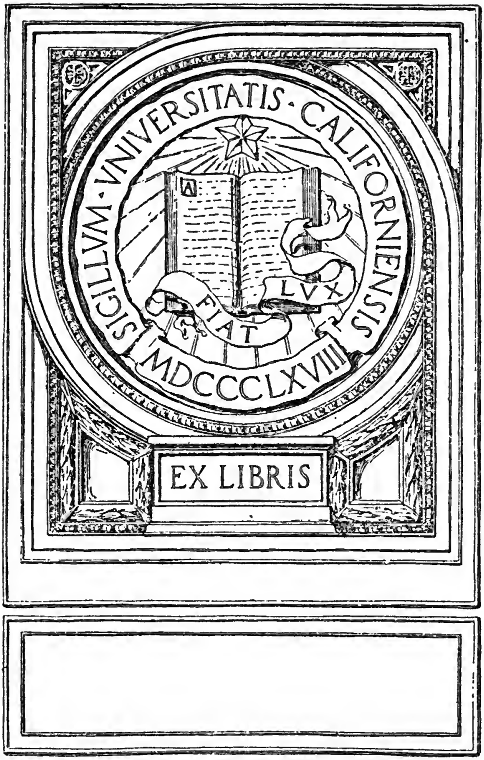
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ECONOMIC MINERALOGY

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A PRACTICAL GUIDE TO THE STUDY OF USEFUL MINERALS

UNIV. OF
CALIFORNIA

BY

THOMAS CROOK

CHIEF OF THE INTELLIGENCE AND PUBLICATIONS SECTION, IMPERIAL MINERAL RESOURCES BUREAU, LONDON
ASSOCIATE OF THE ROYAL COLLEGE OF SCIENCE, DUBLIN
FELLOW OF THE GEOLOGICAL SOCIETY
MEMBER OF THE INSTITUTION OF MINING AND METALLURGY

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PREFACE

The aim of this book is to deal with the subject of mineralogy in such a way as to meet the needs of those who wish to restrict their attention to the utilitarian side of the subject. It will be seen from a glance at the contents that the subject has not been treated in a narrow way. In fact, anyone who wishes to understand the economic aspects of mineralogy must make a fairly complete study of the scientific elements of the subject. The scientific scope of economic mineralogy is as wide as that of academic or pure mineralogy. Some aspects of the subject that are treated elaborately and at considerable length in books on pure mineralogy, the crystallographic aspect, for example, can be treated quite simply and briefly from the economic point of view without the sacrifice of essentials. On the other hand, many topics call for notice from the economic point of view that do not receive consideration in books on purely scientific mineralogy.

In the following pages, crystal symmetry is treated only as an introduction to crystal optics. Crystal optics and the use of the polarizing microscope are indispensable to the student who wishes to be well equipped for determinative work in the examination of minerals, and often lead to quick identification in instances where chemical and general physical data of a satisfactory character are less readily obtained. Laboratory methods of mineral separation and concentration merit the careful attention of students of economic mineralogy, and a chapter is given to that subject.

A chapter is devoted to geological matters, for the purpose of elucidating the origins and modes of occurrence of minerals.

In the description of mineral occurrences the attention of the reader is in the main directed to accounts of those which are of importance from the standpoint of the mining industry, and in a general way the order in which they are taken is the order of their importance in the world's mineral production.

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For the purpose of facilitating determinative work, minerals are tabulated in the last chapter according to those of their properties that are most readily observed.

In conclusion, I have to thank my friend Mr. L. J. Spencer of the British Museum (Natural History) for the trouble he has kindly taken to read and correct the proofs, and also for much help he gave me when photographing the specimens (marked B.M.) shown in the photographic illustrations. For permission to photograph these specimens my thanks are due to the Trustees of the Museum.

THOS. CROOK.

Kew, Surrey,
1921.

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CHAPTER I.

INTRODUCTION.

Minerals may be defined as the comparatively simple, homogeneous, natural substances which enter into the composition of the earth's crust. They have fairly definite physical and chemical characters; and, with one or two exceptions, *e.g.* mercury (quicksilver) and petroleum they occur in the solid state.

The number of minerals recognized as distinct species may be estimated roughly at about 1000 in number. Most of them are comparatively rare. It has been estimated that felspars, quartz, amphiboles, pyroxenes, and micas, together make up not less than 92 per cent. of the accessible portion of the earth's crust. The remaining 8 per cent. consists chiefly of a few common minerals, notably olivine, calcite, and iron oxides. From this we see that only a few of the minerals recognized as distinct species by mineralogists enter largely into the composition of the earth's crust. These occur in a number of characteristic associations called rocks, the study of which constitutes the science of petrology, a branch of geology.

Rocks may be defined as those materials which, in the form of beds and other masses, build up the crust of the earth. Usually they are complex or heterogeneous, and can be resolved into two or more minerals, as in granites, gabbros, mica-schists, and many other rocks; but this is not invariably the case, and a rock may consist entirely or almost entirely of one mineral, as is the case with rock masses of dunite (olivine rock), serpentine, gypsum, rock-salt, crystalline limestone, magnesite, dolomite, quartzites, and some other rocks.

As constituents of the earth's crust, therefore, most minerals have a sparse or limited distribution, some of them being so rare that they are only to be found at single localities. We need to remember, however, that the volume of the earth's crust is enormous; and a mineral may be a comparatively insignificant constituent of it as a whole, and yet occur as deposits of relatively large magnitude at certain localities.

This is frequently the case with economic minerals, *i.e.* those minerals which are mined or quarried as sources of metals and other useful products.

The study of the distinctive features of economic minerals demands a fairly wide and thorough knowledge of the elements of mineralogy as a working basis. But whereas in purely scientific mineralogy the student usually confines his attention to well-developed specimens showing crystal form, he finds when he comes to the study of economic minerals that he has to broaden his sympathies, and indeed has most commonly to deal with minerals which, from a crystallographical point of view, are in an imperfect condition. For this reason, the economic mineralogist finds comparatively little scope for goniometry (crystal measurement), and has to depend almost entirely on methods of study which are applicable to massive specimens or complex mixtures of minerals. Moreover, he takes a very great interest in the way minerals associate with one another. He attaches much importance to the detailed study of these associations of minerals, their modes of occurrence and relation to one another, and endeavours to ascertain as far as possible their order of formation and mode of origin, as these considerations are of significance in enabling him to form some idea of the probable extent and value of workable deposits.

Thus the mental bias of the economic mineralogist differs from that of the academic mineralogist; and whereas the latter regards the development of excellent crystal form as the prime essential of a mineral specimen, it is decidedly otherwise with the former, who pays great respect to many an unlovely specimen which the ordinary collector of minerals would despise.

In the following chapters, minerals have been considered with a utilitarian bias; and an attempt has been made to deal with the subject in an elementary but practical manner, according to the requirements of the numerous students whose aims are economic rather than purely scientific.

CHAPTER II.

CRYSTALS AND THEIR SYMMETRY.

DEFINITION OF A CRYSTAL.—Crystals are the faceted shapes which many solid substances tend to assume when they are formed under conditions which offer freedom of growth, as on deposition from solution by slow evaporation. Minerals frequently assume these definite shapes, a knowledge of which is often of great use in identification, since the crystal form of a mineral is one of the most important of its characteristic features.

THE SYMMETRY OF CRYSTALS.—The distribution of faces and angles on crystals is according to certain conditions of symmetry; and the degree of symmetry varies. Symmetry in crystals results from the repetition of similar faces and angles. The degree of symmetry in a crystal is expressed in terms of one or more planes, one or more axes, and a point.

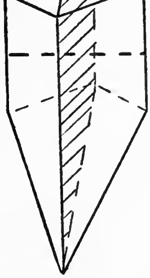

FIG. 1.—Axis and plane of symmetry.

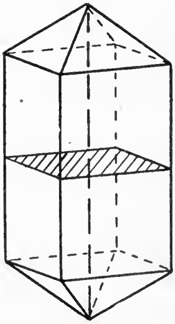

FIG. 2.—Principal axis of symmetry.

A plane of symmetry (figs. 1 and 2) is such that there is an equal distribution of faces and angles on both sides of it; so that for each face or angle on one side there is a similar face or angle on the other; and when the crystal is regularly developed, lines at right angles to the plane of symmetry emerge from the crystal on opposite sides at corresponding points. Some crystals have no plane of symmetry. A crystal may have 1, 2, 3, 4, 5, 6, 7, or 9 planes of symmetry. No crystal can have eight planes of symmetry, and none can have more than nine.

An axis of symmetry (figs. 1 and 2) is a line or direction around which there is a two-fold, three-fold, four-fold, or six-fold repetition of similar faces and angles. Hence on turning a uniformly developed crystal about an axis of symmetry through 360°, it comes twice, three, four or six times into the same portion of space, according to the degree of symmetry. No crystal can have an axis of more than six-fold symmetry, and no five-fold axis occurs.

When one axis and one only of three-fold, four-fold, or six-fold symmetry is present in a crystal, this is termed the principal axis; and if a plane of symmetry is present at right angles to the axis, it is called the principal plane of symmetry (fig. 2).

Even when there are no planes or axes of symmetry in a crystal, we find, as a rule, that the faces and angles on the crystal occur in pairs, so that for every face there is a similar one parallel to it on the opposite side of the crystal (fig. 3). It is customary to describe such crystals as *centrosymmetrical*, *i.e.* as having symmetry with respect to a point or centre, in order to distinguish them from crystals in which a centre of symmetry is absent, and in which therefore the faces are not necessarily all arranged in parallel pairs.

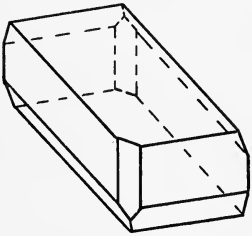

FIG. 3.—Crystal showing only a centre of symmetry.

Planes, axes, and a point or centre of symmetry constitute what are called the elements of symmetry.

DEFINITION OF CRYSTAL FORM.—In any given crystal, a set of faces which have the same disposition and properties in relation to the elements of symmetry, constitutes what is called *a crystal form.* The number of faces in a form therefore depends upon the degree of symmetry, being higher as a rule when planes and axes of symmetry are well represented than when these planes and axes are few or absent.

A crystal may consist of one form only, though as a rule it consists of a combination of two or more forms.

NOMENCLATURE OF FORM-TYPES.—Crystal forms are numerous, and are named according to their shapes and symmetry. In the cubic system, owing to the high degree of axial symmetry, each type has a distinctive name, and it is unnecessary to speak of pyramid forms, prism forms, etc. In systems other than the cubic, however, with one or two exceptions, the same name is used repeatedly in the description of form-types; thus we have hexagonal pyramids and prisms, tetragonal pyramids and prisms, and so on. We may here conveniently define the terms which are used repeatedly in describing those form-types which have certain features in common in crystals other than those of the cubic system.

Pedion.—A pedion form consists of one plane only. Such forms occur in hemimorphic (polar) crystals. In tourmaline, for instance (see fig. 202), the faces are differently developed at the opposite ends of the principal axis; and if, as is frequently the case, there is a basal plane, *i.e.* one at right angles to the principal axis, this constitutes a pedion form. There is a possible class in the triclinic system in which all the forms are pedions, owing to the absence of centrosymmetry; but crystals of this class are not known to occur among minerals.

Pinakoid.—A form consisting of only a pair of parallel faces is called a pinakoid form. All triclinic crystals consist of combinations of simple pinakoid forms. Pinakoid forms can also occur in all other systems except cubic, *e.g.* the pair of planes (basal planes) lying at right angles to the principal axis in many hexagonal, trigonal, and tetragonal crystals (see figs. 31, 173); and the planes lying at right angles to the axes of symmetry in the orthorhombic and monoclinic systems (see figs. 197, 241).

Pyramids and Bipyramids.—In the hexagonal, trigonal, tetragonal and orthorhombic systems (see figs. 4, 5, 6, 38,) a simple form consisting of three or more triangular faces, the apices of which meet at a point, is called a pyramid form. The faces of a pyramid may be repeated

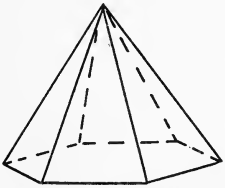
FIG. 4.—Hexagonal pyramid.

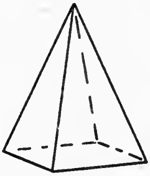
FIG. 5.—Tetragonal pyramid.

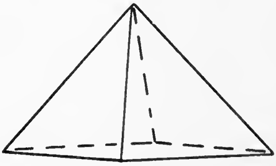
Fig. 6.—Orthorhombic pyramid.

owing to the presence of a centre of symmetry, and we then get a form consisting of two pryamids having their bases on a plane of symmetry. Such a double pyramid form is called a bipyramid (see figs. 23, 29). In the monoclinic system, a group of faces corresponding to the bipyramid in the above systems consists of a combination of two prism forms (see fig. 47); whilst in the triclinic system, the corresponding group of faces consists of a combination of four pinakoid forms (fig. 50).

Prisms.—A prism is a form consisting of three or more faces the lines of intersection of which all lie in the same direction. In the trigonal, tetragonal, and hexagonal systems, the prism forms consist of 3, 4, and 6 faces respectively (see figs. 25, 31, 40) or twice these numbers (see figs. 24, 30, 39); and the prism edges are in each case parallel to the principal axis. In the orthorhombic and monoclinic systems, a prism form consists of four faces (see figs. 44, 48). The corresponding group of four faces making up a prism in the triclinic system (fig. 51), consists of two pinakoid forms, the pinakoid being the highest simple form possible in the triclinic system.

Dome.—This is the name given to a roof-like form occurring in one of the classes of the orthorhombic system. In its detached condition, it is represented by two faces, sloping equally from a common edge so as to yield a form having two planes of symmetry, one along and the other at right angles to the common edge (see fig. 7). The term dome is also frequently applied to certain prism-building forms of the monoclinic and triclinic systems, which have their intersecting edges horizontal or obliquely inclined when the crystal is held in its conventional position.

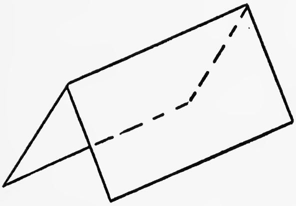

Fig. 7.—Dome.

Sphenoid and Bisphenoid.—In the tetragonal and orthorhombic systems there are certain wedge-shaped forms, of low symmetry, which are termed sphenoids. A form consisting of a double wedge, such as seen in figs. 27, 46, 240, is called a bisphenoid.

CLASSIFICATION OF CRYSTALS.—It has been found that all possible crystals can be divided into thirty-two classes. Each of these classes is characterized by certain conditions of symmetry by which it can be distinguished from the rest. At one extreme we have a class in which there are thirteen axes and nine planes of symmetry, and in which one of the simple forms has forty-eight faces (fig. 8). At the other extreme there is a class in which none of the elements of symmetry is present, and in which a simple form consists of one face only.

For the purpose of this book, it is not necessary to enter into a detailed consideration of the distinctive symmetry-conditions in all the thirty-two possible classes of crystals, some of which are rarely represented among minerals, whilst others are only known in artificial salts, and still others have not yet been observed at all. Only about twenty-two of the thirty-two classes are represented among minerals, and some of these are uncommon, especially among economic minerals.

For the practical purposes of mineralogy it is convenient to group the classes into seven systems, viz. cubic, hexagonal, tetragonal, trigonal, orthorhombic, monoclinic, and triclinic. The symmetry characteristics of these seven systems and the more important classes of each system may be defined as follows :

CUBIC SYSTEM.

The essential characteristics of symmetry in the cubic system are three equivalent axes of symmetry at right angles to each other, and four equivalent axes of three-fold symmetry.

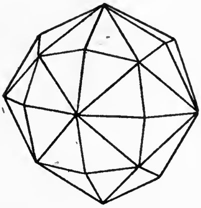

FIG. 8.—Hexakisoctahedron.

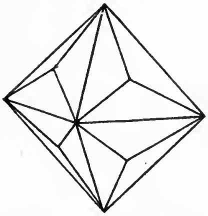

FIG. 9.—Triakisoctahedron.

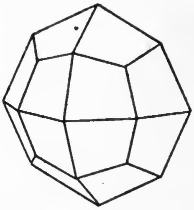

FIG. 10.—Icositetrahedron.

Galena (hexakisoctahedral) class.—In this class there are thirteen axes and nine planes of symmetry. The three equivalent axes of symmetry at right angles to each other are of four-fold symmetry; whilst in addition to these and the four equivalent axes of three-fold symmetry there are six equivalent axes of two-fold symmetry.

In this class there are seven sorts of simple forms, namely, the *hexakisoctahedron* (fig. 8) bounded by forty-eight scalene triangles; the *triakisoctahedron* (fig. 9) by twenty-four isosceles triangles; the *icositetrahedron* (fig. 10) by twenty-four trapezoids; the *octahedron* (fig. 11) by eight equilateral triangles; the *tetrakishexahedron* (fig. 12) or four-faced cube, by twenty-four isosceles triangles; the *rhombic dodecahedron* (fig. 13) by twelve rhombus faces; and the *cube* or *hexahedron* (fig. 14) by six square faces. Examples are: galena (fig. 142), garnet (fig. 189), fluorite or fluorspar (fig. 223), magnetite (fig. 137), spinel, chromite, gold, silver, platinum, and copper.

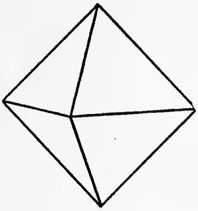

Fig. 11.—Octahedron.

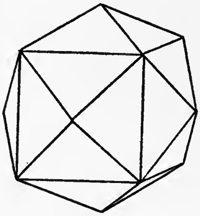

Fig. 12.—Tetrakishexahedron.

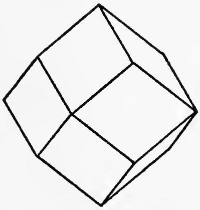

Fig. 13.—Rhombic dodecahedron.

Tetrahedrite (hexakistetrahedral) class.—In this class there are only seven axes of symmetry. The three equivalent axes of symmetry at right angles to each other are of two-fold symmetry. There are also six planes of symmetry, but no centre of symmetry.

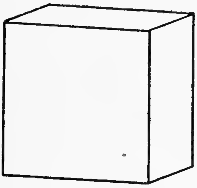

Fig. 14.—Cube.

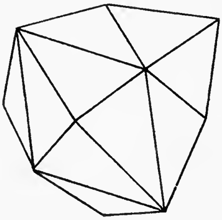

Fig. 15.—Hexakistetrahedron.

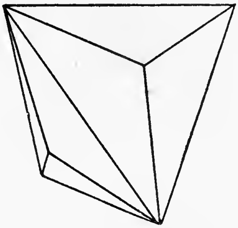

Fig. 16.—Triakistetrahedron.

The characteristic simple forms of this class are the *hexakistetrahedron* (fig. 15) bounded by twenty-four scalene triangles; the *triakistetrahedron* (fig. 16) by twelve isosceles triangles; the *deltoidal dodecahedron* (fig. 17) by twelve deltoidal faces; and the *tetrahedron* (fig. 18)

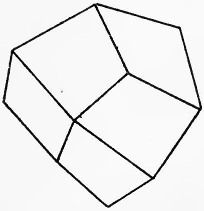

Fig. 17.—Deltoidal dodecahedron.

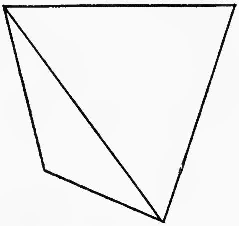

Fig. 18.—Tetrahedron.

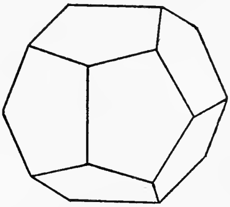

Fig. 19.—Pentagonal dodecahedron.

by four equilateral triangles. The cube, rhombic dodecahedron, and tetrakishexahedron also occur in this class. Examples are tetrahedrite (fig. 133), diamond (fig. 182), zinc-blende (fig. 165), and boracite.

