerals. The tin ore near the surface in these veins is replaced at greater depths by sulphide ores, and the late Professor A. W. Stelzner considered it probable that the tin was originally present as stannite, which in the upper part of the veins had become altered by atmospheric weathering to the more stable form of tin oxide, in the same way that iron-pyrites gives place to limonite and copper-pyrites to cuprite and limonite. Bolivia is, in fact, noted for the complex sulphide compounds of tin mentioned above (p. 184), several of which have not been found in any other part of the world.

By the denudation of the rocks containing the veins of tin ore, the latter is set free, and, being a very stable compound of high specific gravity, it collects as pebbles in the beds of streams and rivers, and is then found under exactly the same conditions as alluvial gold (p. 76). Stannite, if present in the veins, will be decomposed, and the oxide of tin so formed may be deposited in a concretionary form as wood-tin; this, indeed, explains the more frequent occurrence of wood-tin in alluvial deposits than in veins. Many of the associated minerals in the tin veins will also be decomposed by weathering and their products carried away by running water. The tin ore (cassiterite) of such alluvial deposits is known as *stream-tin*, and is not only much purer and more suitable for smelting than vein-tin, but it is also far more easily mined. Deposits of stream-tin are thus the first to be worked, and even at the present day the bulk of the ore raised consists of stream-tin.

Of the tin-producing countries, the Malay Peninsula (Straits Settlements) is the richest, with a yield of four-sevenths of the total for the whole world. The ore occurs here in veins and especially in alluvial deposits. The somewhat water-worn crystal shown in plate 38, fig. 2, is from Selangor. Many of the richest tin placers have already been exhausted, but, with the present high price of tin, the very widely distributed poorer deposits can be worked at a very considerable profit. There is no immediate prospect of any decline in the production, and when, at some future time, this should happen there still remain the unexploited deposits in the northern states of the peninsula. The richest occurrences lie along a belt extending from the northern border of Malacca through the Federated Malay States and the state of Kedah, and across the Kra Isthmus far into Burma. There is scarcely a valley which does not contain more or less stream-tin. The richness in tin of this region was known long before the Christian era, and the deposits have been worked by the natives and the Chinese from the very earliest times.

Tin ore occurs under very similar conditions also in the Dutch islands of the Malay Archipelago, especially in Banka (known since 1710) and Billiton (since 1852). The tin gravels are worked by the Chinese under the direction of European engineers. Tin ore is also mined in Siam, China and Japan, though in the two latter countries only sufficient for home consumption.

Throughout the whole of Australia and New Zealand deposits of tin ore are widely distributed, and they may be considered as an extension of the Malayan deposits. The mode of occurrence is exactly the same, there being true veins and disseminations in granite and porphyry and in addition extensive alluvial deposits. The latter are not

only of recent date in the beds of the present streams and rivers, but also occur in ancient river beds of Tertiary age, and these are sometimes covered over by ancient flows of basaltic lava. The conditions here are thus exactly the same as with the more ancient gold sands of California which also are protected from destruction by a capping of basaltic lava. One of the richest of Australian deposits is that of Mount Bischoff in the north-western portion of Tasmania, where since the year 1873 both the gravels and the veins have been worked. Other tin fields are situated in the northern part of New South Wales (Emmaville district), in Queensland (Herberton district) and in Western Australia (Greenbushes).

In America, the most important tin-producing country is Bolivia. Here alluvial deposits are of no importance, and it is only during the last twenty years or so that the veins have been worked on a larger scale. In Mexico tin ore is widely distributed, but the production is not of much account. Recently, extensive alluvial deposits have been discovered in Alaska.

In Europe, the only tin-producing district of any importance at the present day is Cornwall, where the rich tin ores have been worked since very early times. The largest vein, the Dolcoath main lode, is $2\frac{1}{4}$ miles in length and on it are situated the important mines of Carn Brea, Tincroft, Dolcoath, and Cook's Kitchen. The annual production of ore reached a maximum of 16,759 tons in the year 1871, since when it has steadily declined owing to the great depreciation in the price of tin; more recently, however, with an increase in the price of tin, many of the old mines have been reopened. The tin-bearing districts in the Erzgebirge between Saxony and Bohemia were mainly exhausted from the fourteenth to the sixteenth centuries, and are now only of scientific interest, though wolframite is still being obtained.

In France, tin ores have been won at various spots in Brittany, principally at Piriac and La Villeder, but the numerous attempts have led to no very lasting results. A zone of tin deposits extends through the Spanish provinces of Zamora, Pontevedra and Orense into the Portuguese province of Traz oz Montes; the ore occurs in veins and gravels and has been won during several centuries. It is indeed probable that the Romans obtained their first supplies of tin from this region. The production of Spanish ore for the year 1897 amounted to 2378 tons, but this ore is poor in tin. In Italy, deposits are known in Tuscany, but the ores are of little value; they are said to have been worked by the Etruscans.

The production of tin during the year 1901 is given in the following table: all other countries taken together do not produce as much as half a per cent. of the total amount.

<i>Straits Settlements</i>	50,352 tons.
<i>Dutch East Indies</i>	19,350 ,,
<i>Bolivia</i>	7400 ,,
<i>Australia</i>	3076 ,,
<i>Cornwall</i>	4700 ,,

The average price of a ton (1016 kilograms) of tin in the year 1900 was about £135, while in 1897 it was only half this amount.