Pyrite (dyakisdodecahedral) class.—In this, as in the preceding class, there are seven axes of symmetry, but only three planes of symmetry. The three planes of symmetry intersect in the three equivalent axes at right angles, which are axes of two-fold symmetry. The characteristic simple forms are, the *pentagonal dodecahedron* (fig. 19) bounded by twelve pentagonal faces; and the *dyakisdodecahedron* (fig. 20) bounded by twenty-four quadrilateral faces. There are two varieties of each, distinguished from one another as right and left. The icositetrahedron, triakisoctahedron, octahedron, rhombic dodecahedron, and cube also occur in this class. Examples are pyrite (fig. 245), cobaltite, and smaltite.

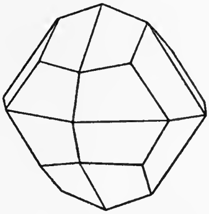

Fig. 20.—Dyakisdodecahedron.

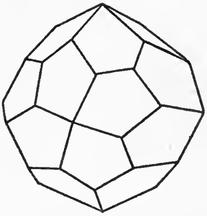

Fig. 21.—Pentagonal icositetrahedron.

Cuprite (pentagonal-icositetrahedral) class.—In this class all thirteen axes of symmetry are present; but there is no plane or centre of symmetry. The characteristic simple form of this class is the *pentagonal icositetrahedron* (fig. 21), bounded by twenty-four irregular pentagons. The icositetrahedron, triakisoctahedron, octahedron, tetrakishexahedron, rhombic dodecahedron, and cube also occur. Examples are cuprite and sylvite (potassium chloride).

Tetragonal System.

Among minerals, the essential characteristic of symmetry in this system, with the exception of one class, is the axis of four-fold symmetry (the principal axis). The exception is the class to which chalcopyrite belongs; and this class is characterized by three axes of two-fold symmetry at right angles to one another, two of which are equivalent.

Cassiterite (ditetragonal-bipyramidal) class.—In this class there are five axes of symmetry, namely one four-fold, and four others at right angles to this, which are two-fold. There are also five planes of symmetry, four of which intersect in the principal axis, the fifth being at right angles to this axis. The simple forms are the ditetragonal bipyramid (fig. 22), tetragonal bipyramids (fig. 23), ditetragonal prism (fig. 24), tetragonal prisms (fig. 25), and basal pinakoids (figs. 24, 25). Examples are cassiterite (fig. 159), rutile, and zircon (fig. 204).

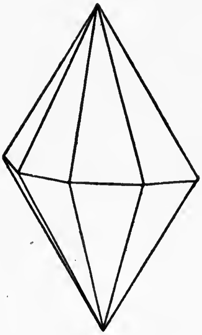

FIG. 22.—Ditetragonal bipyramid.

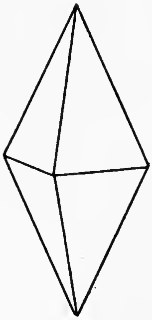

FIG. 23.—Tetragonal bipyramid.

Scheelite (bipyramidal) class.—In this class there is only one axis of symmetry, which is four-fold, and one plane of symmetry at right angles to it. The characteristic simple forms are tetragonal bipyramids and prisms. Scheelite is an example (fig. 163).

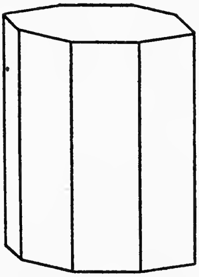

FIG. 24.—Ditetragonal prism.

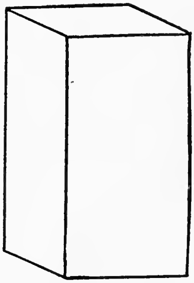

FIG. 25.—Tetragonal prism.

Wulfenite (pyramidal) class.—In this class there is only one axis of symmetry (the four-fold axis); and there is no plane or centre of symmetry. The only difference between this and the preceding class is in the absence of centrosymmetry. Hence instead of bipyramids we get pyramids. Wulfenite is an example (fig. 156).

Chalcopyrite (scalenohedral) class.—In this class there are three axes of two-fold symmetry at right angles to each other. Two of these are equivalent ; the third axis corresponds to the principal axis of the higher classes, and in it two planes of symmetry intersect. The characteristic simple forms are the tetragonal scalenohedron (fig. 26), and the bisphenoid (fig. 27). An important example is chalcopyrite (fig. 132).

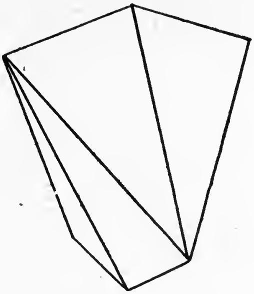

FIG. 26.—Tetragonal scalenohedron.

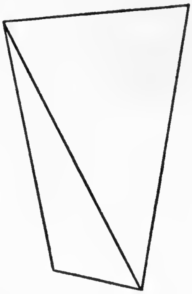

FIG. 27.—Tetragonal bisphenoid.

HEXAGONAL SYSTEM.

The essential characteristic of symmetry in this system is the principal axis of six-fold symmetry, which is present in all crystals belonging to the hexagonal system.

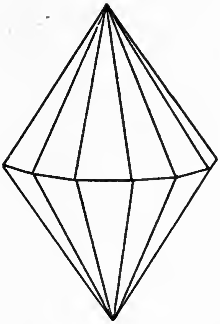

FIG. 28.—Dihexagonal bipyramid.

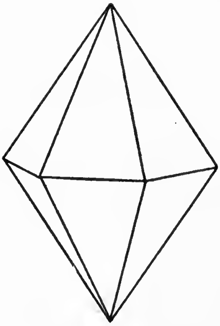

FIG. 29.—Hexagonal bipyramid.

Beryl (dihexagonal-bipyramidal) class.—In this class there are seven axes of symmetry, one of six-fold symmetry (principal axis), and six of two-fold symmetry at right angles to it. There are also seven planes of symmetry, six of which intersect in the principal axis and one is at right angles to it. In this class the simple forms are the dihexagonal bipyramid (fig. 28), hexagonal bipyramids (fig. 29), dihexagonal prism (fig. 30), hexagonal prisms (fig. 31), and basal pinakoid pair (figs. 30, 31). Beryl is an example (fig. 31).

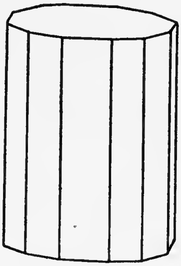

FIG. 30.—Dihexagonal prism.

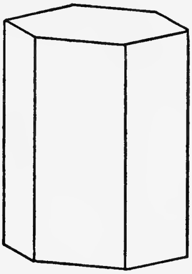

FIG. 31.—Hexagonal prism.

Greenockite (dihexagonal-pyramidal) class.—This class differs from the last in having no centrosymmetry, and consequently no plane of symmetry at right angles to the principal axis. As a result of this we get pyramid forms instead of bipyramids, and the basal planes constitute two pedion forms. Otherwise the forms resemble those of the preceding class. Examples are greenockite and zincite (fig. 171).

Apatite (hexagonal-bipyramidal) class.—In this class the axis of six-fold symmetry is the only axis of symmetry present, and a plane of symmetry at right angles to it, the only plane. The characteristic forms are hexagonal bipyramids and prisms. Examples are apatite (fig. 173), vanadinite (fig. 164), pyromorphite, and mimetite.

Nepheline (hexagonal-pyramidal) class.—In this class, of which nepheline is the only representative, there is one axis of six-fold symmetry but no plane of symmetry.

TRIGONAL SYSTEM.

The essential characteristic of symmetry in this system is the principal three-fold axis which is present in all trigonal crystals.

Calcite (ditrigonal-scalenohedral) class.—In this class there are four axes of symmetry, one of three-fold (principal axis) and three of two-fold at right angles to it. There are also three planes of symmetry, intersecting in the principal axis. The simple forms are the ditrigonal scalenohedron (fig. 32), a hexagonal bipyramid, rhombohedra (figs. 33 to 36), the dihexagonal prism, hexagonal prisms, and the basal pinakoid pair. Examples are calcite (figs. 210, 211), magnesite, chalybite, rhodochrosite, smithsonite, corundum (fig. 181), hæmatite (fig. 138), and bismuth.

Tourmaline (ditrigonal-pyramidal) class.—In this class there are three planes of symmetry intersecting in the axis of three-fold symmetry. The crystals are polar (hemimorphic). The simple forms are the ditrigonal pyramid (fig. 37), a hexagonal pyramid, a trigonal pyramid (fig. 38), ditrigonal prism (fig. 39), a hexagonal prism, trigonal

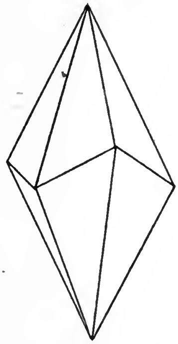

Fig. 32.—Ditrigonal scalenohedron.

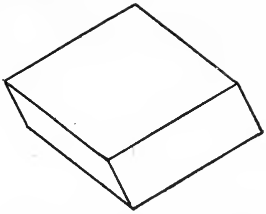

Fig. 33.—Positive rhombohedron.

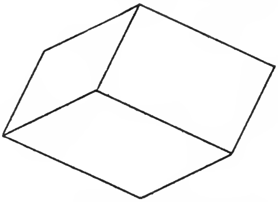

Fig. 34.—Negative rhombohedron.

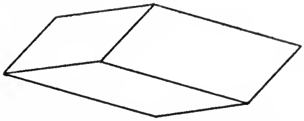

Fig. 35.—Obtuse rhombohedron.

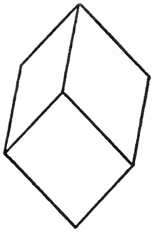

Fig. 36.—Acute rhombohedron.

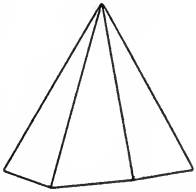

Fig. 37.—Ditrigonal pyramid.

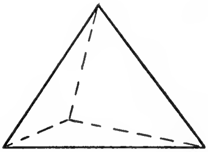

Fig. 38.—Trigonal pyramid.

prisms (fig. 40), and the two basal pedions. Tourmaline (fig. 202), pyrargyrite, and proustite are examples.

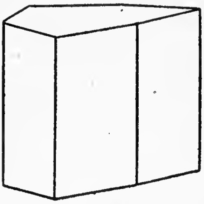

FIG. 39.—Ditrigonal prism.

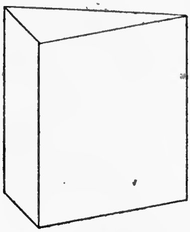

FIG. 40.—Trigonal prism.

Quartz (trapezohedral) class.—In this class there are three axes of two-fold symmetry at right angles to the axis of three-fold symmetry. There is no centrosymmetry. The simple forms are the trigonal trapezohedron (fig. 41), a trigonal bipyramid (fig. 42), a rhombohedron, the ditrigonal prism, a trigonal prism, a hexagonal prism, and the basal pinakoid pair. Examples are quartz (fig. 196) and cinnabar.

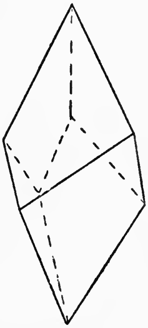

FIG. 41.—Trigonal trapezohedron.

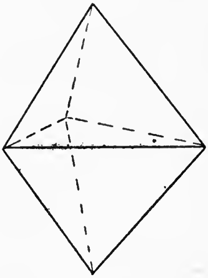

FIG. 42.—Trigonal bipyramid.

Dioptase (rhombohedral) class.—In this class there is only one axis of symmetry (the three-fold axis). There is also centrosymmetry, but no plane of symmetry. The characteristic simple forms are rhombohedra and hexagonal prisms of low symmetry, and the basal pinakoid pair. Examples are dioptase (fig. 184), phenakite (fig. 194), willemite, dolomite, and ilmenite (fig. 162).

ORTHORHOMBIC SYSTEM.

The crystals of this system are usually characterized by three inequivalent axes of two-fold symmetry at right angles to one another. In one class, however, there is only one axis of two-fold symmetry, in which two planes of symmetry intersect.

Sulphur (bipyramidal) class.—Crystals of this class have three planes of symmetry at right angles to each other, intersecting in three inequivalent axes of symmetry. In this class the simple forms are the bipyramid (fig. 43), prisms (fig. 44) including the so-called domes, and three pinakoid forms (fig. 45). Examples are sulphur (fig. 243), orpiment, stibnite, arsenopyrite (fig. 126), chalcocite, witherite, cerussite, barite (fig. 236), celestite (fig. 238), anglesite, staurolite, olivine (fig. 193), and topaz (fig. 200).

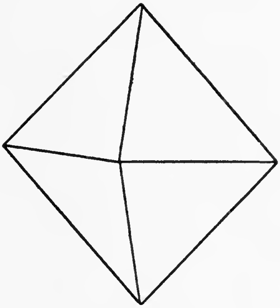

FIG. 43.—Orthorhombic bipyramid.

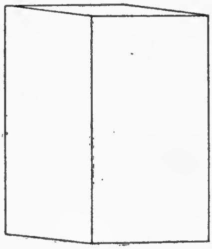

FIG. 44.—Orthorhombic prism.

Hemimorphite (pyramidal) class.—In this class there is only one axis of two-fold symmetry, in which two planes of symmetry intersect. The forms include a pyramid, a prism, two domes, two pinakoids, the faces of which are parallel to the axis of symmetry. The third pinakoid pair, the faces of which are at right angles to the axis of symmetry, constitutes two separate pedion forms. Hemimorphite is an example (fig. 169).

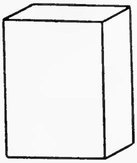

FIG. 45.—Orthorhombic pinakoids.

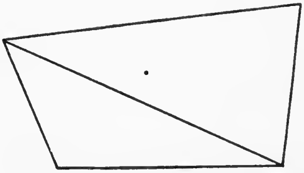

FIG. 46.—Orthorhombic bisphenoid.

Epsomite (bisphenoidal) class.—In this class there are the three inequivalent axes of two-fold symmetry at right angles to each other, but no planes of symmetry. The characteristic simple form is the rhombic bisphenoid (fig. 46), consisting of a double wedge, the four faces of which are scalene triangles. The three prism forms and three pinakoid pairs also occur. Epsomite is an example (fig. 240).

MONOCLINIC SYSTEM.

Gypsum (prismatic) class.—In this, the only monoclinic class of importance, there is one axis of two-fold symmetry, at right angles to which there is a plane of symmetry. The simple forms include prisms and pinakoids. Unlike the orthorhombic bipyramid, which is a simple form, the monoclinic bipyramid is made up of two prism forms (fig. 47).

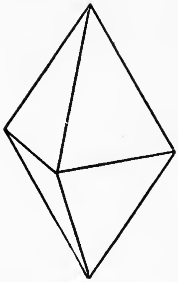

FIG. 47.—Monoclinic bipyramid.

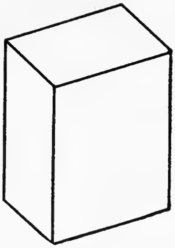

FIG. 48.—Monoclinic prism.

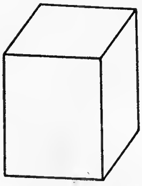

FIG. 49.—Monoclinic pinakoids.

Fig. 48 shows a combination of prism and basal pinakoid pair. Fig. 49 shows a combination of three pinakoids. Examples are gypsum (fig. 241), realgar, mica, orthoclase felspar (fig. 186), epidote borax, and trona (fig. 217).

TRICLINIC SYSTEM.

Kyanite (pinakoidal) class.—In this, the only important class of the triclinic system, there is no plane or axis of symmetry; the only feature of symmetry present is centrosymmetry. All the simple forms of this class are pinakoid pairs (figs. 50, 51, 52). The triclinic

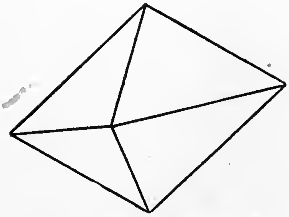

FIG. 50.—Triclinic bipyramid.

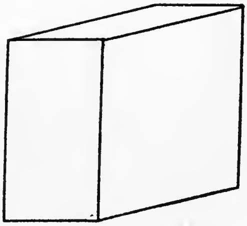

FIG. 51.—Triclinic prism.

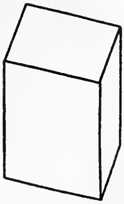

FIG. 52.—Triclinic pinakoids.

bipyramid (fig. 50) is made up of four pinakoid pairs. Examples are kyanite (fig. 191), microcline, plagioclase felspar, rhodonite (fig. 152), and axinite (fig. 176).

TWIN CRYSTALS.—In a fully developed simple crystal, all the angles are salient. Many crystals, however, are seen to be made up of two or more parts that have grown together in such a way that it is necessary to move one part through an angle of 180° around a certain axis in order to bring it into normal relation with the part adjacent to it. These compound crystals usually show re-entrant angles, and are known as *twin crystals.* The two parts of such a twin crystal exhibit symmetry about a common plane (the twin plane) which is a possible face, or a common axis (the twin axis) which is a possible edge.

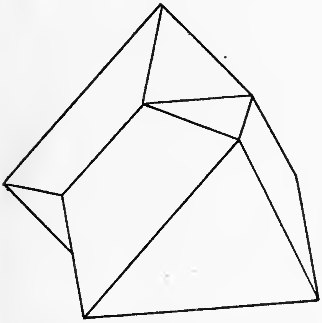

FIG. 53.—Contact twin of magnetite.

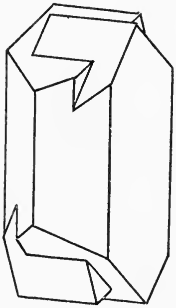

FIG. 54.—Contact twin of orthoclase.

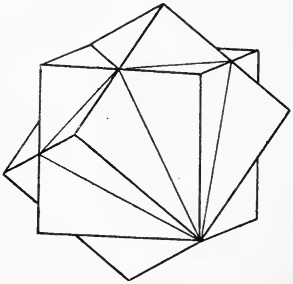

FIG. 55.—Interpenetrant twin of fluorite.

As a rule twin crystals are such that rotation of one part through 180° on the twin plane or around the twin axis would result in the formation of a simple crystal. When the two parts of a twin crystal are united by a twin plane, the twin is described as a *contact twin* (figs. 53, 54) to distinguish it from the type of twin crystal known as *interpenetration twin* (fig. 55) in which two individuals appear to penetrate each other.

In some instances the twinning is repeated many times. As a consequence of this, pseudo-symmetrical complex crystals may be formed, and in these there may or may not be re-entrant angles. In witherite, for instance, a pseudo-hexagonal form results from a repetition of the twinning effect on the orthorhombic prism face, and a mimetic crystal like that of fig. 215 is produced. This type of twinning is known as *repeated* twinning. Other examples of it are cerussite (fig. 147) and alexandrite (fig. 179). It is very common in the plagioclase felspars, and is the cause of the striated appearance (twin striation) on the basal cleavage so frequently seen in oligoclase and labradorite (see figs. 187 and 188).

Two crystals may be attached to each other with their like edges parallel, and are then known as *parallel growths.* Such parallel growths and crystals that have grown in irregular juxtaposition should not be confused with twin crystals.

THE FURTHER STUDY OF CRYSTALS.—The student should obtain a set of models of the various crystal forms, and actual combinations of these shown by crystals of the more important minerals, as it is only by the use of such models that the symmetry of crystals can be conveniently studied by the beginner. After that he can more successfully study actual crystals, measure angles by means of a goniometer and proceed to the study of mathematical crystallography as outlined in books specially devoted to that subject.

Many students of economic mineralogy, however, may not have time or inclination to go beyond the elementary study of crystal symmetry as here briefly outlined. It is therefore worthy of note that, on this simple consideration of crystal symmetry as a basis, one can proceed to the study of crystal optics, a knowledge of which is of great use in the examination and determination of minerals.

CHAPTER III.

THE GENERAL PHYSICAL CHARACTERS OF MINERALS.

MASSIVE FORMS OF MINERALS.