The applications of tin are very varied, and in the history of mankind tin is one of the most important of metals. Its early discovery is readily explained by the ease with which the metal may be obtained by smelting from the ore, and the occurrence of the ore as heavy pebbles in river gravels would soon attract attention. The metal obtained from stream-tin has also the advantage of being very pure, whilst that yielded by vein-tin is contaminated by copper, iron and arsenic. Alloyed with

lead or antimony it is largely used for household utensils, table services, toys, organ pipes, medals and plates; of other alloys, bronze (an alloy of tin and copper, p. 113), is the most important. The metal is also largely used for coating the surface of sheets of iron (tin-plate) and for coating copper. When rolled out into thin sheets, we have the well known tin-foil, largely used for packing confectionery and tobacco. Tin-foil amalgamated with mercury is employed as the coating at the back of glass mirrors.

Salts of tin find an application in dyeing, their action being that of a mordant to fix the colouring matter in the fibres of the fabric.

Titanium Compounds.

The three minerals, rutile, anatase and brookite represented on plate 39 are identical in chemical composition, but different in crystalline form and physical characters. They consist of titanium dioxide, TiO_2 , which is usually known as titanitic acid. Rutile is tetragonal with a prismatic habit, anatase tetragonal with a pyramidal habit, and brookite is rhombic. We have here an excellent example of polymorphism.

Rutile presents many points of interest in the development of its tetragonal crystals, though well-developed simple crystals are by no means common. The crystal shown in plate 39 fig. 1 (like the crystal of cassiterite in text-fig. 147) is bounded by square tetragonal prisms of the first and second orders, and by tetragonal pyramids of the two orders. The smaller pyramidal face to the front of the figure is taken as belonging to the primary pyramid P , with angles of $123^\circ 8'$ between its faces; its edges are truncated by the larger faces of the pyramid of the second order $P\infty$. The prism faces to the left and the right falling directly beneath the latter belong to the prism of the second order $\infty P\infty$, while the prism face to the front is of the first order ∞P . The crystals in figs. 2 and 3 show the same forms, but they are represented with the prism and the pyramid of the second order to the front; in figs. 2 and 4 the prism faces are vertically striated and rounded; in figs. 4 and 5 only one of the pyramids is present.

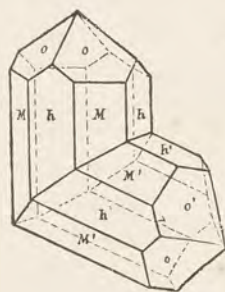


Fig. 149.
Twinned crystal of Rutile.

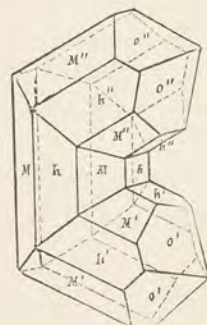


Fig. 150.
Trilling of Rutile.

Twinned crystals of rutile are of much more frequent occurrence. In the twins shown in text-figs. 149 and 150 the faces o are the primary pyramid of the first order, M the prism of the first order, and h the prism of the second order. The twin-plane is a face of the pyramid of the second order $P\infty$; in fig. 149 and in the lower part of fig. 150 the twin-plane is parallel to a face which would truncate the upper left-hand edge of o , while the upper individual of fig. 150 is twinned on the face which would truncate the upper right-hand edge of o . In fig. 150 we thus have the twinning taking place on two faces of pyramid $P\infty$, so that the compound crystal, or trilling, here consists of three individuals; and this twinning on different faces of the same form may be several times repeated. The striated prism planes the two portions are inclined at an angle of $114^\circ 25'$, forming a knee-like bend, as is shown in plate 39, fig. 7. In this fig. 7 the twinning is several times repeated on

the same plane, giving rise in the upper portion to a step-like or lamellar structure. In figs. 6, 8, 9 and 10 the twinning is repeated on different planes, and the several individuals (eight in fig. 10) form a closed ring.

Another twin-law met with in rutile is illustrated in fig. 13 and text-fig. 151, the twin-plane here being a face of a steeply inclined pyramid of the second order $3P\infty$; this is known as the "arrow-head" twin. The prism faces are recognizable by their vertical striations; in fig. 11 the pyramid faces are much rounded and water-worn.

Other results of twinning in rutile are represented in plate 19, figs. 9 and 10, where, instead of thick prismatic crystals, we have delicate acicular crystals repeatedly twinned together according to one or both of the two twin-laws just mentioned, giving rise to an intricate network. Such network forms of growth in rutile receive the special name *sagenite*, and they are frequently much more delicate than represented in the figures. Sometimes these sagenite webs are found embedded in crystals of quartz (plate 54, fig. 8), while the enclosure of tufts of delicate needles and hairs of rutile are of frequent occurrence (plate 55, fig. 4).

Of the three modifications of titanium dioxide, that which crystallizes as rutile is the most stable, as is shown by the occurrence of crystals of anatase (plate 39, fig. 17) and brookite (plate 19, fig. 13) altered into rutile, but never the reverse alteration. Anatase and brookite when strongly heated are converted into rutile by artificial means. In an alteration of this kind there is no change in chemical composition, and though the crystal preserves its external crystalline form its internal crystalline structure is destroyed; the mass now consists of a confused aggregate of needles of rutile, which on the surface give rise to a moiré-like appearance when viewed in different positions by reflected light (plate 19, fig. 13).

Prismatic crystals of rutile often form regular intergrowths with crystals of haematite, as already described (p. 153), and sometimes the tabular crystals of haematite may be almost completely replaced by an interlacing network of rutile needles arranged at angles of 60° (plate 19, figs. 11 and 12).

In its physical characters, rutile also presents several points of interest, especially in its very high refractive index and its strong double refraction. The refractive index for the ordinary ray is 2.6158 and for the extraordinary ray 2.9029, and the difference, 0.2871, is a measure of the double refraction. The refraction is thus greater than for diamond, while the double refraction is stronger than that of calcite; but unfortunately the mineral is never colourless and transparent.

The colour is dark red, passing into brown or black; crystals are opaque or only translucent, but on their smooth faces they possess a brilliant metallic-adamantine lustre: the streak is yellowish-brown. The dark colour of the mineral is due to the presence of iron oxide to the extent of $2\frac{1}{2}$ to 14 per cent.; this impurity is not present as enclosed particles, but it is dissolved in the rutile substance, like a salt is dissolved in water. The specific gravity is about 4.2, increasing with the amount of iron to 4.5; the crystal in fig. 5 has a specific gravity of 4.20, and that in fig. 11 the value 4.23. The hardness is 6— $6\frac{1}{2}$. Crystals possess perfect cleavages parallel to the faces of the two prisms.

Rutile is found in veins and crevices in crystalline rocks (granite and gneiss) often together with rock-crystal, and not infrequently it is actually embedded in the quartz crystals (plate 54, fig. 8 and plate 55, fig. 4); other associated minerals may be anatase, brookite and iron-glance. Under these conditions the mineral is found at several

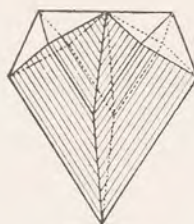


Fig. 151.
Twinned crystal of Rutile.

places in the Alps: for instance, in the Binnenthal in Wallis (plate 39, figs. 2 and 6; plate 19, figs. 11 and 12), Tavetsch in Graubünden (plate 39, fig. 9), Medels Pass in Switzerland (plate 19, figs. 9 and 10); in Norway (plate 39, fig. 1), the Ural Mountains (fig. 8), North America (figs. 3, 7, 10), Brazil (plate 39, fig. 11, and plate 55, fig. 4). The water-worn crystal shown in fig. 11 is from the diamond-bearing sands of Brazil.

In quantities sufficiently large for mining it is met with in Norway, and in a quartz-felspar-rock on the Tye river near Roseland in Nelson Co., Virginia. Besides being employed for the preparation of the little-used compounds of titanium, rutile also finds an application in the manufacture of special kinds of cast-iron and cast-steel. The price per ton varies between 350 and 450 dollars.

Anatase usually crystallizes in the form of acute tetragonal pyramids, which are opaque and dark steel-blue in colour (plate 39, fig. 12). The tips of the crystals are often broken off by a smooth cleavage face parallel to the base, the angle between the pyramid faces and the base being $97^{\circ} 52'$. These crystals are always quite small in size, and only rarely larger than that represented in fig. 12.

Crystals of quite a different habit and appearance are found in the Binnenthal in Switzerland; these are much larger, and are transparent with an Isabel-yellow or yellowish-brown colour (plate 39, figs. 13—15); they are bounded by a profusion of brilliant faces, and in their perfection of development far surpass the crystals of anatase from any other locality. In fig. 13 and 14 the forms present are the prism of the second order and smaller and larger pyramids of the first order; in fig. 15 the prism of the second order, an eight-sided pyramid P_3 with rough faces of variable size, and a pyramid of the first order $\frac{1}{3}P$. A third habit of anatase is represented by the thick-tabular crystals from Brazil (fig. 16) with an acute pyramid and the base.

In addition to a perfect cleavage parallel to the base, crystals of anatase also possess perfect cleavages parallel to the faces of the acute primary pyramid; the latter are represented in fig. 14 by the two patches of paler colour, due to the reflection of light from cleavage cracks inside the crystal. The refractive index and the double refraction are high, though somewhat less than for rutile; the refractive index for the ordinary ray being 2.535, and for the extraordinary ray 2.496. Corresponding with this high refractive power, the faces of the crystals, when smooth, display a brilliant adamantine lustre; but frequently they are rough and uneven, and are then dull. The colour is steel-blue, yellow to brown, or sometimes reddish-brown. The specific gravity of crystals from the Binnenthal is 3.83.

The crystal shown in fig. 17 is a paramorph of rutile after anatase. These are found in the diamond-bearing sands of Brazil, and are known to the Brazilians as "captivos". With the contact-goniometer the angle between the pyramidal faces was measured as 96° — 98° , so that the form is that of the primary pyramid as in fig. 12. The specific gravity of this specimen was determined to be 3.78, but this low value is probably due to the presence of interspaces between the minute rutile prisms of which the paramorph is composed; other specimens of these "captivos" have a specific gravity of 4.02 and 4.06, which more nearly approach the true value for rutile.

Crystals of anatase are found attached to the walls of crevices in crystalline rocks (granite and mica-schist) in the Alps (at Bourg d'Oisans, Tavetsch, Binnenthal), and loose in the diamond-bearing sands in the province of Minas Geraes in Brazil and in the southern Urals. Microscopic crystals are found in many sedimentary rocks, where they owe their origin to the alteration of ilmenite.