THOUGH usually crystalline, minerals seldom show a good development of crystal faces, owing to the fact that, as a rule, crystallization has proceeded around innumerable different centres of growth. In consequence of this, the individual particles of the mass have not been free to develop crystal facets, but have had to take on the shapes allotted to them by their surroundings. Hence we find that minerals are usually massive, *i.e.* consist of an aggregate of crystalline individuals which show no definite shapes. These massive forms of minerals receive different names according to the structure or mutual arrangement of their parts and their mode of growth. The following are the chief varieties of texture and modes of growth to which special names are given among massive minerals

Granular.—This name may be given to any mass of mineral which is made up of grains of more or less uniform size and coarseness of texture. The terms coarse-grained, medium-grained, and fine-grained are useful as indicating in a general way the variability in relative size of the constituent grains.

Compact.—The term compact implies that a rock or mineral is made up of a mass of microscopically small particles, *e.g.* certain iron and manganese ores. A specimen with a compact texture usually breaks with a fairly even and dull surface.

Brecciated.—Breccia consists of coarse and usually angular fragments embedded in a comparatively fine-grained matrix. It is commonly formed by crushing due to movement along fault-planes, etc., and should be distinguished from a conglomerate of detrital origin, in which waterworn pebbles are embedded in a matrix of sand.

Earthy.—This is a descriptive name for such easily friable minerals as wad (bog manganese ore), which may soil the fingers.

Powdery.—This indicates the loose or incoherent condition of some minerals, such as kaolin.

Flaky or scaly.—These are useful terms for describing certain forms of graphite, molybdenite, hæmatite, mica, and other minerals occurring in the form of small thin plates.

Fibrous, e.g. the different varieties of asbestos (fig. 208).

Dendritic, i.e. branching growths such as those often assumed by native copper (fig. 130).

Filiform.—This is the name given to a wiry condition, as exemplified by mode of growth of native silver (fig. 158).

Reniform and mammiform.—The kidney-like surface sometimes assumed by masses of hæmatite is described as reniform (fig. 140). When the curved surfaces are flatter and suggest mammæ, they are described as mammiform, mammillary, or mammillated.

Botryoidal.—A form similar to that of a bunch of grapes (fig. 141).

Nodular or concretionary, occurring in the form of rounded nodules, embedded in a matrix; *e.g.* nodules of calcium carbonate in clay, flint nodules in chalk, etc. An aggregate of globules each of which shows a well-marked concentric structure, is named *pisolitic* when the globules are about the size of peas (fig. 123), and *oolitic* when the globules resemble those of the hard roe of a herring.

Stalactitic.—The icicle-like form assumed by mineral matter deposited on the roof of a cave or other hollow (fig. 151).

Amorphous.—Used in its strictly correct mineralogical sense, this term implies absence of crystalline structure as well as crystalline form, and in this sense it should only be used of such substances as opal, which are in a non-crystalline condition. The term has a certain vogue, however, in describing various compact or earthy forms of minerals. It is used in the graphite trade, for instance, in describing dull, compact graphite, to distinguish it from the well-crystallized "flaky" variety.

COLOUR.

As a rule, colour is a constant and characteristic feature only among the more opaque minerals, which are chiefly those of metallic and submetallic lustre, *e.g.* gold, silver, copper, galena, magnetite, pyrite, pyrrhotite, chalcopyrite, hæmatite, and wolframite. Many opaque minerals, more especially the sulphides, readily suffer alteration when exposed to atmospheric changes. Hence, in making observations as to colour in such cases, care should be taken to see that the surface examined is in a fresh unweathered condition. Otherwise, the characteristic colour and appearance may be dulled or more seriously modified by the secondary compounds formed as a result of oxidation and other changes; though a knowledge of the nature of these changes is often helpful to the experienced observer in making a diagnosis. We may say therefore that the colour of opaque minerals is fairly constant and characteristic.

It is otherwise with many of the more transparent minerals, such as quartz, fluorite, and most gemstones, notably the varieties of corundum (ruby, sapphire, and others). The colour of these more or less transparent minerals is often due to an inestimably small amount of impurity which has been incorporated during growth. Some varieties of smoky quartz are black in the mass, but become colourless and transparent when heated in a Bunsen flame. Many minerals have their colour readily destroyed by heat in this way; whilst in many other cases the colour becomes radically changed, without any serious change of chemical composition. In such cases colour is of little or no diagnostic value.

In some transparent minerals, however, where the colour is due to an essential constituent of the mineral, the colour is a more constant and significant feature. Copper minerals, as well as those of chromium, uranium, and several other metals, furnish good instances of this; and in these colour is a feature of diagnostic value.

STREAK.

The streak of a mineral is the colour of its powder. The name arises from the fact that the usual method of observing the colour is to make a streak of the mineral by rubbing it on a plate of white, unglazed porcelain. Such a piece of porcelain is called a streak-plate, one of which should always be kept clean and ready for use by the practical mineralogist, since the observation of streak is often a helpful factor in identifying a mineral. Many minerals that appear quite black or opaque in the mass, give a coloured streak, owing to the fact that the minute particles of the powder are not opaque. A familiar example of this is crystalline hæmatite, the powder of which has a characteristic red colour, though a freshly fractured surface may appear almost black and opaque.

It is among the more opaque minerals that the streak-test finds its chief application. The great advantage of using a streak-plate is, that it enables us to judge the colour of the powder of a mineral without defacing a crystal, or by using a minimum amount of material.

Some minerals are too hard to permit good streak-tests to be made on a porcelain plate. With these minerals, an alternative method for observing streak is to crush a fragment to fine powder in a mortar. This is a method of observation specially suitable for black varieties of such minerals as rutile and cassiterite The brown colour of the powder of black cassiterite is a useful characteristic; and taken in conjunction with other physical evidences, notably the lustre and specific gravity, affords strong evidence for identification.

LUSTRE.

In describing minerals, it is convenient to have a few terms by which we can indicate the nature of the optical effect (apart from colour) produced by the incidence of light on a fresh crystal or the freshly fractured surface of a mineral. To this effect mineralogists give the name *lustre*, a property which is determined partly by the degree of transparency, and partly by the refractive power of a mineral.

Lustre is thus a complex property, but one which is found to be of considerable value as a descriptive feature. When a high refractive power and a high degree of opacity are combined in a mineral, we get metallic lustre, a brilliant effect due to a copious reflection of the light rays which fall on the surface. This lustre is well seen in metals and metallic sulphides. With a lower degree of opacity, such as that shown by wolframite and chromite, splinters of which are translucent, submetallic lustre is obtained. The more transparent minerals yield a vitreous lustre, *i.e.* a lustre like that of glass, when the refractive power is low, as in quartz; and adamantine lustre when, as in diamond and rutile, the refractive power is very high.

The chief types of lustre therefore are: *metallic*, *submetallic*, *adamantine*, and *vitreous*. Less frequent types of lustre are those described as *resinous*, *waxy*, *greasy*, *pearly*, and *silky*, from the resemblance of their appearances to the various substances referred to in these adjectives.

HARDNESS.

The degree of ease with which a mineral can be scratched is usually a fairly constant feature in any given mineral, but varies with different minerals. This behaviour affords, indeed, a very useful piece of evidence, which is readily obtained, in testing a mineral.

Some minerals, such as graphite, gypsum and mica, are very soft, and can be scratched by a thumb-nail. Other minerals, such as spinel and corundum, are extremely hard, and cannot be scratched by the hardest steel.

The hardness of a mineral is determined by a rough comparison with certain known minerals which are adopted as standards, and which constitute what is called a *scale of hardness*. The ten minerals usually employed for this purpose are as follows, in diminishing order of hardness :

10. Diamond.
9. Corundum.
8. Topaz.
7. Quartz.
6. Orthoclase.
5. Apatite.
4. Fluorite.
3. Calcite.
2. Gypsum.
1. Talc.

The hardness of a mineral is expressed by a number. That number, in the case of each scale mineral, is the number affixed above. Thus quartz is said to have a hardness of 7. Zinc-blende is said to have a hardness of $3\frac{1}{2}$ because it scratches and is not scratched by calcite, whereas it will not scratch but is scratched by fluorite. Two minerals which scratch one another may be regarded as having the same hardness.

The gaps between the successive pairs of minerals in the scale of hardness are very irregular, and the scale is only useful as a means of rough comparison. For practical purposes, a rough idea of the hardness of most minerals can usually be obtained by testing with the tip of a pocket knife. If it is necessary to determine the hardness more accurately, the minerals of the scale should be used for comparison. For field use it is convenient to carry small fragments of corundum and quartz. These, with a pocket knife (hardness about $5\frac{1}{2}$) and a thumbnail (hardness about $2\frac{1}{2}$), enable one after a little experience to form a fairly accurate idea of the comparative hardness of minerals.

In determining hardness, care should be taken to ensure, as far as possible, the purity of the mineral tested, and the specimen should be closely examined with a pocket lens. A soft mineral sometimes contains small grains of a harder mineral, and the latter are apt to mislead the observer in testing hardness. A good example of this is massive chalcopyrite (hardness $4\frac{1}{2}$) which often contains particles of quartz (hardness 7). Such a piece of chalcopyrite may scratch felspar by virtue of the quartz present, although the mass itself is readily scratched by the pocket knife. The importance of caution in this particular case is made obvious by the fact that hardness is one of the distinctive tests between chalcopyrite ($4\frac{1}{2}$) and pyrite ($6\frac{1}{2}$).

It is clear, therefore, that the test of hardness is one which, though simple, requires care, especially when dealing with the minerals in a massive condition. Minerals in this condition are much more liable to admixture than are well-developed crystals. In fact, however, crystals themselves often contain inclusions of other minerals.

CLEAVAGE AND PARTING.

True cleavage.—Cleavage is the name given to the property, which some minerals possess, of splitting along one or more planes of structural weakness. A plane of true cleavage is determined by the disposition of the molecules of which the crystal is composed, and all parts of the crystal manifest a tendency to split along this direction. Mica is a well-known example of a mineral possessing one such plane of very pronounced structural weakness or cleavage (fig. 56), whilst tremolite shows two cleavages, which cause its crystals to split into prismatic fragments (fig. 57). Calcite shows three good cleavages in consequence of which its crystals can be broken into rhombohedral fragments (fig. 212). A cube of galena breaks readily along three cleavage planes which are parallel to the cube faces, *i.e.* at right angles to each other, yielding smaller cubes (fig. 146). A cube of fluorite, on the other hand, breaks along four different cleavage planes parallel to the faces of the octahedron, and can be broken so as to yield a good octahedron.

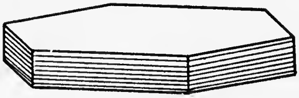

FIG. 56.—Platy cleavage in mica.

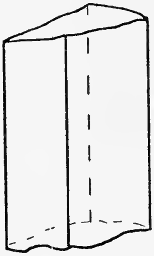

FIG. 57.—Prismatic cleavage in tremolite.

All these are examples of true cleavage, the tendency to which exists equally at all points of any crystal in which the property of true cleavage exists. The property is one which can often be used in identifying minerals, since crystalline structure is frequently well developed even when there is no evidence of the actual crystalline form. When present, cleavage is a characteristic, and supplies useful evidence bearing on crystalline symmetry, especially when considered in connection with the form and physical properties of cleavage plates and fragments. For this reason cleavage is an important property in the study of economic minerals. In the gem-cutting trade, as in diamond splitting, the property of cleavage is utilized to great advantage. It is, moreover, largely to this property that some minerals, notably the micas, owe their economic value.

It is customary to use the term *perfect* in describing the cleavage in such minerals as mica, gypsum, calcite, and galena, in which cleavage yields perfectly smooth surfaces.

Parting.—In some cases, crystals cleave readily along certain planes which are not true cleavage planes in the sense defined above. Corundum is a good example of this. A fresh, transparent crystal of corundum shows no tendency whatever to cleave along definite planes, but fractures conchoidally (for definition of conchoidal fracture see below) much like quartz. Very often, however, crystals of corundum cleave along the basal plane, and also along rhombohedral planes, yielding three parallel sets of striations on the base, as shown in fig. 58. This behaviour is limited to those crystals which have suffered alteration. In other minerals, as in magnetite, for instance, planes of ready separation arise in consequence of twinning.

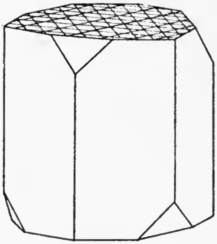

FIG. 58.—Partings in corundum.

These planes are called *partings.* They differ from true cleavages in that they are not essential to the mineral, and occur only in twinned or altered crystals. Even in these they are restricted to certain planes, whereas a true cleavage is possible at all points of a crystal.

Ordinary corundum, which owes its commercial value to its abrasive properties, is less effective as an abrasive when partings are abundantly developed. For the manufacture of the jewelled bearings of watches and other instruments, it is still more important that the corundum should in this respect be flawless; and it is obviously desirable that sapphires and rubies—the gem varieties of corundum—should be free from partings. Hence we see that the presence or absence of partings, in the case of this mineral, is a matter of considerable economic significance.

FRACTURE.

When cleavage is absent, or but poorly developed, a crystal breaks along a more or less irregular surface. The nature of this surface is called its fracture. The different kinds of fracture usually recognized are (1) *Even fracture,* when the surface is fairly regular; (2) *Uneven fracture,* when the surface is irregular; (3) *Conchoidal fracture,* when the surface shows a series of curved lines suggesting the marks on certain bivalve shells; (4) *Splintery fracture*, as in fibrous minerals; (5) *Hackly fracture*, when very rough and jagged in appearance, as is the broken surface of metals such as copper.

SPECIFIC GRAVITY.

The density of a substance is its mass per unit volume. The best practical method of comparing densities is to use water as a standard of comparison, calling its density 1. The relative density of a substance compared with water is called its specific gravity.

For any given mineral, the specific gravity is fairly constant, sometimes remarkably so. Moreover, scarcely any two minerals have the same specific gravity; hence the determination of specific gravity in any particular case is a factor of great importance in identifying a mineral.

The most trustworthy of the various methods of determining the specific gravity of minerals may be enumerated as follows:

(1) Direct hydrostatic weighing.
(2) Use of a specific gravity bottle.
(3) Use of a spring balance.
(4) Suspension in heavy liquids.

(1) Direct hydrostatic weighing.—By this method a piece of the mineral is weighed, first suspended in air, and then in water. In each case the weight recorded is not the real weight of the piece of mineral, but is less than that by an amount equal to the weight of the displaced medium. The apparent weight in air is, owing to the extremely low density of air, sufficiently near the real weight to make correction unnecessary for ordinary purposes, so that we may take the air-weighing as being practically the true weight. By subtracting from this the apparent weight in water, therefore, we get the weight of the water displaced by the piece of mineral. Hence we get:

$$\text{Specific gravity of mineral} = \frac{\text{Weight in air}}{\text{Weight in air} - \text{apparent weight in water}}.$$

In making this determination the left arm of the beam of the balance should be provided with a small wire basket, suspended from it by a piece of fine wire, the basket and part of the wire support being immersed in water. The extent to which the basket and its supporting wire are immersed, should remain as constant as possible throughout the experiment, so as to ensure that the difference between the two weighings will represent the weight of the water displaced by the mineral. For the same reason, care must be taken to secure the proper wetting of the fragment over its entire surface when ascertaining its apparent weight in water, any air-bubbles that may be present being brushed or gently rubbed off, or removed *in vacuo.*

By this method, specific gravities can be determined with accuracy to the second place of decimals with very little trouble; and this degree of accuracy is quite adequate for determinative purposes in mineralogy. Indeed, accuracy at the first place of decimals is usually quite sufficient for determinative work.

By direct hydrostatic weighing, using a chemical balance, specific gravities can be determined on fragments weighing not more than 0·050 grams. With such small fragments, however, special care is necessary to secure accuracy at the second place of decimals; and the error due to imperfect wetting or the presence of air-bubbles in such a case is then obviously very serious. With such small fragments a suitably small cup or spring clip conveniently takes the place of the wire basket for holding the mineral.

The degree of accuracy varies with the density and volume of the fragment used, the determination tending to greater accuracy for the lighter than for the heavier minerals when similar volumes are taken. This is especially true when the fragments are small, since the weight of water displaced is small, and the error of weighing more significant. For this reason, the degree of accuracy for small heavy fragments is increased by determining the apparent weight of the fragment in some heavy liquid, such as bromoform or methylene iodide of maximum density, the exact specific gravity of this liquid having been carefully determined beforehand.

(2) Use of a specific gravity bottle.—When the mineral is in the form of sand or of numerous small fragments, it is convenient to use a small, narrow-necked glass vessel which is provided with a carefully-fitted glass stopper. For ordinary work it is sufficient to have a stopper with a capillary bore to enable the excess of water to escape when the stopper is inserted, so that the vessel can be obtained full of water without air-bubbles, the vessel and stopper being carefully dried after the latter has been inserted.

To determine the specific gravity of a sand, or broken fragments by this means, we require to know:

(1) Weight of sand (w).
(2) Weight of the vessel full of water (w_1).
(3) Weight of the vessel filled up with water after the sand has been inserted (w_2).

With a knowledge of these three facts we can find the specific gravity of the sand; thus, since w = weight of the sand in air, and

$$(w+w_1)-w_2 = \text{weight of an equal volume of water,}$$

we get:

$$\text{Specific gravity of sand} = \frac{w}{w+w_1-w_2}.$$

In making this determination the air-bubbles should be boiled off, and the water cooled down again to normal temperature. It is desirable that the sand should occupy about half the volume of the vessel. For ordinary purposes, when there is sufficient of the mineral, a bottle having a volume of 25 c.c. may be used. For smaller amounts, the capacity of the bottle should be correspondingly smaller.

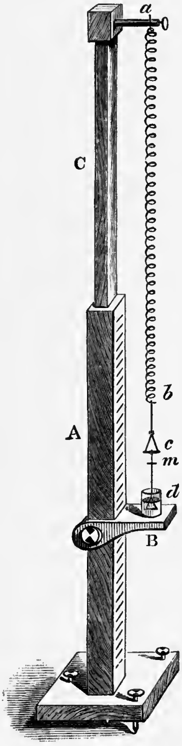

FIG. 59.—Jolly's spring balance.

(3) **Use of a spring balance.**—One of the readiest methods of determining the specific gravity of a piece of mineral is that of using a spring balance such as the well-known Jolly balance. This balance (see fig. 59) consists of a long spring (ab) suspended from a screw pinch which is fixed at the upper end of an adjustable rod (C). This adjustable rod fits into a slot in the main upright (A) and can be fixed in any required position by a screw clamp. Suspended from the lower extremity of the spring are two pans (c and d), the lower one of which is immersed in water throughout the experiment. The beaker carrying the water is supported on a small sliding platform (B), which can be fixed at any required level by means of a screw clamp which grips the main upright.

On the wire supporting the upper pan there is a white cylindrical bead which is used as an index in making the readings. In the figure the index is shown at m, below the upper pan. The front of the main upright carries a fixed graduated mirror to enable the displacement of the bead to be measured. The correct reading for any position of the bead is that made by placing the eye on a level with the top of the bead and its reflexion in the mirror, and noting the reading on the scale. The smallest division on the scale is a millimetre, but in making the reading the observer should judge fractions of this division as accurately as possible.

Three readings are required, viz.:

(*a*) Reading with both pans empty.
(*b*) Reading with mineral in upper pan.
(*c*) Reading with mineral in lower pan.

The extent to which the spring is stretched, and consequently the displacement of the bead, is proportional to the stretching weight. Hence, since $b-a$ represents the displacement due to the weight of the fragment in air, and $b-c$ the displacement due to the weight of an equivalent volume of water, we get:

$$\text{Specific gravity} = \frac{b-a}{b-c}.$$

Care must be taken to wet the fragment properly, and avoid air-bubbles, when making the "*c*" reading; and the extent to which the lower pan is immersed must be the same for both readings.

The Jolly balance is very useful as a ready, cheap, and quickly-operated means of ascertaining the approximate specific gravity of a mineral fragment. It is capable of yielding results accurate at the second plane of decimals for fragments weighing two or three grams. For fragments having about the same weight, the degree of accuracy is higher for minerals of low specific gravity, such as quartz and calcite, than it is for minerals of high specific gravity, such as cassiterite, wolframite, and uraninite.

Two or more springs are usually provided with the instrument, a coarser one for use with large fragments, and a fine one for small fragments.

(4) Suspension in heavy liquids.—On account of its extreme sensitiveness, this is undoubtedly, where applicable, the best method of determining specific gravities with accuracy; and it has the advantage of being available for use with very small fragments. The following is a list of the heavy liquids in use:

	Maximum sp. gr.	
Bromoform	about 2·85	Liquid at ordinary temperature; dilute with benzol or xylol.
Acetylene tetrabromide	,, 3·00	
Methylene iodide	,, 3·33	
Cadmium borotungstate	,, 3·25	Aqueous solutions at ordinary temperature; dilute with distilled water.
Mercury potassium iodide	,, 3·20	
Mercurous nitrate	,, 4·3	Solid at ordinary temperatures, but melt about 75° C., yielding clear liquids. Dilute with distilled water.
Silver thallium nitrate	,, 4·5	
Thallium mercury nitrate	,, 5·3	

By placing a mineral fragment in one of these liquids, and adjusting the density by dilution until the fragment remains suspended in any position, we know that under these conditions the fragment and the liquid have the same density. All we have to do then is to ascertain the specific gravity of the liquid. A useful apparatus for doing this for liquids such as bromoform and methylene iodide is the Westphal balance (fig. 60).

This balance consists of a steelyard arrangement carrying a glass sinker which is loaded with mercury and acts as a thermometer. The beam of the steelyard is brought into equilibrium by means of standardized riders which enable the specific gravity of a liquid to be read off directly to the third place of decimals.

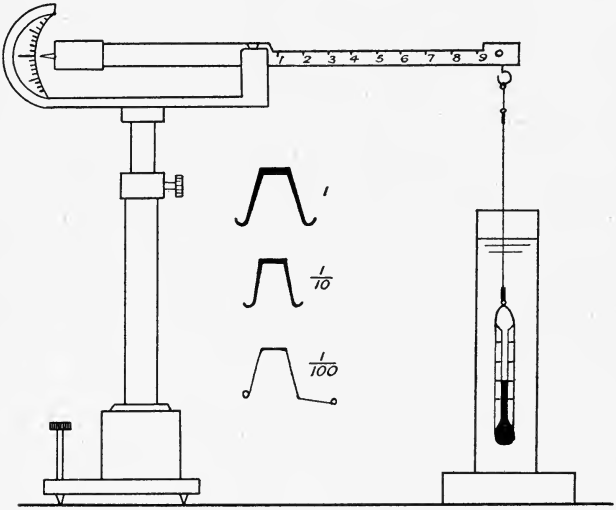

FIG. 60.—Westphal balance.

The arm carrying the sinker is divided into ten equal divisions, numbers 1 to 10 from the fulcrum, and the sinker is suspended by a very fine platinum wire at the tenth division. There are three kinds of riders, one of which is the unit, another a tenth of this in weight, and the third a hundredth. The unit-rider is such that the beam is in equilibrium when the sinker is immersed in pure water at about 15° C., and when the unit-rider is placed at the tenth division, *i.e.* that from which the sinker is suspended. When a unit-rider is placed on any of the other divisions, it gives readings at the first place of decimals. The tenth-rider, when placed at the tenth division, indicates 1 in the first place of decimals ; and when placed on the other divisions gives readings at the second place. Similarly, when the hundredth-rider is placed in the tenth division, it indicates 1 at the second place of decimals, and gives readings at the third place when placed on the other divisions.

Thus, if the beam is in equilibrium at 15° C. with 2 unit-riders at the tenth division, a unit-rider at the seventh division, a tenth-rider at the second division, and a hundredth-rider at the fifth division, the reading for the specific gravity will be 2·725.

In the absence of a Westphal balance, the density of a liquid can be ascertained in the ordinary way, suspending a sinker from one arm of a chemical balance, and comparing its apparent loss of weight in the heavy liquid with that in water, thus :

$$\text{Specific gravity of heavy liquid} = \frac{\text{Apparent loss of weight in heavy liquid}}{\text{Apparent loss of weight in water}}.$$

Another way of finding the density of a liquid used for the determination of specific gravities by the suspension method is to use mineral fragments or artificial bodies of known specific gravity as indices. A series of liquids in small tubes, each having its specific gravity indicator or indicators, is of considerable practical value in determinative work, as it often enables one to ascertain quickly the approximate specific gravity of a mineral. It is especially important in the suspension method to guard against air-bubbles on the surface of small fragments.

It frequently happens that the fragment of mineral of which we wish to determine the specific gravity sinks in the heaviest liquid. Indeed, the heaviest liquid which can be used conveniently in the determination of specific gravities by the method of suspension is methylene iodide (specific gravity 3·33). How then can we, by the method of suspension in methylene iodide, ascertain the specific gravity of minerals having a specific gravity greater than 3·33 ? Most of the minerals having a metallic lustre fall into this category, and likewise many of the minerals with non-metallic lustre.

This can be done by means of floats, various kinds of which have been suggested by different workers. Small spring clips made of glass can be used, but these are readily broken. Aluminium clips are better. Clamped in one of these clips, a heavy mineral fragment can be suspended in methylene iodide. Knowing the weight of the mineral fragment (w), the weight of the float (w_1), the specific gravity of the float (g_1), and the specific gravity of the liquid which just suspends the float and the mineral fragment (G), we can find the specific gravity of the mineral (g) by the following relation :

$$w+w_1 = G\left(\frac{w}{g}+\frac{w_1}{g_1}\right);$$

$$\therefore\ g = \frac{G\,.\,w}{w+w_1-\dfrac{G\,.\,w_1}{g_1}}.$$

This is the best form of the equation from which to calculate the value g, *i.e.* the specific gravity of the mineral fragment.

FUSIBILITY.

Minerals differ widely from one another in their temperatures of fusion, and this fact often affords a useful test in distinguishing them from one another. The degree of fusibility of a mineral is tested by taking an elongated fragment or splinter which has a fine edge or point, and heating it in an ordinary or, if necessary, a blowpipe flame. The splinter should be small, not exceeding about one millimetre in thickness, and may be held in the flame by means of a pair of forceps. In this way the splinter can be held so that it is well exposed to the high temperature of the blowpipe flame.

As in the determination of hardness, so with fusibility, it is convenient to have a scale of minerals of varying fusibility for use as a standard of comparison. The scale usually employed consists of the following minerals :

1. *Stibnite* (*Antimonite*).—Fragments several millimetres in diameter fuse easily to a globule in an ordinary flame, and with extreme readiness in a blowpipe flame.

2. *Chalcopyrite.*—Splinters fuse to a globule slowly in an ordinary flame, but readily in a blowpipe flame.

3. *Almandine garnet.*—Splinters do not fuse to a globule in an ordinary gas flame, but fuse to a globule with little difficulty in a blowpipe flame.

4. *Actinolite.*—Splinters are readily rounded on the edges in a blowpipe flame. Only the sharp points become fused to a globule with readiness.

5. *Orthoclase.*—Splinters have their edges rounded with difficulty in a blowpipe flame. Sharp points fuse to a globule with difficulty.

6. *Bronzite.*—Very slightly fusible. Edges and points rounded with great difficulty.

It is necessary to become familiar with the behaviour of the minerals of this scale before determinations of fusibility can be made quickly. In making tests, one should compare freely the behaviour of any mineral under examination with the minerals of the scale, in order to get the best approximation possible. As in the case of hardness, the degree of fusibility of a mineral is expressed by a number, indicating approximately its position in the scale. When the finest points and sharpest edges of a splinter give no signs of rounding in a blowpipe flame, the mineral is said to be infusible.

Metals and metallic sulphides should not be held in platinum forceps when testing fusibility as they may alloy with the platinum, and so destroy the forceps. Fragments of such minerals should be held in iron forceps or placed on charcoal.

Fragments of certain minerals expand considerably in volume by intumescence or exfoliation when tested for fusibility, owing to the presence of water. Other minerals (*e.g.* barite) detonate mildly, and break up. In testing fusibility any colour-changes that take place should be noted. If the splinter becomes white, and is infusible, it should be moistened with cobalt nitrate and re-heated (see p. 78); and a separate one should be tested for alkalinity with a piece of litmus paper (alkalies turn red litmus blue).

CHAPTER IV.

THE PRACTICAL ELEMENTS OF CRYSTAL OPTICS.

In this chapter it is proposed to consider briefly and simply those aspects of crystal optics that are of practical importance in their application to the use of the polarizing microscope in the optical examination of minerals.

Nature of Light.

To explain the phenomena of light, it is convenient to assume that the space separating the atoms and molecules of ponderable matter is occupied by a medium which is susceptible to disturbances and capable of transmitting these disturbances in the form of wave-motion. This medium, the so-called "æther," is so highly attenuated that its existence cannot be demonstrated, or its properties studied, by the ordinary methods applied to the study of ponderable matter.

According to the wave theory of light, this imponderable æther pervades all space, and light is propagated through it by transverse wave-motion in a manner analogous to that by which wave disturbances are propagated in water. Two waves of water whose crests and troughs coincide, combine additively to produce a wave of greater amplitude as shown in fig. 62, the amplitude being doubled if the waves are equal. If, on the other hand, the crest of one wave coincides with the trough of another, the amplitude is diminished, as shown in fig. 61, and becomes zero if the waves are equal, in which case the two waves annul each other. This phenomenon of the union of vibratory

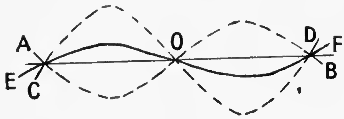

FIG. 61.—Wave motion; opposing waves resulting in diminished amplitude.

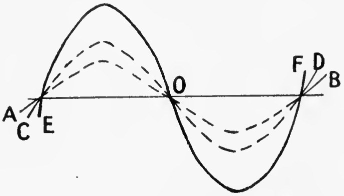

FIG. 62.—Wave motion; supporting waves resulting in increased amplitude.

effects in wave movement is known as *interference*, and explains the fact that two waves of light can unite to strengthen or nullify each other according as the crest of one coincides with the crest or the trough of the other. Two waves of light of equal length and amplitude destroy each other, and yield darkness, if the crest of one coincides with the trough of the other. This principle of interference is of great importance in explaining the action of crystals under the microscope, as will be seen below.

The length of a light wave is extremely small, and varies for different colours. White light is compounded of lights of different colours, as can be shown by its decomposition on allowing it to traverse a prism, when a spectrum is obtained. At one end of the spectrum is the least refracted red light, made up of longer waves. The refrangibility increases as the wave length diminishes through orange, yellow, green, and blue to violet, violet being the colour of greatest refrangibility and shortest wave length. The wave lengths of the different colours of the spectrum vary from 0·000768 millimetres for red light to 0·000382 millimetres for violet light.

Substances can be divided into two classes according to the way in which they affect a ray of light, by virtue of the influence of their molecular structure upon the æther which permeates them. One of these classes is named *isotropic* or singly refracting, the other *anisotropic* or doubly refracting. Before we go on to study the difference in behaviour between these two classes of substances, it will be convenient to define briefly the difference between ordinary and polarized light.

Ordinary and Polarized Light.

To explain the phenomena of ordinary light, it is convenient to regard it as being due to vibrations of æther particles in all directions at right angles to the direction of propagation. Thus fig. 63 represents a ray of ordinary light in which the direction of propagation is at right angles

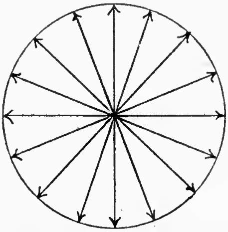

FIG. 63.—Representing vibrations of ordinary light in all azimuths at right angles to direction of propagation.

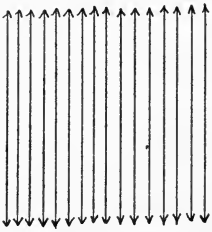

FIG. 64.—Representing vibrations of polarized light restricted to one azimuth.

to the plane of the paper. The vibrations in such a ray are not limited to any one direction in the plane of the paper, but take place in all possible directions in this plane. When the direction of vibration is restricted, so that instead of taking place in all directions at right angles to the line of propagation, they take place in one direction only, as represented in fig. 64, the light is said to be polarized.

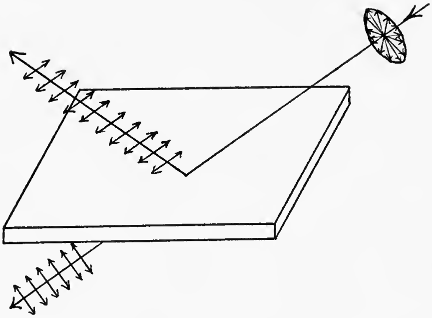

FIG. 65.—Polarization by reflection and refraction.

Polarized light can be obtained from ordinary light in various ways: (1) by reflection (fig. 65), as from a plate of glass, at a certain angle which varies with the nature of the substance, and which is known as the angle of polarization (for crown glass this angle is about 56½°); (2) by double refraction accompanied by partial absorption, as by transmitting light through a suitably cut plate of a strongly pleochroic mineral such as tourmaline (fig. 66); (3) by using a nicol prism (see p. 40). Of these methods, the most efficient is that involving the application of a nicol prism; but pleochroic plates are useful. For an explanation of pleochroism, see p. 52.

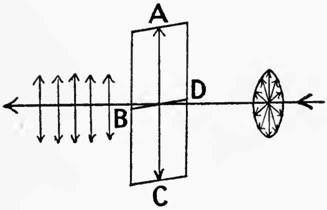

FIG. 66.—Polarization by absorption.

Isotropic or singly-refracting substances.

Amorphous (*i.e.* non-crystalline) substances, such as air, most liquids, and unstrained glass, receive and transmit light rays of normal incidence along any direction as single rays, without altering the vibration-direction of the ray. Ordinary cubic minerals, such as fluorite and rock-salt, act in the same way. The velocity of light changes on entering a substance of this class, and refraction takes place if the ray falls on the limiting surface obliquely; but it pursues its course as a single ray. This inability of amorphous and cubic substances to disturb the singleness of rays of light, arises from the fact that the æther which permeates them has the same properties in all directions. Hence these amorphous and cubic substances are said to be isotropic or single refracting. For any direction of propagation in an isotropic substance, the transmitted ray can vibrate in all azimuths. Therefore, after a ray of ordinary light of normal incidence has traversed a cubic crystal, it still has the properties of ordinary light; and a ray of polarized light of normal incidence traverses a cubic crystal as a single ray in all directions, generally without any change of its vibration-direction.

Refractive index.

The phenomenon of refraction is well exemplified by the familiar bent appearance of a stick when it is partly immersed in water and held in an oblique position.

When light is refracted on passing from one medium to another, as from air into water, the extent of the refraction depends on the difference between the velocities of light in the two media. Let the line *SE* (fig. 67) represent a surface of water, the line *AO* a beam of light in air passing into water at the point *O*. *VOL* is the normal, *i.e.* a line at right angles to the water surface.

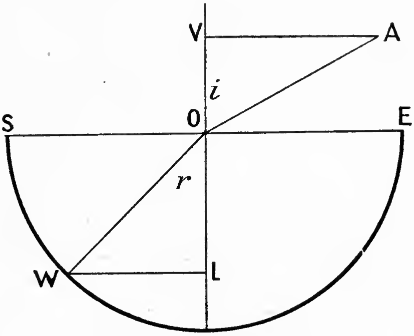

FIG. 67.—Refractive index.

On entering the water the light travels more slowly, and the beam *AO* is therefore bent towards *OL*. If the direction of the beam *AO* be changed, the direction *OW* will also change, but for all directions, the ratio *AV*/*WL*, *i.e.* the ratio of the sine of the angle of incidence (*AOV*) to the sine of the angle of refraction (*WOL*), is constant, and is called the *refractive index*. Hence the rule that *the ratio of the sine of the angle* *of incidence to the sine of the angle of refraction is the refractive index of a substance.* This ratio has reference to air as the standard. Thus for water at ordinary temperature the refractive index is sin i/sin $r = 1{\cdot}333$. The refractive index of minerals is as a rule much higher than this, the values ranging from 1·35 in cryolite up to 3·02 in cinnabar.

When light passes from an optically rarer into an optically denser medium, the ray is bent towards the normal; and for all angles of incidence, the light can enter the denser medium. As will be seen from a consideration of fig. 68, however, it is otherwise when light passes from the denser into the rarer medium, as from water into air. Under these conditions there is a certain limiting angle of incidence for which the angle of refraction is 90°. When the angle of incidence exceeds this limiting value, as in the ray *BO* in the figure, the light is unable to get into the rarer medium and is totally reflected from the surface. This limiting angle of incidence is called *the critical angle.* Its magnitude depends on the relative refractive powers of the two media concerned. For water and air the critical angle is about 48½°. For diamond and air it is about 24½°. It is to this fact that a well-faceted diamond owes its extraordinary brilliance.

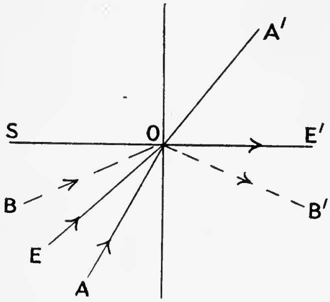

FIG. 68.—Total reflection.

Dispersion.

The refractive index of light varies with the wave length; it is greater for blue rays than for yellow, and greater for yellow than for red. In consequence of this fact, white light is to some extent decomposed into its constituent colours in traversing a transparent mineral, and this phenomenon is called *dispersion.*

It is to dispersion that the so-called "fire" of certain gemstones, notably that of the diamond, is due. The dispersive power of the diamond contributes greatly to the value of this mineral as a gem, and is a feature by which it can be distinguished from quartz and some other transparent stones that lack "fire" owing to their low dispersive power.

A high dispersive power is a desirable feature in gemstones, to which it adds great beauty. For some optical purposes, however, a high degree of dispersion is undesirable. In making spectacles, for instance, quartz (more commonly known as "pebble" among opticians) is exceptionally well suited on account of its low degree of dispersion. In fluorite (fluorspar), the degree of dispersion is extremely low; and fluorite is for this reason used with great advantage in the manufacture of apochromatic lenses.

Anisotropic or doubly-refracting substances.

For crystals other than those of the cubic system, the disposition of the molecules is not the same for all directions, and in consequence of this the properties of the pervading æther are not the same for all directions. Hence the physical properties of such crystals vary with the direction, and these crystals are said to be anisotropic.

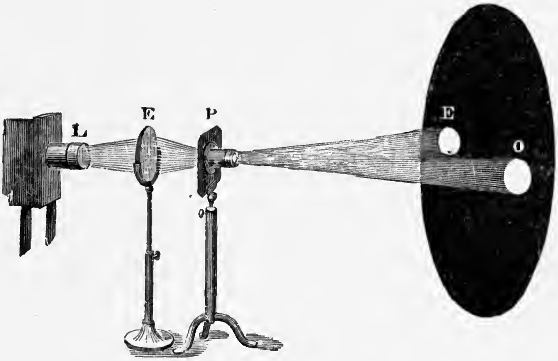

FIG. 69.—Double refraction by cleavage rhomb of calcite. (From Tyndall's "Light").

When light is transmitted through an anisotropic crystal along a direction which is not an axis of optical symmetry (and this is the general case for such crystals), it cannot continue as a single ray, but necessarily becomes resolved into two rays, the vibration-directions of which correspond to the axes of maximum and minimum elasticity for that particular line of transmission. It is clear that, since refractive index depends on velocity, the refractive indices of these two rays will be different, and that as a rule they will traverse different paths.

Hence, corresponding to any given incident ray, there are, for non-cubic or anisotropic crystals, generally two rays, the vibration-directions of which are at right angles to each other. These two rays are transmitted through the crystal with different velocities, and are therefore as a rule differently refracted. It is for this reason that anisotropic substances are said to be *doubly refracting* or *birefringent.*

The phenomenon of double refraction is exceptionally well shown by calcite, in which the difference between the refractive indices for the two rays is very pronounced. If a transparent crystal or cleavage rhomb of calcite is held over an ink spot or other mark, a double image is seen, due to double refraction. The production of two beams of light by sending a single beam through a piece of calcite is shown in fig. 69.