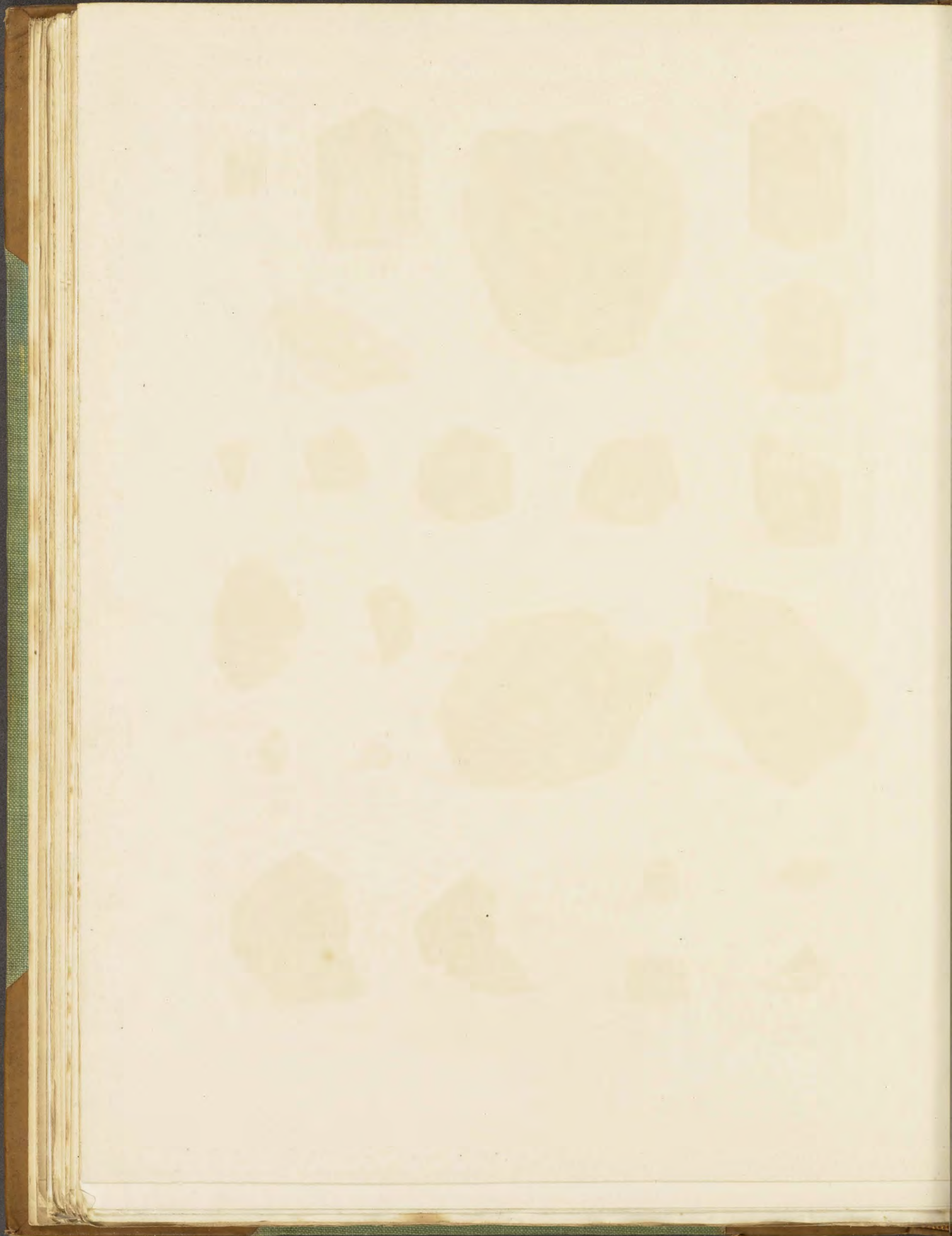


Titanium Compounds I.

Fig.