The Nicol prism.

In connection with the phenomenon of double refraction it is convenient to consider the nicol prism, which is used as a means of obtaining polarized light, and which is an indispensable part of a petrological microscope such as is used in determinative mineralogy.

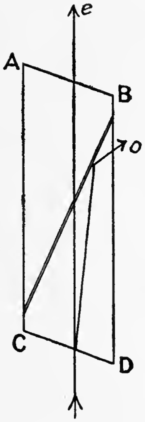

FIG. 70.—Nicol prism.

A nicol prism is made from a cleavage rhomb of the clear and transparent variety of calcite known as Iceland spar. A rhomb about three times longer than broad is used. This is cut diagonally; the two halves are then cemented together by a layer of Canada balsam; and the end faces are slightly ground so as to make them at right angles to the plane of section, as shown in fig. 70, in which the plane of section lies along the shorter diagonal.

Light incident at the end of such a prism is resolved into two rays by double refraction. The more refracted of these two rays (the ordinary ray) is totally reflected from the plane of section because its angle of incidence exceeds 69° 4′, the critical angle for this ray. The other ray (the extraordinary ray) falls on the plane of section at an angle less than the critical angle; it is consequently able to traverse the layer of Canada balsam and emerges at the other end of the prism. Since the two rays resulting from double refraction are both polarized, with their vibration-directions at right angles to each other, a nicol prism, by eliminating one of these rays and allowing the other to pass, yields a beam of polarized light.

In a polarizing microscope there are two nicol prisms, one below the stage (the polarizer), and another above the stage (the analyser). When the two nicols have their vibration-directions at right angles to each other, the light transmitted by the polarizer cannot pass through the analyser, since it traverses the latter as ordinary rays which are totally reflected. In this position the nicols are said to be crossed. By examining minerals between crossed nicols we can tell whether they are isotropic or anisotropic; and if anisotropic, it is generally possible to ascertain whether the fragments are those of a uniaxial or a biaxial mineral. This knowledge of the optical behaviour of fragments often affords evidence of prime value in determinative work on economic and other minerals.

The polarizing microscope.

The polarizing microscope is indispensable in the study of the optical properties of minerals. Its chief features may be described with reference to fig. 71, which represents a very useful form of a microscope

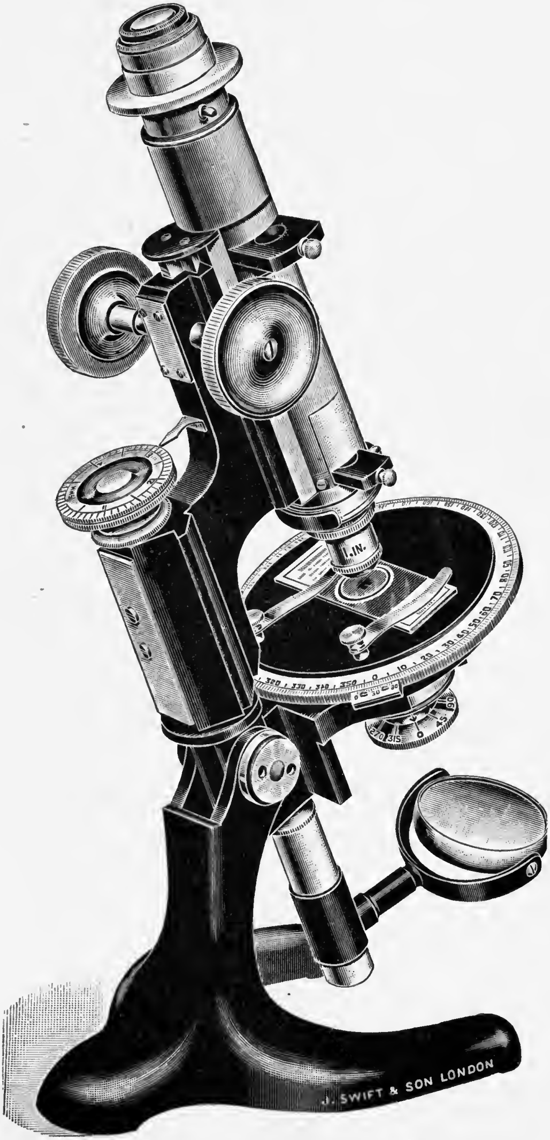

FIG. 71.—Polarizing microscope (rotating-stage pattern).

with a rotating stage, manufactured by Messrs. Swift and Son of London.

The coarse adjustment for focusing is effected by a rack and pinion arrangement. The fine adjustment is made by means of a micrometer screw, the milled head of which is divided to read to 0·01 mm. A differential screw giving readings of 0·01 mm. can be fitted if required.

The eye-piece is provided with two cross-lines which intersect at right angles in the centre of the field, and is slotted for the insertion of a micrometer, a gypsum plate, or a quartz wedge.

The objectives are fitted on a centring nose-piece ; a convenient form is one that will carry three objectives, preferably a 1-inch, a $\frac{1}{4}$-inch, and a $\frac{1}{12}$-inch (oil immersion). With such an arrangement the magnification can be altered with a minimum of trouble, by simply rotating the nose-piece.

The polarizing apparatus consists of two nicol prisms, one placed below the stage (the polarizer), and one above the stage (the analyser). Two analysers are provided ; one of these fits in a slot at the lower end of the microscope tube, so that it can be moved in or out as required ; this analyser is fixed with its short diagonal (*i.e.* its vibration-direction) in a north and south direction in relation to the observed field of the microscope. A second analyser, at the top of the tube, is provided for use with the Bertrand lens ; it rests on a divided circle and clicks when in the crossed position with the polarizer.

The polarizer can be rotated, and should click when in a crossed position with the analyser. The crossed position is the one mostly required for optical observations, and is recognized by the fact that it is the position of total or maximum extinction of light when the field is occupied by an isotropic body. The polarizer is mounted on a hinged fitting, so that it can be swung out of the field, independently of the condenser, when not required for use.

A Bertrand lens, for the observation of interference figures, is fitted in a slot through the upper portion of the tube, and can be moved in and out as required.

A sub-stage condenser with a screw-focusing adjustment is provided. This is furnished with centring screws for adaptation according to the requirements of the objective, and can be swung out of the field, independently of the polarizer, when not required for use. The top lens of the condenser can be pushed aside by means of a small lever, when not required for obtaining interference figures or for special illumination.

Below the condenser is an iris diaphragm which is useful for the observation of refractive indices by the shadow and bright-line methods and also for controlling illumination. Immediately below this diaphragm is a rotating cell which accommodates stops for oblique illumination, and which can be rotated so that light from any azimuth can be obtained.

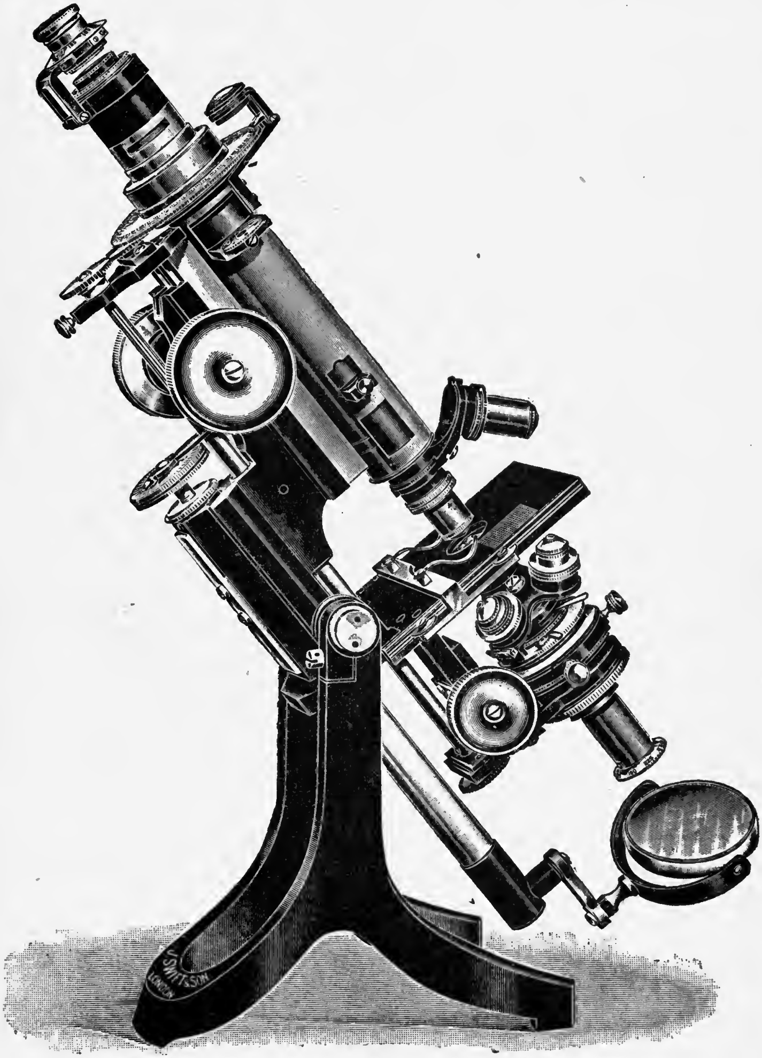

FIG. 72.—Polarizing microscope (fixed-stage pattern).

The mirror should be free to move, but not too easily, so that stable illumination can be readily obtained.

The frame of the instrument is hinged at about the level of the stage, so that the axis of the microscope can be inclined if necessary.

More useful in many ways is the microscope in which the nicols rotate instead of the stage; though this type is rather more expensive. Different makers adopt different methods for rotating the nicols; fig. 72 shows a modern type of one of these instruments as manufactured by Messrs. Swift and Son.

Interference colours.

When ordinary (non-polarized) white light falls with normal incidence on a thin plate of a flawless and colourless crystal, and traverses the plate along a direction of double refraction, the plate exhibits the same optical effect when examined by means of a nicol prism as it does when examined in ordinary light. If, however, the incident light is polarized, the conditions are then favourable for the production of coloured light when the doubly refracted components of the polarized beam are brought back into one and the same plane of vibration by means of a nicol prism or other polarizing agency.

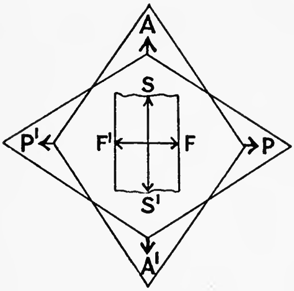

FIG. 73.—Doubly refracting crystal plate between crossed nicols (extinction position).

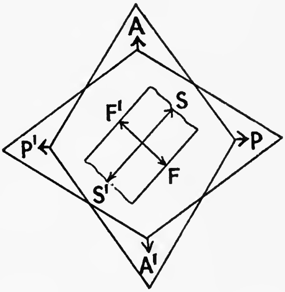

FIG. 74.—Diagonal position of doubly refracting crystal plate between crossed nicols, resulting in illumination.

It is for use in this way that the polarizer and analyser of a mineralogical microscope are mounted below and above the stage respectively. Their action in producing coloured light when a thin crystal plate is examined between crossed nicols may be briefly explained as follows: In fig. 73 let PP' and AA' represent the vibration-directions of the polarizer and analyser respectively, FF' and SS' the vibration-direction of a crystal plate. When a polarized ray vibrating along PP' passes into the plate, it traverses the plate with its vibration-direction unaltered, and is therefore rejected by the analyser. This is a position of extinction, for which the vibration-directions of the crystal plate coincide with those of the polarizer and analyser. For other positions, as shown in fig. 74, the ray from the polarizer is resolved into two rays, one of which vibrates along *FF′* and the other along *SS′*. On entering the analyser, each of these two vibration-directions is again resolved into two components, one of which passes through the analyser as an extraordinary ray and emerges vibrating along *AA′*, whilst the other is not allowed to pass, since it enters the analyser as an ordinary ray.

The two rays produced by double refraction in the crystal plate traverse the plate with different velocities ; hence on emerging from the plate, the slow ray (*SS′*) will be behind the fast ray (*FF′*). If white light is used, and if the plate is of suitable thickness, so that the amount of retardation corresponds to a difference of one wave length of a certain colour (or half a wave length if the nicols are parallel), rays of this colour will be destroyed by interference, and coloured light will consequently be produced. The colours thus produced by the action of thin crystal plates on polarized white light are known as interference colours, and, judged in relation to the thickness of the plate, they indicate the degree of birefringence in the mineral.

The interference colours of thin crystal plates in polarized light closely resemble the colours of Newton's rings, and like the latter are divisible into three or four orders of distinct colours. The more distinctive of these colours, and the relative retardations or phase differences in millionths of a millimetre corresponding to them for the 1st, 2nd, 3rd, and 4th orders are as follows :

Phase difference in millionths of a mm.		Colour between crossed Nicols.	Colour between parallel Nicols.
First order	40	Iron-grey.	White.
	259	White.	Light red.
	332	Bright yellow.	Blue.
	551	Deep red.	Yellowish green.
Second order	575	Violet.	Greenish yellow.
	664	Sky-blue.	Orange.
	747	Green.	Light carmine red.
	910	Pure yellow.	Indigo.
	998	Bright orange red.	Greenish blue.
Third order	1128	Light bluish violet.	Yellowish green.
	1258	Greenish blue.	Flesh coloured.
	1376	Bright green.	Violet.
	1534	Carmine red.	Green.
Fourth order	1682	Greyish blue.	Greenish yellow.
	1744	Bluish green.	Lilac.
	1811	Light green.	Carmine.
	2007	Whitish grey.	Bluish grey.

The most striking colours are those of the first and second orders. The colours of the third and fourth orders are progressively less distinctive, and merge into the quite indistinct colours of the higher orders, which are whitish in appearance due to mixing of the colours. These colours may be studied with advantage by examining a quartz wedge (see p. 62) between crossed and parallel nicols. Quartz is a mineral of low birefringence ($\epsilon - \omega = 0{\cdot}009$) and gives the first order yellow in plates about 0·04 mm. thick. Rutile is a mineral of extremely high birefringence ($\epsilon - \omega = 0{\cdot}287$), and its colours may exceed those of the fourth order in plates not more than 0·01 mm. thick. Minerals of extremely high birefringence therefore cannot be expected to show bright colours in the sections and fragments usually examined; and even when these fragments are suitably cut or broken to show colour, the colour bands are as a rule very closely crowded.

The table on p. 47 will serve to show the range of variation in birefringence and interference colours among minerals. The second column gives the birefringence, the third column the highest colours to be seen when sections having a thickness of 0·04 millimetres are examined between crossed nicols.

It will be seen from a consideration of the table that minerals with a birefringence of 0·050 and upward show distinctive colours only in very thin plates. Moreover the higher the birefringence the thinner the plate requires to be. First and second order colours are seen in fairly broad bands in quartz grains measuring as much as 0·5 mm. in diameter; but this is a sure sign of low birefringence. Grains of monazite or zircon of this size usually show no appreciable interference colour, and give only high-order whites.

The student should familiarize himself with the colour effects in sections and grains of variable thickness, by examining known specimens. He should also study the effect of cleavage and parting in regularizing the interference effects in microscopical fragments where these planes of separation determine the form of the fragments.

Uniaxial crystals.

In any crystal of the trigonal, tetragonal, and hexagonal systems, the principal axis (*i.e.* the threefold, fourfold, and sixfold symmetry-axes respectively) is a unique direction in the crystal. All directions equally inclined to it have the same birefringence values, and generally the same optical values in other respects. It is because of their possession of this unique direction, which is usually one of complete optical symmetry,

Mineral.	Birefringence, *i.e.* the difference between the maximum and minimum refractive index values.	Colour seen in plates about 0·04 mm. thick.
Apatite	0·003	Bluish grey.
Pyromorphite	0·006	Yellowish white.
Orthoclase	0·007	Pale yellow.
Beryl	0·007	,, ,,
Quartz	0·009	Bright yellow.
Corundum	0·009	,, ,,
Chrysoberyl	0·009	,, ,,
Celestite	0·009	,, ,,
Rhodonite	0·010	Orange-yellow.
Gypsum	0·010	,, ,,
Vanadinite	0·010	,, ,,
Zincite	0·010	,, ,,
Topaz	0·011	Orange.
Andalusite	0·011	,,
Barite	0·012	Red.
Kyanite	0·016	Sky-blue.
Phenakite	0·016	,,
Scheelite	0·016	,,
Amblygonite	0·018	,,
Tourmaline	0·020	Greenish blue.
Alunite	0·020	,, ,,
Mimetite	0·020	,, ,,
Spodumene	0·021	Yellowish green.
Hemimorphite	0·022	Yellow.
Anthophyllite	0·024	Orange.
Crocidolite	0·025	Orange-red.
Borax	0·026	Red.
Tremolite	0·027	Reddish violet.
Colemanite	0·028	Indigo.
Realgar	0·030	Blue.
Phlogopite	0·034	Yellowish green.
Muscovite	0·041	Dull purple.
Pyrophyllite	0·041	,, ,,
Monazite	0·045	Light green.
Talc	0·050	Whitish grey.
Zircon	0·062	Greys and whites of the higher orders.
Cassiterite	0·096	
Strontianite	0·152	
Calcite	0·172	
Malachite	0·200	
Magnesite	0·202	
Pyrargyrite	0·203	
Chalybite	0·241	
Hæmatite	0·250	
Nitratine	0·250	
Proustite	0·270	
Cerussite	0·274	
Rutile	0·287	
Sulphur	0·290	
Cinnabar	0·347	

that crystals of the trigonal, tetragonal, and hexagonal systems are called *uniaxial crystals*.

In a uniaxial crystal, all directions of transmission excepting the optic axis are directions of double refraction. The two rays produced by double refraction have their vibration-directions at right angles to one another, one of these vibration-directions in all cases being at right angles to the optic axis, the other vibrating in the principal plane and varying its vibration-direction with the direction of propagation. The former is called an ordinary, the latter an extraordinary ray.

The refractive index of the ordinary ray is constant, but that of the extraordinary ray varies, reaching its maximum or minimum when its direction of propagation is at right angles to the optic axis. The refractive index of the extraordinary ray (ϵ) may be higher or lower than that of the ordinary ray (ω); if higher the crystal is said to be optically positive, if lower it is said to be optically negative.

A thin plate of a uniaxial crystal cut at right angles to the optic axis acts towards a beam of parallel polarized rays of normal incidence in the same way as a section of an isotropic substance. When rotated between crossed nicols it remains dark in all azimuths. Towards a beam of convergent polarized rays, however, it acts very differently from an isotropic section, since the obliquely incident rays are doubly refracted. Under these conditions, with nicols crossed, it yields a characteristic figure, whereas a section of an isotropic substance is quite inert.

This figure, which is known as a uniaxial figure, consists of a black cross with concentric rings (fig. 75). The production of a uniaxial figure is readily understood if we map out the vibration traces of the rays of the convergent beam as shown in fig. 76. The rays lying in the planes *AA* and *PP* have vibration-traces coinciding with those of the analyser and polarizer; hence these rays suffer extinction and produce a black cross as shown in fig. 75. The rays in the intervening quadrants suffer double refraction, the amount of which increases from the centre outwards as the rays become more oblique. If monochromatic light be used, a series of black rings is obtained, as shown in the figure, the outer rings being closer together than those near the centre of the figure. If white light be used a series of coloured rings is produced corresponding to those seen in a quartz wedge between crossed nicols in parallel polarized rays.

If the nicols are placed in the parallel, instead of in the crossed position, a luminous cross takes the place of the black cross; but the rings remain, though they change their position slightly.

When such a uniaxial section is rotated between crossed nicols, the cross and rings remain undisturbed, owing to the fact that all directions at right angles to the principal axis have the same optical value.