1. **Rutile**, simple (i. e. untwinned) crystal with dull faces. Prisms and pyramids of the first (small) and second (large) orders.
Lofthus, Snarum, Norway.
2. **Rutile**, simple crystal with rounded prism faces.
Binnenthal, Wallis, Switzerland.
3. **Rutile**, large, simple crystal with parallel grouping of sub-individuals.
Graves Mountain, Lincoln Co., Georgia, U. S. A.
4. **Rutile**, simple crystal with rounded prism faces.
Söndeled, Risör, Norway.
5. **Rutile**, simple crystal. The prism of the first order and the pyramid of the second order predominate.
Adelaide, South Australia.
6. **Rutile**, twin-crystal (twin-plane $P \infty$) in quartz.
Binnenthal, Wallis, Switzerland.
7. **Rutile**, knee-shaped twin-crystal, showing in one portion lamellae due to repeated twinning on the same plane of the pyramid of the second order $P \infty$.
Parksburg, Pennsylvania, U. S. A.
8. **Rutile**, ring-shaped twin, due to repeated twinning on several faces of the pyramid $P \infty$.
Uramos, Kossoibrod, Ekaterinburg, Ural Mountains.
9. **Rutile**, ring-shaped twin of at least six individuals.
Tavetsch, Graubünden, Switzerland.
10. **Rutile**, ring-shaped twin.
Magnet Cove, Arkansas, U. S. A.
11. **Rutile**, "arrow-head" twin (twin-plane $3 P \infty$).
Dattas, Minas Geraes, Brazil.
12. **Anatase**, acute pyramid on mica-schist.
Santa Brigitta, Tavetsch, Graubünden, Switzerland.
13. **Anatase**, thick prismatic crystal on mica-schist.
Binnenthal, Wallis, Switzerland.
14. **Anatase**, prism of the first order with pyramid of the second order.
Binnenthal, Wallis, Switzerland.
15. **Anatase**, eight-sided pyramid (dull faces) with prism of first order (bright faces.)
Binnenthal, Wallis, Switzerland.
16. **Anatase**, tabular crystal, with base and pyramid.
Minas Geraes, Brazil.
17. **Anatase**, altered to rutile; so-called "captivos" from the diamond-bearing sands of Brazil.
18. **Brookite**, rhombic prism with pyramid, $\infty P, P$.
Magnet Cove, Arkansas, U. S. A.
19. **Brookite** (variety "Arkansite"), prism with pyramid, $\infty P, P^2$.
Magnet Cove, Arkansas, U. S. A.
20. **Brookite**, tabular crystal, with star-shaped enclosure.
Tscharren, Maderanerthal, Switzerland.
21. **Brookite**, tabular crystal.
Tscharren, Maderanerthal, Switzerland.
- 22 and 23. **Brookite**, tabular crystals.
Nillgrabenthal, Prägratten, Tyrol.





Brookite has the same chemical composition as the two preceding minerals, but differs from them in crystalline form and physical characters; it is named after the English mineralogist H. J. Brooke.

In the form of its crystals it sometimes exhibits a certain resemblance to rutile, being bounded by prism and pyramid planes (plate 39, fig. 18); but these crystals are rhombic and the angle between the prism faces is $99^{\circ} 40'$ instead of 90° . The pyramid with horizontal edges above the prism faces shown in fig. 18 is the primary pyramid P ; while the pyramid in fig. 19 (e in text-fig. 152) with sloping lower edges has the symbol $P\bar{2}$. The latter combination of the prism ∞P and the pyramid $P\bar{2}$ presents quite the appearance of a hexagonal pyramid. Crystals of this kind are found in Arkansas, and are for this reason known as arkansite.

More usually, however, brookite crystallizes in thin plates, as shown in text-fig. 153 and plate 39, figs. 20—23. In the text-figure the large face a set up vertically

in front is one of the two planes of macro-pinacoid $\infty P\infty$, p is the vertical prism ∞P , c the base $0P$, e a pyramid $P\bar{2}$, and t a brachy-dome $2P\infty$. In the actual crystals the large macro-pinacoid faces are always deeply striated parallel to their intersection with the prism faces. In fig. 21 the basal plane is present as a long narrow face, while in figs. 22 and 23 it is absent. The crystal shown in fig. 20 contains dark enclosures grouped along six lines radiating from the centre of the crystal.

The colour of brookite is brownish-yellow, reddish-brown or black. Black crystals, as in the variety arkansite (plate 39, fig. 19), display a bright metallic lustre. The optical characters of brookite are of special interest, this mineral affording the best example of the phenomenon of crossed dispersion of the optic axes. The observation can be made directly through one of the tabular crystals, providing this is sufficiently transparent. When such a crystal is placed flat on the stage of the polariscope and examined in convergent monochromatic light the usual biaxial interference-figure of a rhombic crystal will be seen. In red or yellow light the plane of the optic axes (i. e. the line joining the centres of two systems of rings) is parallel to the base, and in green or blue light the optic axial plane is perpendicular to the base, while for an intermediate yellow-green colour the interference-figure is uniaxial. In white light the figures corresponding to all the different colours overlap and a very peculiar interference-figure results.

The specific gravity of brookite varies considerably; for the translucent crystal represented in fig. 21 it was determined on the Westphal balance to be 3.94; the crystal in fig. 18 has the value 4.24, while for the crystal of the arkansite variety in fig. 19 it is only 3.77. The hardness is $5\frac{1}{2}$ —6. As already mentioned, brookite is sometimes altered to rutile (plate 19, fig. 13). Brookite occurs under the same conditions as rutile and often in association with it; thus at Maderaner-thal and Prägratten in the Alps, at Tremadoc in North Wales, and at Magnet Cove in Arkansas; but it occurs sparingly at only a few localities.

TITANATES. — Titanium dioxide, or titanous acid, the different modifications of which we have just considered, occurs also in combination with other elements forming the salts known as titanates. The simplest of these compounds is perovskite, a titanate

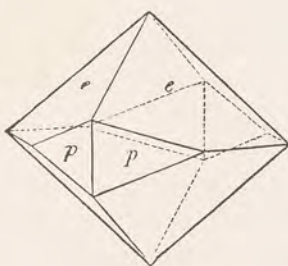


Fig. 152.
Crystal of Brookite
(var. Arkansite).

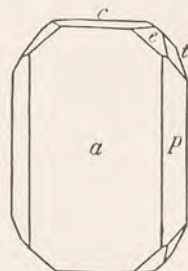


Fig. 153.
Crystal of Brookite.

of calcium with the chemical formula CaTiO_3 . Sphene contains silica in addition to these constituents, the formula being CaTiSiO_5 .

A third mineral belonging to this group is ilmenite, which is essentially a titanate of ferrous iron, FeTiO_3 . This formula when doubled shows that the mineral may be regarded as a mixture of ferric oxide and titanium sesquioxide: $\text{Fe}_2\text{Ti}_2\text{O}_6 = \text{Fe}_2\text{O}_3 + \text{Ti}_2\text{O}_3$; the very close similarity in the crystalline form of ilmenite and haematite favours this view. On the other hand, the mineral frequently contains some magnesium, which can be present only as magnesium titanate, MgTiO_3 . We must therefore conclude that the iron is also present as titanate, and that it is partly replaced by magnesium, in the same way that iron and magnesium are isomorphous in many other minerals (e. g. olivine). For this reason ilmenite is placed here with the titanates, though in some systems of classification it is placed with the oxides.

In addition to the minerals mentioned above, titanium also occurs in some specimens of magnetite, augite, hornblende, garnet, etc., but only in small amounts. A few other titanium compounds are known, but these being minerals of great rarity need not be considered in this work.

Perovskite occurs as cubic crystals bounded usually by only a few simple forms: the cube (plate 40, figs. 1—4) is the most usual, the rhombic-dodecahedron (fig. 5) and octahedron (fig. 6) being rare. The striations on the faces of the cube are sometimes parallel to only one of the edges, as in iron-pyrites, and it has consequently been asserted that perovskite is pentagonal-hemihedral. In other crystals, however, the striations are parallel to two adjacent cube edges, so that if the mineral be hemihedral it is necessary to assume such crystals as interpenetration twins. In addition to these simple crystals, perovskite is sometimes found as crystals extremely rich in faces, the distribution of which point to holohedral-cubic symmetry. When, however, crystals of perovskite are examined optically it is found that they are doubly refracting, whereas we know that cubic crystals are singly refracting. The true symmetry of the mineral is probably rhombic, and this lower degree of symmetry is completely obscured in the external form by twinning, the crystals being really pseudo-cubic, though in their interfacial angles they do not differ from true cubic crystals. Sometimes the crystals are deeply corroded and hollow.

The colour of perovskite is reddish-brown to black, and pale coloured crystals are extremely rare; the black crystals possess an almost metallic lustre. The specific gravity is about 4, and the hardness 5—6. In addition to calcium and titanium, perovskite almost always contains small amounts of iron. The crystals of octahedral habit from Magnet Cove, Arkansas (fig. 6), however, contain appreciable amounts of rare earths (tantalum, niobium, cerium, yttrium, etc.); but these are perhaps not true perovskite, but more nearly related to the rare mineral dysanallyte.

True perovskite is found embedded in chlorite-schist at the Findelen glacier near Zermatt (plate 40, figs. 1 and 2); attached to the walls of crevices in chlorite-schist at Wildkreuzjoch in the Pfitschthal, Tyrol; embedded in chlorite-schist and limestone in the Nikolaje-Maximilianovskoi and the Eremeyev mines at Achmatovsk, near Zlatoust in the Urals (figs. 3, 4 and 5). The octahedral crystals from Magnet Cove, Arkansas (fig. 6), occur embedded in limestone. Microscopically small cubes of perovskite are present in melilite-basalts.

Titanite, or sphene, is a mineral which, while extremely constant in chemical composition, exhibits wide variations in its external form and habit. The crystals are monoclinic and they vary so much in their development that sometimes one and sometimes another set of faces may be taken as the vertical prism: in fact, different mineralogists