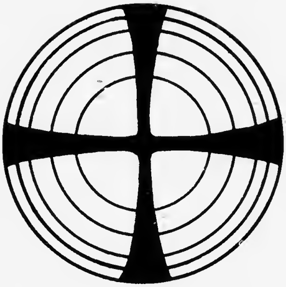

FIG. 75.—Uniaxial figure.

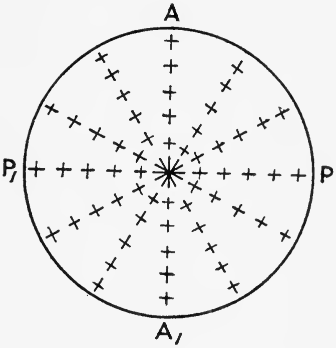

FIG. 76.—Vibration-traces (uniaxial).

If the section is not exactly at right angles to the optic axis, we may still get a good uniaxial figure, but it will be excentric or partial, and the point of the intersection of the black cross will rotate round the centre of the field. A little consideration will make it clear that when the point of intersection of the cross falls outside the field of view, only one bar at once will be visible, and on rotating the stage the bars will move across the field without developing any curvature. This fact usually permits a partial uniaxial interference figure to be distinguished from a partial biaxial figure.

Biaxial crystals.

In orthorhombic, monoclinic, and triclinic crystals there is no symmetrical optic axis such as that possessed by uniaxial crystals. There are, however, in each crystal belonging to these systems, two directions which have some features resembling those of the optic axis of a uniaxial crystal; but they are not axes of symmetry. We may therefore distinguish them from the uniaxial optic axis by calling them unsymmetrical optic axes. Because there are two of them in each crystal, crystals of the orthorhombic, monoclinic, and triclinic systems are called *biaxial crystals*.

The optic axes of biaxial crystals are inclined to one another, and the acute angle between them is called the *optic axial angle*; this angle is usually a constant for any given mineral, but in some minerals of variable composition it varies in a definite way with the composition.

The line bisecting the acute angle made by the intersection of the two optic axes in a biaxial crystal is called the *acute bisectrix* ; and the line at right angles to this, which bisects the obtuse angle, is called the *obtuse bisectrix* (broken lines in fig. 77). These are two important directions, because they are the vibration-directions of the fastest and slowest rays that the crystal can transmit. In a biaxial crystal, then, we get the maximum birefringence in rays that are propagated along a direction at right angles to the plane containing the optic axes, *i.e.* the *optic axial plane.* If the rays whose vibration-directions coincide with the acute bisectrix have the greatest refractive index, the crystal is said to be optically positive. If, on the other hand, the rays whose vibration-directions coincide with the acute bisectrix have the least refractive index, the crystal is said to be optically negative.

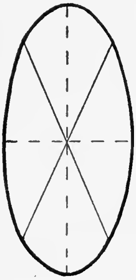

FIG. 77.—Bisectrices.

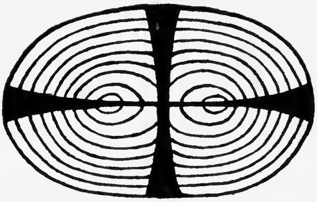

FIG. 78.—Biaxial figure (normal position).

In biaxial crystals, the maximum refractive index is usually represented by the letter γ, and the minimum by the letter α ; a third value, that for rays whose vibration-directions are normal to the optic axial plane, is represented by the letter β. When, therefore, one refers in an unqualified way to the birefringence of a biaxial crystal, one refers to the maximum value represented by the difference $\gamma - \alpha$; but it should be remembered that the birefringence effect due to this maximum value is only seen in sections and fragments that are parallel to, or approximately parallel to, the optic axial plane. Just as in a uniaxial crystal a section normal to the optic axis shows no birefringence in parallel rays although the maximum birefringence ($\epsilon - \omega$ or $\omega - \epsilon$) of the mineral may be very high, so in biaxial crystals the visible effect in any given section may be very low although the value $\gamma - \alpha$ may be high. It is important that this fact should be kept in mind in diagnosing a mineral by optical tests ; and where a mineral has a good cleavage, the relation of this cleavage to the optical orientation of the crystal should be studied.

When a section or cleavage plate at right angles to the acute bisectrix in a biaxial crystal is examined in a beam of convergent rays between crossed nicols, it shows a characteristic figure (biaxial interference figure, fig. 78), which is readily distinguished from a uniaxial figure. The vibration-traces for the rays of a convergent beam in such a plate are shown in fig. 79, in which the black dots represent the optic axes. With the nicols crossed, the vibration-directions of the rays lying parallel to and at right angles to the optic axial plane coincide with those of the analyser and polarizer, and along these two directions we get extinction. The two bars of the cross are dissimilar, however, and in this respect differ from the uniaxial cross.

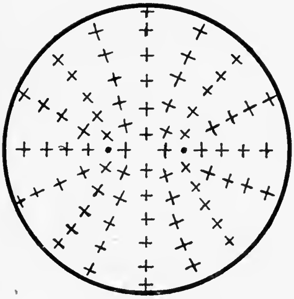

FIG. 79.—Vibration-traces (biaxial).

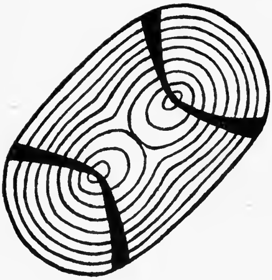

FIG. 80.—Biaxial figure (diagonal position).

There is also a difference in the isochromatic rings. Instead of the circular rings of the uniaxial figure, we get, in a plate of suitable thickness, a set of oval rings around the point of emergence of each of the optic axes. Embracing these are larger curves that sweep round both axes as shown in fig. 78. When the degree of birefringence is low, it is only in comparatively thick plates that the figures show two independent series of rings around the optic axes. By thinning the plate the relative retardation is reduced; the independent sets of rings consequently diminish in number, and for very thin plates no coloured rings are seen at all, but only the black cross on a white or grey ground. These changes can be studied very conveniently in cleavage plates of muscovite mica of different thicknesses, since these plates are biaxial, and the cleavage is practically normal to the acute bisectrix.

Unlike a centric uniaxial figure, a centric biaxial figure does not remain unchanged when the crystal plate is rotated between crossed nicols. When rotated through 45° from the position described above, the bars of the biaxial cross are broken, and form two hyperbolic curves, the apices of which pass through the optic axes as shown in fig. 80.

On moving through 90°, however, the cross is restored. If the observations are made with parallel instead of crossed nicols, the black cross and hyperbolic curves give place to a luminous cross and curves.

In sections that are not normal to the acute bisectrix, an excentric biaxial figure is obtained. In such a partial figure when only one bar is seen at once, this can usually be distinguished from a uniaxial bar by the fact that it does not maintain parallelism of position with itself and the vibration-directions of the nicols in its movement across the stage, but curves round in a manner which furnishes quite a contrast with the movement of a typical uniaxial bar. Much caution is necessary, however, when dealing with a partial biaxial figure if the axial angle is very small.

A section normal or nearly normal to one of the optic axes of a biaxial crystal shows in a convergent polarized beam between crossed nicols only a single bar with a series of concentric rings (see fig. 81). This bar moves round as the section is rotated, and usually shows a slightly gibbous shape on rotation, the hump being directed towards the acute bisectrix. Such a figure is well seen in a cleavage fragment of a green epidote; and it is also seen to advantage in fragments of well-crystallized sugar. These sections normal to an optic axis in a biaxial crystal have the peculiar property of showing no extinction between crossed nicols when examined in a beam of parallel polarized rays, in consequence of the depolarizing action of such sections on a polarized beam. The absence of extinction effects makes it possible to pick out these sections very readily when making the ordinary observations in parallel rays between crossed nicols.

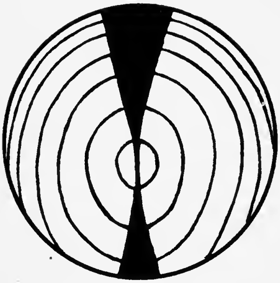

FIG. 81.—Biaxial figure for a section at right angles to an optic axis.

In making observations on the optical figures of microscopic fragments in a convergent polarized beam with nicols crossed, the observations should be repeated on many fragments, and the results interpreted in the light of any observations that may have already been made on the presence or absence of cleavage and on extinction effects in parallel polarized rays.

Pleochroism.

A homogeneously coloured isotropic (cubic) crystal shows no variation of colour when ordinary light traverses it in different directions, *i.e.* there is no change of absorption with change of direction. Coloured anisotropic crystals, on the other hand, show variation of absorption with change of direction, and they sometimes show a marked change in colour from this cause when rotated in a beam of ordinary light. This phenomenon is known as pleochroism. The presence or absence of pleochroism in a mineral, and its nature when present, are easily observed, and often furnish useful evidence in determinative work.

In a uniaxial crystal, the extreme tints are seen along and at right angles to the optic axis, as is well shown by suitably cut plates of tourmaline and sapphire. Tourmaline is a rather exceptional case; for a plate of it is usually opaque to rays incident normally on the basal plane (ordinary rays), though it is fairly transparent to extraordinary rays, and therefore to rays of ordinary light incident normally to the prism face. When a pleochroic uniaxial crystal is held with its optic axis along or at right angles to the line of sight, it exhibits no colour change on rotation about this axis.

In biaxial crystals, on the other hand, there is no axis of pleochroic symmetry. A pleochroic orthorhombic crystal usually exhibits colour variation when rotated with any of the three axes of symmetry at right angles to the line of sight. This is shown very well by examining a crystal of cordierite (iolite), or better still a cube cut from the crystal; the colour seen through the basal pinakoid is blue, whereas the colours seen through the other two pinakoids are bluish green and yellowish green.

When examined in a convergent beam of ordinary rays, plates of certain pleochroic crystals show characteristic absorption figures. These as a rule are of little significance in uniaxial minerals; but in certain biaxial minerals they yield striking and easily-observed effects. "Amber" mica (brown phlogopite) is quite the best instance of such a mineral. This variety of mica usually shows a fairly pronounced axial angle; and if a sufficiently thick cleavage plate be held close to the eye and examined against the sky, it shows a very good biaxial absorption figure due to pleochroism, both optic axes being visible (see fig. 82). By tilting the plate so that one optic axis only lies along the line of sight, the absorption figure for one optic axis only is seen. The latter effect is well shown in cleavage plates of epidote; but these are not so readily obtained as are cleavage plates of mica. Various other minerals show these absorption figures very well, notably cordierite and andalusite, but as a rule, these require to be very carefully cut, and are rather expensive.

The above remarks on pleochroism refer, as already stated, to observations made by using ordinary light; and the colours thus observed when a crystal plate is examined in parallel rays of normal incidence, are known as *facial colours.* When seen along a direction of double refraction these facial colours represent the mixed colours arising from the absorption of two rays vibrating at right angles to each other.

If instead of using ordinary light, a beam of polarized light from a single nicol is allowed to pass through the crystal plate, the two colours of which a facial colour is composed are seen separately on rotating the nicol, and appear alternately with one another if the nicol is rotated so that its vibration-direction comes into coincidence first with one and then the other of the two vibration-directions in the crystal plate. These colours seen when a pleochroic crystal plate is examined in a beam of polarized light are called *axial colours.*

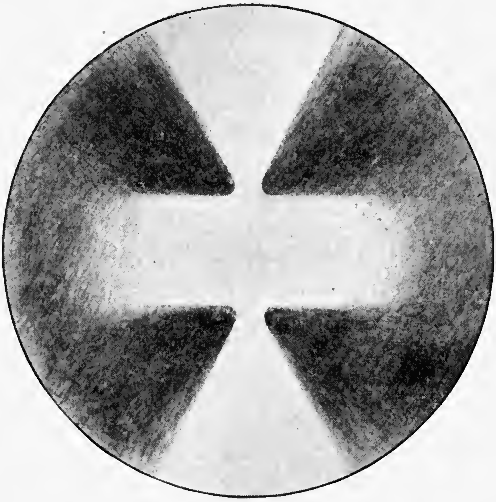

FIG. 82.—Biaxial absorption figure for brown phlogopite.

To observe axial colours it is usually necessary, but not invariably so, to use a nicol or a dichroscope (see below). One instance in which the reflection polarization of the plate itself suffices to show these axial colours is worthy of note. It is that of "amber" mica, which has already been referred to as giving a good biaxial absorption figure. A plate of this mineral shows axial pleochroism very well when it is rotated in an obliquely incident beam of ordinary light.

In making observations on axial colours by means of a nicol, it is immaterial whether the nicol is placed between the plate and the source of light or between the plate and the eye. Hence in using the microscope for the observation of axial pleochroism, either the polarizer or the analyser can be used, but not both. Examined in this way a plate of a pleochroic uniaxial crystal cut at right angles to the optic axis shows no change of colour (except in certain abnormal cases) when the polarizer is rotated under it, since in all azimuths the colour seen is that of the ordinary ray. All other sections show a change of colour, but the contrast of the two axial colours reaches its maximum in sections parallel to the optic axis, since it is in these sections that the extreme colour effect of the extraordinary ray is observed; and in a uniaxial crystal the pleochroism is the same for all plates parallel to the prism edge. Uniaxial crystals therefore yield two characteristic axial colours, one corresponding to the ordinary, and the other to the extraordinary ray; and it is for this reason that the pleochroism of uniaxial crystals has been called "dichroism," though by some writers the terms "dichroism" and pleochroism are used synonymously.

In biaxial crystals, the axial pleochroism is more complex, as might be expected. It has already been noticed that if a cube of cordierite, cut with its faces normal to the axes of symmetry, is examined in a beam of ordinary parallel rays, the face colour seen through each pair of faces differs from that seen through either of the other two pairs. When examined in a beam of polarized light, each of these colours is decomposed into two axial colours. Thus the basal pinakoid yields grey and blue, the front pinakoid yellow and blue, and the side pinakoid grey and yellow; so that there are three characteristic axial colours, viz., grey, yellow and blue, corresponding to vibration-directions along the acute bisectrix, the obtuse bisectrix, and the line normal to the optic axial plane, respectively. It is for this reason that the pleochroism of biaxial crystals has been called "trichroism." It is, however, neither necessary nor desirable to use the terms "dichroism" and "trichroism," especially as the pleochroism of many biaxial crystals is approximately of the "dichroic" type. The more general term pleochroism is preferable.

Instead of using a nicol to examine axial colours, we may, if the crystal plate is sufficiently large, use an ordinary cleavage rhomb of calcite. The rhomb should be long enough to produce a double image, and its ends can be rubbed down until they are at right angles to the rhombohedral edge. A dichroscope consists of such a rhomb of calcite mounted between two pieces of cork in a metal tube at one end of which there is a small square aperture (fig. 83). This slides into another metal tube which carries a small lens for focusing the images of the square aperture. The double image seen when a pleochroic plate is examined by means of the dichroscope shows both axial colours at once, so that the colours can be compared more effectively. The two images are seen side by side, without overlapping, as shown to the left of the figure.

Fig. 83.—Dichroscope.

The pleochroism of a uniaxial crystal is defined with reference to the axial colours corresponding to the rays of maximum and minimum refractive index, *i.e.* those seen in sections parallel to the optic axis. Thus we say of the pleochroism of tourmaline that $\omega > \epsilon$, meaning that the absorption of the ordinary ray is greater than that of the extraordinary ray; and in any given case the actual colours may be stated. The axial colours naturally vary with the colour of the crystal, but in all coloured tourmalines the expression $\omega > \epsilon$ holds true.

The pleochroism of a biaxial crystal is defined with reference to the three axial values corresponding to the rays of maximum, mean, and minimum refractive index respectively. Thus in cordierite γ=blue, β=grey, and α=yellow; or to state it more generally $\gamma > \beta > \alpha$.

Determination of refractive index.

To determine approximately the refractive index of transparent or translucent mineral fragments by means of a microscope, the grains may be mounted in liquids of known refractive indices, and the refractive powers of the grains compared with those of the liquids in which they are immersed. The following is a convenient set of liquids to use for this purpose:

	Refractive index.		Refractive index.
Water	1·33	Monobrombenzol	1·561
Ethylene chloride	1·450	Orthotoluidine	1·571
Olive oil	1·469	Aniline	1·583
Benzol	1·501	Bromoform	1·590
Cedar oil	1·505	Cinnamon oil	1·605
Monochlorbenzol	1·523	Moniodobenzol	1·619
Ethylene bromide	1·536	α-Monochlornaphthalene	1·635
Canada balsam	1·54	α-Monobromnaphthalene	1·655
Clove oil	1·544	Methylene iodide	1·740
Nitrotoluol	1·546	Sulphur in methylene iodide	1·8
Nitrobenzol	1·552		
Dimethylaniline	1·558		

When the crushed fragments of a mineral are immersed in one of these liquids, the degree of relief exhibited by the fragments serves to indicate roughly whether the refractive index of the mineral approximates to, or differs widely from, that of the liquid. A colourless transparent mineral fragment is practically invisible in a liquid having the same refractive index; but its borders are very well defined if the difference between the refractive indices is considerable; and if the difference is great, the shadow round the border of the grain becomes thick. This can be very well seen by mounting fragments of fluorite separately in ethylene chloride, cedar oil, and monobromnaphthalene; the fragments are very indistinct in ethylene chloride, well-defined in cedar oil, and show heavy borders in monobromnaphthalene.

It is of practical importance to bear this fact in mind when examining colourless fragments, and to vary the medium when there is reason to suspect the presence of fragments that are indistinct or invisible owing to the identity of their refractive index with that of the medium in which they are mounted. By taking advantage of this fact, moreover, one can sometimes blot out the chief constituent in a mixture of fragments of different minerals, and thereby render more distinct, and less liable to oversight, the fragments of some minor and less obvious constituent. When a few fragments of colourless fluorite are mixed with numerous fragments of quartz, for example, the fluorite might be overlooked if the mixture is mounted in cedar oil, but if mounted in nitrobenzol the quartz becomes practically invisible, and the few grains of fluorite are seen alone in strong relief.

To ascertain whether the refractive index of a fragment is higher or lower than the medium in which it is immersed there are two very useful tests, namely, the *shadow test* and the *bright-line test.* These two tests can be applied together by using the one-inch objective; but it is very useful to make the bright-line test separately, using the quarter-inch objective.

The *shadow test* is applied by using a low-power objective (a one-inch objective is very convenient) and observing the position of the shadow on the margin of a grain when the light is cut off from a portion of the field of the microscope by tilting the mirror, or by introducing one's finger between the mirror and the stage.

To apply the shadow test experimentally, have the sub-stage condenser in its normal, *i.e.* raised position. Mount a few fluorite fragments in cedar oil, and tilt the mirror or insert a finger under the stage so as to produce a shadow in the vicinity of the grain. It will be noticed that the edge of the grain adjacent to the shadow is bright whereas the edge remote from the shadow is dark. If the fluorite fragments ($n=1{\cdot}43$) are mounted in water ($n=1{\cdot}33$) instead of in cedar oil ($n=1{\cdot}50$), the positions of the dark and bright edges of the grain in relation to the position of the shadow are reversed, *i.e.*, the edge remote from the shadow is bright. Hence we get the following rule for the shadow test with the condenser in its normal (raised) position: *When the bright edge of the grain is remote from the shadow, the grain has a higher refractive index than the medium in which it is immersed; when the bright edge of the grain is adjacent to the shadow, the refractive index of the grain is lower than that of the medium.*

To apply the bright-line test, focus the edge of the grain, using the ¼-inch objective. Then alternately raise and lower the objective from the focused position, using the fine adjustment screw. It will be observed that there is generally a bright line visible along the border of the grain and that this bright line moves into the mineral or into the liquid as the objective is moved away from the focused position. When the fragment has a higher refractive index than that of the liquid, the bright line moves into the fragment when the objective is raised and into the liquid when the objective is lowered. If the mineral fragment has a lower refractive index than the liquid, the bright line moves into the liquid when the objective is raised and into the mineral when the objective is lowered.

The rule for the action of the bright line thus observed may be stated briefly and mnemonically as follows: When the objective is *lowered* from the focused position, the bright line moves into the medium of *lower* refractive index; when the objective is raised (moved *higher*) from the focused position, the bright line moves into the medium of *higher* refractive index. This test, which is known as the bright-line test, is a very useful one. The student should practise with known fragments in known media of different refractive values until he is satisfied that he can make trustworthy use of the test.