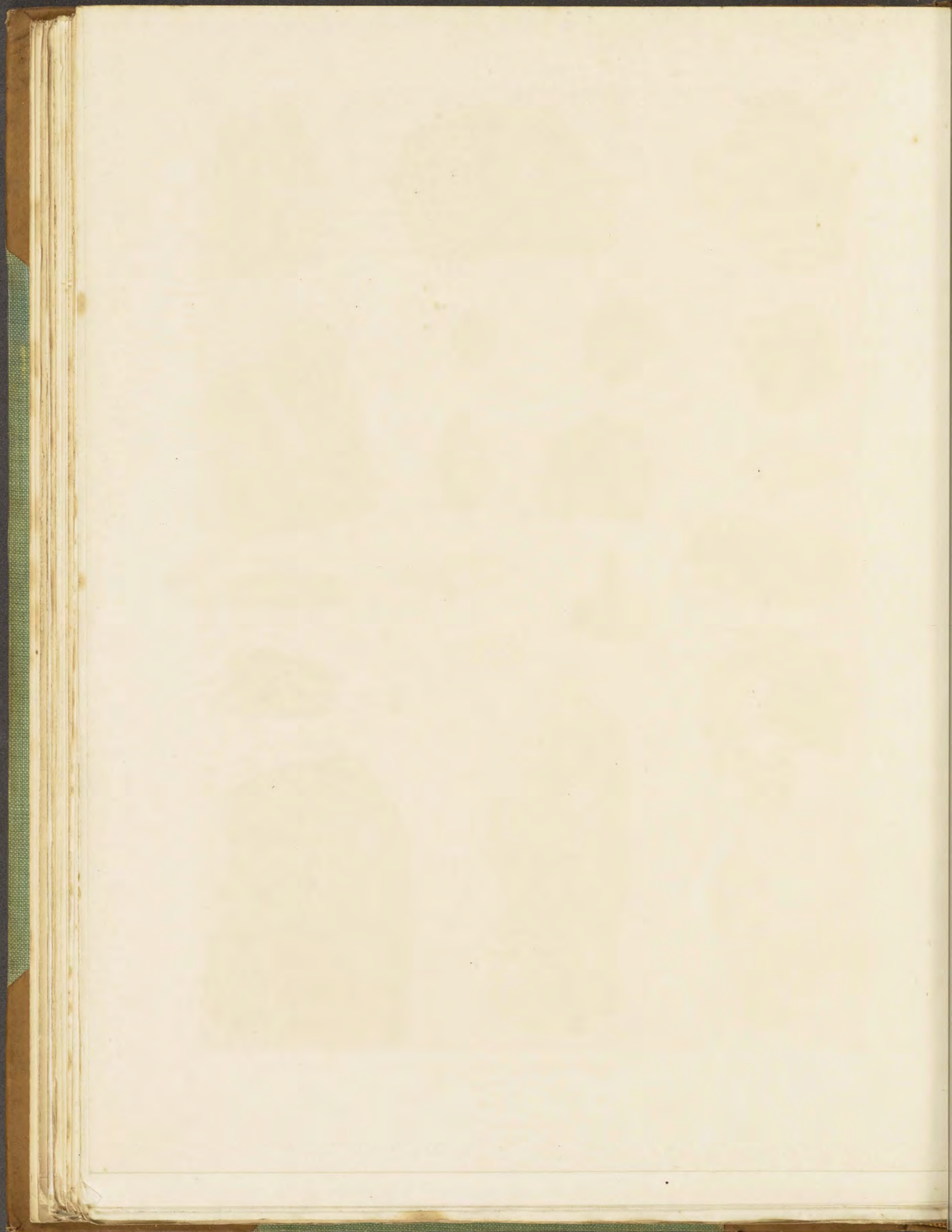


Titanium Compounds II.

Fig.

1. **Perovskite**, large cubes partly encrusted with chlorite.
Findelen glacier, Zermatt, Switzerland.
2. **Perovskite**, isolated cube.
Findelen glacier, Zermatt, Switzerland.
3. **Perovskite**, cubes in chlorite-schist.
Achmatovsk, Zlatoust, Ural Mountains.
4. **Perovskite**, cube.
Achmatovsk, Zlatoust, Ural Mountains.
5. **Perovskite**, rhombic-dodecahedron.
Achmatovsk, Zlatoust, Ural Mountains.
6. **Perovskite**, octahedron.
Magnet Cove, Arkansas, U. S. A.
7. **Sphene** (Titanite), simple, tabular crystal.
Tavetsch, Graubünden, Switzerland.
8. **Sphene**, with pyramid, ortho-dome and prism.
Rympfischwäng, Zermatt, Switzerland.
9. **Sphene**, with pyramid faces predominating.
Kragerö, Norway.
10. **Sphene**, simple, tabular crystal with crystallized chlorite and diopside.
Achmatovsk, Zlatoust, Ural Mountains.
- 11 and 12. **Sphene**, pyramid with base.
Eganville, Renfrew Co., Ontario, Canada.
13. **Sphene**, prismatic crystal.
Arendal, Norway.
14. **Sphene**, simple crystal.
Tavetsch, Graubünden, Switzerland.
- 15 and 16. **Sphene**, twinned crystals.
Tavetsch, Graubünden, Switzerland.
17. **Sphene**, twin-crystal.
Kulmatsch, St. Jakob, Dissentis, Switzerland.
18. **Sphene**, simple crystal.
Rothenkopf, Zillerthal, Tyrol.
19. **Sphene**, large, twinned crystal.
Arendal, Norway.
20. **Ilmenite**, hexagonal pyramid with rhombohedron and basal plane.
Miask, Lake Ilmen, southern Urals.
21. **Ilmenite**, massive.
Långbanshyttan, Wermland, Sweden.





have interpreted the crystals in different ways, the form taken by one author as a vertical prism has been taken by others as a clino-dome or a pyramid. These differences are, however, quite unessential and are of no consequence in this place.

The crystal of tabular habit shown in plate 40, fig. 7, has its forms explained by the text-fig. 154 (the relative position of the two figures is, however, slightly different): the large face x is taken as the ortho-dome $\frac{1}{2}P\infty$, the narrow faces at the edges of the crystal as the vertical prism $l = \infty P$, and the small triangular faces as another ortho-dome $y = P\infty$ and the basal plane $P = 0P$.

The thick-tabular crystals in figs. 11 and 12 might be interpreted as a combination of a large base with a pyramid and a prism; but giving these crystals the same orientation as text-figs. 154 and 155, the large face belongs to the ortho-dome $y = P\infty$, and the faces at the edge to the clino-dome $r = P\infty$ and the pyramid $n = \frac{2}{3}P\dot{2}$. The crystal of prismatic habit in fig. 13 is comparable with text-fig. 155, where $n = \frac{2}{3}P\dot{2}$ is a pyramid,



Fig. 154.
Crystal of Sphene.

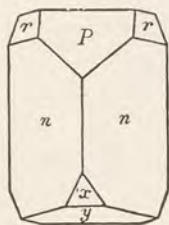


Fig. 155.
Crystal of Sphene.