For isotropic minerals these observations on refractivity can be made with or without polarizer, and no change takes place when the polarizer is rotated. The same is true for sections of anisotropic crystals at right angles to an optic axis. For all other sections of anisotropic crystals there are two values for the refractive index, corresponding to the two vibration-directions of the crystal plate; and both values should be determined, the observations being made with the vibration-direction of the polarizer first along one and then along the other of the two vibration-directions.

The behaviour of a birefringent plate towards the shadow test when polarized light is used is well seen by examining cleavage fragments of calcite mounted in aniline. When the test is made with the short diagonal of the nicol parallel to the short diagonal of the cleavage plate, the result is the reverse of that obtained when the polarizer is rotated through 90°, due to the fact that the refractive index of the extraordinary ray for calcite is lower than that of aniline, whilst that of the ordinary ray is higher (fig. 84).

The observation of the bright-line test, as already described, can be applied to the bright border as seen in the shadow test, using a 1-inch objective. If the objective is raised, the bright border moves towards the medium of higher refractive index, and this affords a confirmatory test.

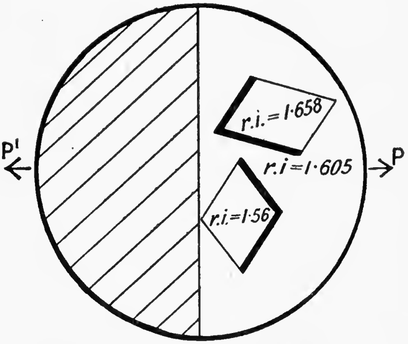

FIG. 84.—Shadow test with cleavage fragments of calcite.

In consequence of the fact that the dispersion of highly refractive liquids is usually much greater than that of minerals, colour fringes are frequently seen in the place of the bright and dark edges, when making the shadow test, if the refractive index of the fragment is near that of the liquid. If the refractive indices of the fragment and the liquid are the same for yellow light, the fragment will have a lower refractive index for blue light and a higher refractive index for red; and under these conditions, if the shadow test is applied, the edge of the grain adjacent to the shadow will be blue, and the edge remote will be orange-coloured or reddish.

These colour fringes indicate that the grain has approximately the same refractive index as the liquid in which it is immersed. To get a definite result from the shadow method under these conditions, monochromatic yellow light should be used in place of white light.

In determining the approximate refractive index of fragments or grains by mounting in various liquids, it is convenient to apply the shadow test first, using the 1-inch objective, then to confirm the result by applying the bright-line test, using first the 1-inch and afterwards the $\frac{1}{4}$-inch objective. The results should agree.

Minerals having refractive indices greater that 1·8 are best identified by other methods, since the media having refractive indices greater than 1·8 cannot be recommended for use.

Test for double refraction.

The test for double refraction in a section or fragment is its behaviour between crossed nicols. Amorphous substances, cubic crystals, and sections at right angles to the optic axis of a uniaxial crystal, suffer " extinction " between crossed nicols, and remain dark when the stage or the crossed nicols are rotated. Under these conditions sections of biaxial crystals cut at right angles to an optic axis are illuminated, and remain uniformly illuminated, when the stage or the crossed nicols are rotated.

All other sections of anisotropic crystals exhibit an alternation of extinction and illumination when rotated between crossed nicols, the light being extinguished when the vibration-directions of the crystal plate coincide with those of the nicols, and restored for other positions. The maximum degree of illumination is obtained when the vibration-directions of the crystal plate make an angle of 45° with those of the nicols. Hence four times in a complete rotation such a crystal section or fragment suffers extinction.

Angle of extinction.

If small crystals of tourmaline, apatite or zircon of typical prismatic shapes, such as are frequently found in sands and soils, are mounted in cedar oil and rotated between crossed nicols, it will be noticed that the light becomes extinguished when the prism edges of the crystals are parallel to one or other of the vibration-directions of the nicols. This is called *parallel* or *straight extinction*, and is shown by all uniaxial and orthorhombic crystals which are elongated along the prism edge. Prismatic sections and cleavage fragments of monoclinic crystals in which the sections or cleavages are at right angles to the plane of symmetry also show straight extinction (fig. 85).

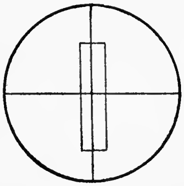

FIG. 85.—Parallel or straight extinction.

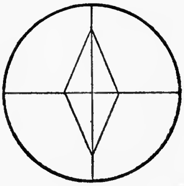

FIG. 86.—Symmetrical extinction.

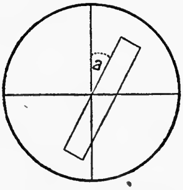

FIG. 87.—Oblique extinction.

Pyramidal cleavages in uniaxial crystals, such as rhomboidal cleavage plates of calcite, show extinction when the vibration-directions of the nicols bisect the angles of the rhomboidal plates. Basal sections of barite (orthorhombic) act similarly. This is known as *symmetrical extinction* (fig. 86).

Monoclinic and triclinic crystal sections and fragments with rectilinear edges usually do not show either straight or symmetrical extinction, and extinguish with the prism edges at some angle with the vibration-directions of the crossed nicols. This type of extinction is known as *inclined* or *oblique extinction,* and the angle less than 45° between the prism edge and these directions (as measured from the position of the cross-wires in the eye-piece) when the fragment is in the position of extinction, is called the *angle of extinction* (fig. 87).

A good example of a mineral showing oblique extinction is kyanite, the main cleavage plates of which show an extinction of about 30°. A second good cleavage exists in this mineral. Plates resting on this less perfect cleavage face show a practically straight extinction ; and though such plates are seldom obtained in cleavage fragments, it is well to be aware of their existence, as otherwise they are liable to be mistaken for those of some other minerals. Where, as in this instance, two good cleavages exist in a mineral, it is advisable to turn the fragment over, and if possible to determine the extinctions on both cleavage faces, since these extinction angles, considered with other optical evidence in relation to the cleavages, often furnish a ready means of identification.

Slow-ray and fast-ray vibration-directions.

We have seen that double refraction in a crystal plate is due to the production of two rays, the vibration-directions of which are at right angles to each other. These two rays travel through the crystals with different speeds, *i.e.* one of the rays is relatively slow and therefore more highly refracted ; the other is relatively fast and less highly refracted. We have also seen that in uniaxial crystals the extraordinary ray may be either more or less refracted than the ordinary ray, the crystal being positive in the former case and negative in the latter. It follows from this that a plate or wedge of a crystal of known optical sign can be cut with its edges parallel to the vibration-directions, in such a way that we know which is the fast-ray and which the slow-ray vibration-direction. Gypsum plates and quartz wedges cut in this way, and mounted on glass slips, are very useful as a means of ascertaining the fast-ray and slow-ray vibration-directions in sections and fragments of minerals.

Gypsum plates are of uniform thickness ; they show a first order red between crossed nicols, and the length of the plate is parallel to the fast-ray vibration-direction. Quartz wedges are usually made with the vibration-direction of the slow ray parallel to the length. For examining thin sections, quartz wedges are made showing only five or six orders of colour. For thicker plates, such as most cleavage plates, and for sand grains, a thicker wedge is useful, showing up to thirty orders or more. Such a thick wedge needs to be graduated, since, as already shown, the higher colours are mixed and indefinable. Graduation-marks at intervals corresponding to 1000 micro-millimetres of relative retardation are convenient (fig. 88).

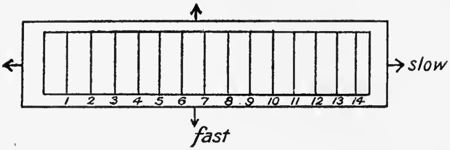

FIG. 88.—Graduated thick quartz wedge.

FIG. 89.—Quartz wedge.

Compensation tests.

When one doubly refracting plate is superposed on another so that the fast-ray vibration-direction of one coincides with that of the other, then the relative retardation produced by the lower plate will be increased as the light traverses the upper plate, the new relative retardation being the sum of the two separate values. In this case we get an additive effect, and if the superposed plates are examined between crossed nicols the order of the colour obtained will be heightened, but only definable if the total effect is sufficiently low.

If the two plates are superposed in such a way that the slow-ray vibration-direction of one coincides with the fast-ray vibration-direction of the other, the effect is subtractive and the relative retardation is diminished, the new resultant value being the difference between the two separate values. In this case the order of the colour will be lowered, and if the relative retardation of the two plates is the same, the result of superposition between crossed nicols will be darkness, since the effect of one plate will be exactly counterbalanced by that of the other. This position is known as the position of compensation, and the gypsum plate or quartz wedge is very useful for making the compensation test.

To illustrate the way of making this test, take a small crystal of zircon, and put it in the position of extinction between crossed nicols. Then turn the stage or the nicols through 45° into the position of maximum illumination, and insert a positive quartz wedge (slow-ray vibration parallel to the length) in the slot usually provided between the analyser and objective of the microscope. If the long edge of the wedge lies parallel to the prism edge, and the crystal is thin enough to show a definite interference colour, it will be noticed that the order of the colour increases, indicating that this is the additive position.

If now the crystal or polarizing system be turned through 90° so that the wedge is inserted at right angles to the prism edge, compensation will take place, and the order of the interference colours will get gradually lower until the position of complete compensation is reached, indicating that this is the subtractive position. This fact tells us that the vibration-direction of the crystal parallel to the prism edge is that of the slow ray, and since it is also that of the extraordinary ray, the crystal must be positive.

The experiment should also be tried with a small crystal of apatite or pale tourmaline, when it will be found that in this case the compensation takes place with the long edge of the positive quartz wedge along and not across the prism edge, showing that the crystal is negative. A mnemonic for this test is that the wedge is in + relation with the prism when the crystal is positive and in – relation when the crystal is negative.

This simple compensation test is therefore quite sufficient to tell us the optical sign of a uniaxial prism. The optical orientation of biaxial crystals is more complex, and other tests have to be applied to them to ascertain the optical sign (see below); but in all crystals where there is a prismatic cleavage, with straight extinction or a low extinction angle it is useful to apply the compensation test, in order to ascertain whether the direction of elongation of the cleavage fragment is that of the fast-ray or slow-ray vibration.

Measurement of birefringence.

After a little experience with the polarizing microscope, one gets familiar with birefringence effects, and can tell roughly at a glance whether fragments or sections have a low, moderate, high or extremely high birefringence, and this often provides useful data in determinative work. Occasionally it is convenient to measure approximately the degree of birefringence, and for this purpose a quartz wedge is very useful. The interference colour seen in a mineral section or fragment between crossed nicols depends on the extent to which the slow ray ha lagged behind the fast ray in its passage through the section. In traversing unit thickness of the section, the fast ray is retarded by an amount $v/v_1-1(=n_1-1)$, where v is the velocity in vacuo, v_1 the velocity of the fast ray in the section, and n_1 the refractive index of the fast ray. The slow ray, of velocity v_2, is retarded by an amount $v/v_2-1(=n_2-1)$. The difference between these two retardations is n_2-n_1, which we have already defined as the birefringence. In other words, birefringence is the relative retardation per unit thickness. Consequently in any section of thickness T the relative retardation is expressed by the equation $R=T(n_2-n_1)$; therefore $n_2-n_1=R/T$. In this equation, R can be found by the method of compensation with the quartz wedge as described above.

If the section is thin enough to show a definite interference colour, the relative retardation corresponding to the colour will be found on the scale of Newton's colours with corresponding phase differences such as that given on p. 45. If the colour is a white of the higher orders such as is frequently seen in grains and fragments, a thick graduated quartz wedge must be used. Having found the relative retardation in this way, the next thing to do is to measure the thickness of the section by means of a micrometer screw gauge (the fine adjustment of the microscope is usually provided with a screw gauge for this purpose). The birefringence is then given by the ratio R/T.

This method is a very useful one for the approximate determination of birefringences in microscopical work. The test should be applied with judgment, and allowance should be made for the difficulty frequently experienced in measuring thicknesses. The variation of the birefringence effect with the direction of the section should also be kept in mind. When these things are taken into account the determination is of considerable practical use, especially in cleavage fragments or small prismatic crystals the optical orientations of which are known. In such cases it often provides a decisive test.

The relation expressed by the equation given above is frequently made use of by petrologists in determining the thickness of a section, when numerous grains of a mineral of known birefringence are present. This is done by noting the highest colour shown by the grains, and then dividing the relative retardation corresponding to this colour by the known maximum birefringence of the mineral. Having done this the process can be reversed, and the birefringence of some other mineral can be determined by dividing the relative retardation corresponding to its interference colour by the thickness of the section.

Determination of optical sign (sign of birefringence).

The sign of birefringence is readily determined in a section or fragment showing a definite interference figure. For this purpose the gypsum plate showing a first order red is very convenient for testing uniaxial figures; whereas for biaxial figures the quartz wedge is perhaps the most convenient thing to use. When possible the determination should be made on an interference figure showing the emergence of the optic axis (if uniaxial), or the emergence of the acute bisectrix (if biaxial). The test can generally be made with excentric figures, but a biaxial figure of low angle is liable to be mistaken for a uniaxial figure if the acute bisectric is not in view.

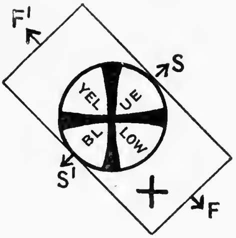

FIG. 90.—Positive uniaxial figure.

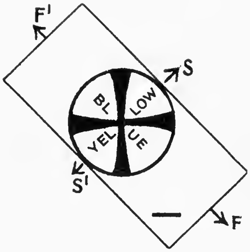

FIG. 91.—Negative uniaxial figure.

In the case of a uniaxial figure, if the gypsum plate is inserted diagonally across the centre of the figure as shown in figs. 90 and 91, the arrangement of the colours at the apices of the quadrants, near the point of intersection of the black bars, depends upon the sign of the crystal. If negative, the fast-ray vibration-direction will lie in the principal plane, and the slow-ray vibration-direction will lie at right angles to the principal plane. Consequently, in the two opposite angles of the quadrants lying along the plate the colour will be blue, since here there is addition, whereas in the two angles of the quadrants lying at right angles to the gypsum plate the colour will be yellow, since here there is compensation (fig. 91). If the crystal is positive the distribution of the colours is the reverse of this, *i.e.* the line joining the blue patches lies across the gypsum plate, whereas the line joining the yellow patches lies along it (fig. 90).

The rule for sign determination with a uniaxial figure, then, may be given thus: If the diameter passing through the blue patches lies along the gypsum plate (*i.e.* makes a negative sign with its length), the crystal is negative. If the diameter joining the blue patches makes a positive sign with the gypsum plate, the crystal is positive. It is, however, perhaps better to remember the reason for the rule, and to bear in mind that the addition colour (blue) results when the fast-ray vibration-direction lies along the principal plane (negative), and the compensation colour (yellow) when the slow-ray vibration direction lies along this plane (positive).

With a biaxial figure it is convenient to use the quartz wedge, and to note the position of the wedge in relation to the optic axial plane when the wedge is inserted in the compensating position. To illustrate this take a cleavage plate of muscovite, which is a negative mineral, and obtain the biaxial figure by using the converging lens and the quarter-inch objective. First of all get the black cross, and then turn the stage or the nicols through 45° so as to obtain the hyperbolic brushes. The centre of the field will now be illuminated; and when the quartz wedge is inserted it will lie either parallel to or at right angles to the optic axial plane. If it lie along the optic axial plane, addition will result and the colour will rise; if it lie at right angles to this plane compensation will take place.

If the experiment be tried on topaz, which is a positive mineral, the reverse of this result will be obtained; *i.e.* compensation will take place when the quartz wedge is inserted along the optic axial plane, and addition when it is inserted at right angles to this plane.

The rule therefore for the sign determination with a biaxial figure and a positive quartz wedge is as follows: If compensation takes place when the wedge is inserted at right angles to (*i.e.* + relation to) the optic axial plane, the mineral is negative, if when parallel to (in − relation) the crystal in positive.

Optical examination of opaque minerals.

Opaque minerals, whether in sections or loose grains, require to be examined in reflected light. For this purpose light can be focused on the object by means of a strong condenser; but the colour of the mineral, and the nature of its surface, can usually be seen in bright daylight by swinging off the mirror and examining by means of the light reflected in the ordinary way from the surface of the fragment or section.

It is convenient, especially when dealing with a complex ore in which it is desired to study the texture of the specimen, to prepare a polished surface or section of the specimen, in order to ascertain the relation of the opaque minerals to one another and to the rock as a whole. The comparative hardness of the opaque minerals shows itself in their resistance to abrasion and the degree of readiness with which they take on polish. The harder grains polish more readily and tend to stand out in relief when a section is rubbed on an abrading surface.

Where the grains are large enough, hardness tests can be made on the polished surface. The action of acids on the polished surfaces also affords useful evidence, as the surfaces of grains susceptible to attack by acids are quickly dulled, whereas those that resist attack keep their polish.

The following opaque minerals arranged according to colour will serve to illustrate the advantage to be gained by examining these opaque minerals optically when possible :

Black or greyish black.
Magnetite.
Ilmenite.
Psilomelane.
Chalcocite.
Bornite (brownish).
Chromite.
Tantalite.

White.
Silver.
Bismuth.
Arsenopyrite.
Smaltite.
Niccolite.

Yellow.
Gold (characteristic yellow).
Pyrite
Marcasite } Pale brassy yellow.
Pentlandite (yellowish bronze).
Pyrrhotite, (frequently bronze coloured).
Chalcopyrite (brassy yellow).

As illustrating the action of acids it may be noted that, of the yellow group enumerated above, *gold* is not attacked by a single acid, whereas pyrrhotite is attacked by hydrochloric acid. *Pyrite, marcasite, pentlandite,* and *chalcopyrite* are not attacked by hydrochloric acid, but are strongly attacked by nitric acid ; they can therefore be distinguished from pyrrhotite in a section or on a polished surface by treatment with hydrochloric acid.

In the black group again, *magnetite, ilmenite,* and *psilomelane* are attacked by hydrochloric acid ; *chalcocite* and *bornite* by nitric acid ; whilst *tantalite* and *chromite* are not attacked by either of these acids.

In the description of the minerals given in the latter half of this book, the colour, hardness, and behaviour towards acids of the various opaque minerals are mentioned, and a list of these minerals arranged according to colour is given at the end of the book. It has already been pointed out that opaque minerals are fairly constant in colour, and in this respect differ markedly from transparent minerals, which frequently show much variation in colour. Hence the colour of an opaque mineral may be regarded as a fairly important diagnostic feature.

In the combined optical and chemical examination of opaque minerals, however, the student should not become too slavishly devoted to cutting and polishing, an operation in which, as in ordinary rock-section cutting, a great deal of time may be wasted. In many cases all the evidence required is to be obtained by examining crushed fragments of the specimen, after an attempt has been made to separate them as far as possible by simple physical methods.

CHAPTER V

CHEMICAL EXAMINATION OF MINERALS

GENERAL CONSIDERATIONS.

Elements and compounds.—Chemists have by their methods of analysis reduced the numerous different kinds of matter to some eighty-three elementary forms, each of which has so far defied all attempts to split it into simpler substances. These simpler forms of matter are called chemical elements. On the opposite page is a list of the elements at present known, with their symbols and atomic weights.

A number of these elements exist in a free state in nature, *e.g.* carbon, copper, gold, mercury, platinum, silver, and sulphur. Most of them, however, occur in a state of combination. These combinations of two or more elements are called chemical compounds. The mineral halite (common salt), for example, is a compound made up of the two elements sodium and chlorine, neither of which occurs naturally in a free state. Nearly all minerals are chemical compounds.