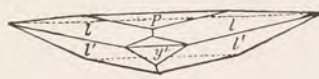


Fig. 156.
Contact-twin of Sphene.

$P = 0P$ is the base, $r = P\infty$ a clino-dome, and $x = \frac{1}{2}P\infty$ and $y = P\infty$ are ortho-domes. In fig. 9 we have an upper and a lower pyramid and an ortho-dome; and in fig. 8 two bright pyramid faces above and the other faces dull and rounded.

Twinned crystals are of frequent occurrence, the twin-plane being the base $P = 0P$, and the crystals either contact-twins (text-fig. 156) or interpenetration-twins. A contact-twin is shown in fig. 10, where the large face to the front is the base and twin-plane; a portion of the second individual behind is visible at the top. The crystals in figs. 15 to 17 are interpenetration-twins.

The variation in colour of sphene is well illustrated in plate 40. Even one and the same crystal may differ in colour in different portions; for example, that in fig. 16 is bright green in the middle but brown at the two ends. The smooth crystal faces display an adamantine to resinous lustre: frequently, however, the crystals are dusted over with chlorite (figs. 7, 14 and 17). There is a rather distinct cleavage parallel to the prism faces. The specific gravity is 3.4—3.6, and the hardness $5\frac{1}{2}$.

The interference-figure shown by sphene in convergent polarized light is somewhat remarkable, the hyperbolic brushes being brightly coloured; this is due to the marked difference in magnitude of the angle between the optic axes for light of different colours, the angle for red light being much greater than for blue.

Crystals of sphene are found attached to the walls of crevices in silicate-rocks (gneiss, mica-schist, etc.) at many places in the Alps; for example, at Tavetsch in Graubünden (plate 40, figs. 7, 14, 15 and 16), Dissentis (fig. 17), Zermatt (fig. 8), Maderaner-thal; on the Rothenkopf in the Zillerthal (fig. 18) and at Pfunders in Tyrol; Stubachthal in Salzburg, etc. Crystals are also found together with chlorite and diopside on the walls of crevices in chlorite-schist at Achmatovsk in the Urals (fig. 10).

Larger, embedded crystals are known from the syenite of Arendal in Norway (figs. 13 and 19), and in crystalline limestone at Eganville, Renfrew Co., Ontario. Small

embedded crystals of a yellow or brown colour are widely distributed in syenite, phonolite, trachyte and allied rocks.

Sphene, when quite transparent and of a good colour, is sometimes employed as a precious stone, but owing to its low degree of hardness it soon shows signs of wear.

Ilmenite, or titaniferous iron-ore. A few remarks concerning the chemical composition of this mineral have already been given (p. 192). In its crystalline form it is

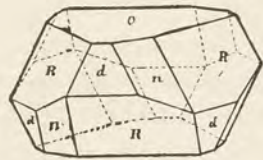


Fig. 157.
Crystal of Ilmenite.

very similar to haematite. The thick-tabular crystals (plate 40, fig. 20, and text-fig. 157) are bounded by the large basal pinacoid $c = 0P$ and two rhombohedra, one of which (R) truncates the edges of the other (d); taking the former to be the primary rhombohedron R , the second, being the next steeper negative rhombohedron, is $d = -2R$. In addition, there are faces (n) truncating the alternate edges between R and d , this form being a rhombohedron of the third order, and the symmetry of the crystals is consequently rhombohedral-tetartohedral, as in diop-

tase (p. 112). In haematite, on the other hand, these faces truncate all the edges between R and d , and the complete form is here a hexagonal pyramid. Crystals of ilmenite and especially crystalline masses are frequently penetrated by twin-lamellae parallel to the three faces of the primary rhombohedron; these give rise to three sets of striations at angles of 60° on the basal plane (fig. 21).

Ilmenite is black in colour with a metallic lustre, and is sometimes slightly magnetic. It is slowly dissolved by hot hydrochloric acid, and in the microcosmic salt bead gives a blood-red colour owing to the presence of titanium. The mineral occurs embedded in igneous rocks (gabbro, diabase, dolerite) and under these conditions is very widely distributed. Fine crystals are found at Miask in the Ilmen Mountains, Urals (plate 40, fig. 20), from which locality the mineral derives its name. Much larger crystals are met with at Kragerö and Arendal in Norway.

The so-called "iron-roses", described under haematite (p. 152) as occurring in crevices of the crystalline rocks of the Alps, are in part to be placed under ilmenite, when they contain a considerable amount of titanium dioxide. According to the predominance of the ferric oxide (Fe_2O_3) or of the ferrous titanate ($FeTiO_3$), these crystals may be considered as haematite containing admixed ferrous titanate or as ilmenite with admixed ferric oxide. It is possible that in some cases the titanium dioxide may be merely due to the inclusion of microscopic needles of rutile.

Massive ilmenite occurs at several places in Sweden and Norway and in Canada and the United States as a magmatic separation from gabbro, and sometimes in sufficient quantity for mining. Water-worn grains of ilmenite (titaniferous iron-sand) are found in the sands of certain rivers, often together with gold and precious stones. Rounded grains of magnetite rich in titanium dioxide are found in certain basalts (e. g. at Unkel on the Rhine); this has an uneven shining fracture and is readily distinguished from ilmenite by its strong magnetic character.

Ilmenite is employed, like rutile, for adding to certain kinds of steel, but its use is only limited.