Atoms and molecules.—We may define a chemical *molecule* of a compound as the smallest particle which contains all the elements present in the compound. An *atom* is the smallest particle of an element which can be transferred from one molecule to another, *i.e.* the smallest particle which can take part in a chemical reaction. Chemists have compared the weights of atoms by taking the atom of hydrogen as representing the unit of weight. The weight of an atom of an element compared with that of an atom of hydrogen is known as the *atomic weight* of the element. It is now the custom, however, to state atomic weights with reference to oxygen as the standard, reckoning this as 16, which is not quite exactly its atomic weight with hydrogen the unit of weight. In the following list of elements, atomic weights are given with reference to oxygen = 16 (instead of 15·96) as the standard. The *molecular weight* of a compound is the sum of the weights of the atoms which build up the molecule of the compound.

Table of Chemical Elements.

Element.	Symbol.	Atomic Weight.
Aluminium	Al	27·1
Antimony	Sb	120·2
Argon	A	39·9
Arsenic	As	74·95
Barium	Ba	137·35
Beryllium = Glucinum	Be	9·1
Bismuth	Bi	208·5
Boron	B	11·0
Bromine	Br	79·9
Cadmium	Cd	112·4
Caesium	Cs	132·8
Calcium	Ca	40·1
Carbon	C	12·0
Cerium	Ce	140·25
Chlorine	Cl	35·45
Chromium	Cr	52·1
Cobalt	Co	59·0
Columbium = Niobium	Cb	93·5
Copper	Cu	63·6
Dysprosium	Dy	162·5
Erbium	Er	167·7
Europium	Eu	152·0
Fluorine	F	19·0
Gadolinium	Gd	157·3
Gallium	Ga	69·9
Germanium	Ge	72·5
Glucinum = Beryllium	Gl	9·1
Gold	Au	197·2
Helium	He	4·0
Holmium	Ho	163·5
Hydrogen	H	1·008
Indium	In	114·8
Iodine	I	126·9
Iridium	Ir	193·1
Iron	Fe	55·85
Krypton	Kr	82·9
Lanthanum	La	139·0
Lead	Pb	207·1
Lithium	Li	6·95
Lutecium	Lu	174·0
Magnesium	Mg	24·3
Manganese	Mn	54·95
Mercury	Hg	200·6
Molybdenum	Mo	96·0
Neodymium	Nd	144·3
Neon	Ne	20·2
Nickel	Ni	58·7
Niobium = Columbium	Nb	93·5
Niton	Nt	222·4
Nitrogen	N	14·0
Osmium	Os	190·9
Oxygen	O	16·0
Palladium	Pd	106·7
Phosphorus	P	31·05
Platinum	Pt	195·2
Potassium	K	39·1
Praseodymium	Pr	140·6
Radium	Ra	226·4
Rhodium	Rh	102·9
Rubidium	Rb	85·45
Ruthenium	Ru	101·7
Samarium	Sm	150·4
Scandium	Sc	44·1
Selenium	Se	79·2
Silicon	Si	28·3
Silver	Ag	107·9
Sodium	Na	23·0
Strontium	Sr	87·65
Sulphur	S	32·05
Tantalum	Ta	181·5
Tellurium	Te	127·5
Terbium	Tb	159·2
Thallium	Tl	204·0
Thorium	Th	232·4
Thulium	Tm	168·5
Tin	Sn	119·0
Titanium	Ti	48·1
Tungsten	W	184·0
Uranium	U	238·5
Vanadium	V	51·0
Xenon	X	130·2
Ytterbium	Yb	172·0
Yttrium	Y	89·0
Zinc	Zn	65·35
Zirconium	Zr	90·6

Symbols and formulæ.—The names of the elements are represented by *symbols*. As will be seen from an inspection of the symbols given in the above list of elements, the symbol consists of the initial of the English or Latin name only, or of the initial followed by the second or some other more convenient letter. The symbol of an element is not merely an abbreviation. When used alone it signifies a single atom of an element. Compounds are represented by *formulæ*. A formula indicates by symbols what elements are present in a compound. It tells us the proportionate number of atoms in a molecule of the compound. If only one atom of an element is present, the symbol is used alone; if two are present, the number 2 is affixed to the symbol, and so on. A formula serves the useful purpose of indicating the composition of a compound, and enables us to calculate, from a knowledge of atomic weights, the percentage chemical composition of a compound.

Estimation of percentage composition by weight from formulæ.—As a simple illustration of this we may take the mineral calcite (calcium carbonate), which is a compound consisting of the three elements calcium, carbon, and oxygen, the atomic weights of which are 40, 12, and 16 respectively. For every calcium atom present there is one carbon atom and three oxygen atoms. Hence the formula of calcite is $CaCO_3$, and its molecular weight is $40+12+(16\times3)=100$. Its percentage composition by weight is therefore as follows:

Calcium - - - -	40 per cent.
Carbon - - - -	12 ,,
Oxygen - - - -	48 ,,

As an alternative to this method of stating the percentage composition, we can state it in terms of the two simpler compounds lime (CaO) and carbon dioxide (CO_2) which enter into its composition, thus:

CaO - - - - -	56 per cent.
CO_2 - - - - -	44 ,,

This method of stating percentage composition in terms of the oxides which enter into their composition is one that is widely adopted for minerals, and is preferable to that of stating the composition in terms of elements, especially when the mineral consists of a complex compound as in the case of a silicate.

Calculation of formulæ from percentage composition found by analysis.—Just as we can calculate percentage composition from a formula, so we can, by reversing the operation, find out the formula of any compound, the percentage composition of which has been determined by analysis. To do this we divide the percentage weight of each constituent element or compound by the atomic or molecular weight of that constituent as shown by the following two examples :

		Percentage found by analysis.	At. Wt.	Ratio.	Formula.
Galena	Pb	86·6	207	0·41	
	S	13·4	32	0·41	PbS.
			Mol. Wt.		
Gypsum	CaO	32·6	56	0·58	
	SO_3	46·5	80	0·58	$CaSO_4 . 2H_2O$.
	H_2O	20·9	18	1·16	

Isomorphism.—Certain minerals resemble one another very closely in their crystalline form, and are said to be isomorphous (Gr. *isos*, equal, and *morphe*, form). This property of isomorphism is displayed usually by compounds of closely related elements that are analogous in composition. A good example of it is provided by the group of rhombohedral carbonates, comprising the minerals calcite ($CaCO_3$), magnesite ($MgCO_3$), chalybite ($FeCO_3$), rhodochrosite ($MnCO_3$), and smithsonite ($ZnCO_3$). All these minerals are trigonal ; they all exhibit a perfect rhombohedral cleavage, with closely similar rhombohedral angles. In such a series one molecule can be replaced by a different but analogous molecule without the crystalline form being seriously affected, and this replacement frequently takes place. Chalybite, for instance, usually contains small amounts of calcite and magnesite as isomorphous replacements. The mineral dolomite is a rhombohedral carbonate consisting partly of calcium carbonate and partly of magnesium carbonate ($CaCO_3 \cdot MgCO_3$) ; and the mineral ankerite [$CaCO_3 \cdot (Mg, Fe, Mn)CO_3$] contains four different but analogous kinds of carbonate molecules.

Among other notable examples of isomorphism the following may be mentioned :

Halite (NaCl) and Sylvite (KCl).
Tetrahedrite ($3Cu_2S \cdot Sb_2S_3$), and Tennantite ($3Cu_2S \cdot As_2S_3$).
Pyrargyrite ($3Ag_2S \cdot Sb_2S_3$), and Proustite ($3Ag_2S \cdot As_2S_3$).
Rutile (TiO_2) and Cassiterite (SnO_2),
Thorite ($ThO_2 \cdot SiO_2$), and Zircon ($ZrO_2 \cdot SiO_2$).
Cerussite ($PbCO_3$), Witherite ($BaCO_3$), and Strontianite ($SrCO_3$).
Barite ($BaSO_4$), Celestite ($SrSO_4$), and Anglesite ($PbSO_4$).

THE QUALITATIVE EXAMINATION OF MINERALS.

The process of analysing a substance consists of treatment with various known substances called *reagents*, for the purpose of producing other substances which can be identified by their distinctive properties.

Qualitative analysis aims merely at ascertaining the number and kind of elements or compounds present. Quantitative analysis goes farther than this, and seeks to estimate the percentage weight of each constituent element or compound present.

As a rule, the evidence provided by a qualitative analysis, together with various items of physical evidence, is sufficient to enable a mineralogist to identify a mineral with confidence. In making a qualitative analysis of a mineral for the purpose of identification, a mineralogist attaches greater importance to the use of the blowpipe than does the chemist; and indeed he is often content to limit his analysis to a series of "dry" tests which the chemist as a rule uses only in a desultory and preliminary style when he does not ignore them altogether. So far as the chemist is concerned, this is due to the fact that experience gives him a very thorough knowledge of the properties of solutions and precipitates, and it is by the manipulation of these that he obtains his valuable quantitative results; hence he pins his confidence chiefly to "wet" methods of analysis; moreover he largely limits himself to chemical evidence in making his identifications.

A mineralogist, on the contrary, usually obtains a considerable amount of important physical evidence in the first place; and this in itself is frequently sufficient either to establish the identity of a mineral, or at least to justify a strong suspicion. Hence for the purpose of identification he does not depend entirely on chemical evidence, but uses it more by way of confirmation, and usually gets what chemical evidence he requires by using the blowpipe and other methods of examination in the "dry" way.

Such qualitative evidence requires careful handling, and due allowance should be made for effects which may be due to impurities. However, when used by way of confirmation only, it is less liable to lead to error than when it is made the evidence in chief. After some experience, one develops confidence in judging which items of such evidence are of most value in the work of identification. Physical evidence and qualitative chemical evidence, though usually effective for the purpose of fixing identity, do not always suffice; and in some instances a complete quantitative analysis has to be made before the identity of a mineral can be established.

Again, in economic mineralogy it is with mixtures of minerals that one has mostly to deal, and even when the minerals present have been ascertained, it may be necessary to have a chemically quantitative estimation of the important constituent or constituents before it can be ascertained whether the material is of any value. It is often possible however, by using physical methods only, to determine whether material is likely to be of value, providing that it exists in sufficient abundance to be worth mining.

APPARATUS REQUIRED.

Crushing apparatus.—For the breaking and dressing of large specimens in a rough way, a geological hammer is required. The detachment of small fragments from a specimen may be effected by means of any small trimming hammer. Small hammers with flat square faces are made specially for this purpose and supplied by mineral dealers. A pair of pliers is a very useful tool by means of which fragments can be broken from a specimen with a minimum risk of injury. If only a small amount of powder is required, this can be scraped off with a file or knife. Before powdering a fragment, it should be coarsely crushed, and suitable pieces selected for testing fusibility.

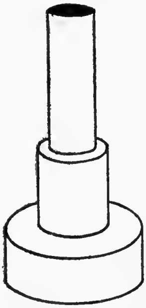
FIG. 92.—Mortar.

The crushing is best done in a so-called "diamond" mortar. This consists of a strong steel plate on the upper surface of which is a shallow cylindrical depression (fig. 92). Into this fits a hollow steel cylinder, and into this again a solid steel plunger which should fit the cylinder well. Such a mortar is a very useful tool, and enables one to crush a fragment to coarse powder without any appreciable loss of the mineral. In this condition it can be transferred to an agate mortar, and ground as finely as possible by means of an agate pestle. If coarse fragments are crushed directly in an agate mortar, a considerable amount of the material may be lost, especially when dealing with tough hard minerals, the coarse fragments of which are ejected from the mortar by the action of the pestle.

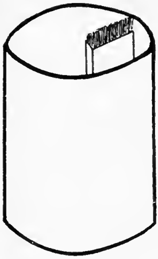
FIG. 93.—Grease lamp.

Burners.—For general use a Bunsen burner is best. When used in blowpipe work, the luminous flame is required. A form of burner which is usually supplied in blowpipe cabinets, and which is very useful to prospectors and others who have not the resources of a laboratory to hand, is that illustrated in fig. 93. It consists of a small cylindrical metal vessel provided with a wick holder. The upper edge of the wick holder is slightly inclined, and the upper end of the wick is trimmed so as to be parallel to this edge. The reason for this is, that in blowpipe operations on charcoal, the flame requires to be directed downwards.

The fuel used with such a burner is either oil or solid paraffin. In the latter case, the paraffin has to be melted first, after which the heat given out by the burning wick is sufficient to maintain the fuel in a molten state. For portable use, as by a prospector, solid paraffin or broken bits of candle should be used. This form of lamp is excellent for blowpipe work even in the laboratory. If oil is used, the vessel should have a tight-fitting cap. Under difficulties, an ordinary candle can be used for blowpipe work, but is not so effective.

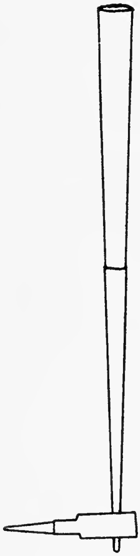

FIG. 94.—Blowpipe.

The blowpipe.—Mouth blowpipes are made in numerous forms, and choice as regards shape is a matter of taste. In one of the most useful forms the main tube of the blowpipe is made of brass, and is about eight inches long. A detachable ivory mouthpiece, though not necessary, is a desirable feature, as it can be readily cleaned. A small tube screws into the lower part of the main tube, at right angles to it, and is provided with a detachable nozzle. It is important that this tube should have a good median and cylindrical bore, which should be symmetrically continuous with the slightly narrowing outlet bore in the detachable nozzle. The orifice at the tip of the nozzle should be circular and about half a millimetre in diameter. It is upon the well-turned and finished character of the outlet tube and nozzle that the efficiency of a blowpipe depends. A large number of blowpipes are carelessly finished in these respects, and it pays at the outset to secure one in which these parts are well made. For the rest, it matters comparatively little what the shape of the main tube and mouthpiece may be.

An excellent collapsible form of blowpipe, especially for portable use, is represented in fig. 94. In this there is no detachable mouthpiece. The outlet tube with its detachable nozzle fits over the lower end of the main tube, from which it can be removed when the blowpipe is not in use, and inserted in the mouthpiece.

Reduction and oxidation with blowpipe.—By using a blowpipe and suitable luminous flame, reduction and oxidation can be effected as required. To produce a reducing flame, the tip of the nozzle should be brought almost into contact with the outer part of the flame. By this means the flame can be deflected as shown in fig. 95; and when the blast is properly regulated, the blowpipe flame thus produced is luminous near its apex, owing to the presence of incandescent particles of carbon. For this reason the luminous portion of such a flame is capable of absorbing oxygen and converting certain metallic oxides, such as those of lead and silver, into a metallic state. Hence this flame is called the reducing flame.

If, instead of merely deflecting the flame, one places the tip of the nozzle well into it (fig. 96), and blows vigorously so as to let the blast from the nozzle mix freely with the burning gas, the blowpipe flame becomes non-luminous. Indeed, such a flame possesses no reducing power in itself. On the contrary, by virtue of the excess of air (*i.e.* oxygen) over the amount required for the rapid consumption of the gas, this flame permits substances heated in it to take up oxygen. A fragment of metallic lead or tin, when heated in the tip of this flame, becomes converted to oxide. Hence such a flame is called an oxidizing flame.

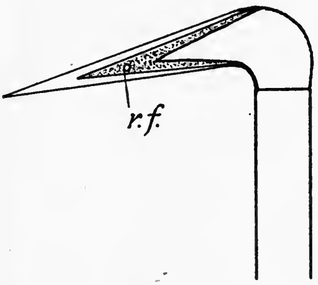

FIG. 95.—Reducing flame.

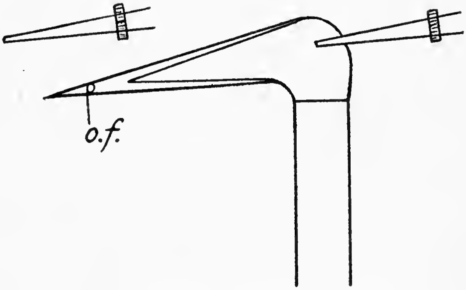

FIG. 96.—Oxidizing flame.

It is indispensable to efficient blowpipe work that one should understand the significance of these two operations of reduction and oxidation, and be able to use the blowpipe to reduce and oxidize substances as required. A little well-directed practice is sufficient to develop this ability. A good test is that of manganese in a borax bead. In this test the bead is colourless in the reducing flame, and a port-wine colour in the oxidizing flame; and one should be able to colour it by oxidation or decolorize it by reduction, at will, assuming that the requisite amount of mineral has been used.

Some people experience difficulty in maintaining a constant blast during a blowpipe operation. To make a continuous blast the cheeks should be kept moderately inflated while breathing is going on normally. This is rendered possible by the fact that the amount of air escaping from the nozzle of a good blowpipe is less than that normally expired. The practice of continuous blowing can be acquired by first breathing with cheeks inflated and mouth closed, without the blowpipe, and then trying the operation with the blowpipe in the mouth. After trying this a few times, one should be able to apply the blowpipe to the flame and blow continuously for some time.

Charcoal blocks.—Charcoal blocks should be rectangular in shape, and a convenient size is 2 × 1 × 1 inches. The charcoal should be of the hard and compact variety. The lighter porous varieties should be avoided, since they absorb the flux and give disappointing results. It is usually convenient to cut a slight depression in the charcoal to give better support to the material under treatment. Such a block as the one mentioned above can be used for numerous tests; but if a fresh surface is exposed by scraping, care should be taken to see that this is done effectively.

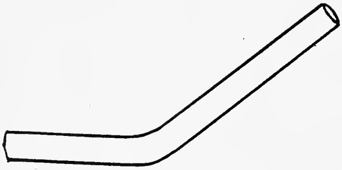

Fig. 97.—" Open " tube.

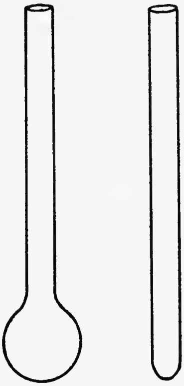

Fig. 98.—" Closed " tubes.

" **Open** " **tubes.**—An " open " tube consists of a piece of hard glass delivery tubing about 15 cm. long, open at both ends. The tube should have an internal diameter of 5 or 6 mm.; and it is an advantage to have it slightly bent (as shown in fig. 97) so that the shorter limb is about 5 cm. long.

" **Closed** " **or bulb tubes.**—These are closed at one end only (fig. 98). It is convenient to use the same sort of tubing as that used for " open " tubes and to have the " closed " tube half the length of the open one, *i.e.* about 7 or 8 cm. A quantity of straight tubes about 15 cm. long should be kept in stock, and from these a number of " open " and " closed " tubes can be made as occasion requires. A bulb tube is a special form of " closed " tube, the closed end of which has been blown into a small bulb. For most purposes, however, the blowing of a bulb is an unnecessary refinement.

Platinum wire.—A piece of platinum wire, about 0·5 mm. thick and 5 or 6 cm. long, looped at one end, is used for the borax and microcosmic salt bead tests, which often provide important evidence. The loop should be about 2 × 3 mm. in size. The unlooped end should be fused into a piece of glass tubing about the size of a "closed" tube, as this serves the purpose of a handle and facilitates manipulation.

Platinum foil and spoon.—For carrying out fusions with a larger quantity of material than is required for bead reactions, a piece of platinum foil 5 × 3 cm. is very useful. Instead of foil a spoon about 1·5 cm. in diameter may be used, and is perhaps more economical, as it is subject to less wear and tear. Instead of a handle, it is cheaper to have a slight projection on the lip of the spoon, so that it can be manipulated by a pair of small tongs. The platinum spoon or foil is especially useful for dissolving powders by fusion in hydrogen-potassium sulphate or sodium carbonate. A small platinum crucible can often be used with advantage.

Platinum-tipped forceps.—These provide a useful means of holding a small fragment of mineral in the blowpipe flame to permit fusibility and flame reactions to be tested; but if acid is not applied in making the test, iron forceps can be used instead.

Ivory spatula, for lifting and mixing powders. For most purposes the clean blade of a knife serves quite well.

In addition to the above-mentioned apparatus which is used for dry reactions, it is useful to have some of the apparatus that is employed in wet analysis. The following are the items likely to be most used in testing solutions:

Test tubes and test tube stand.
A few beakers.
Litmus paper.
Turmeric paper.
Glass filtering-funnel and stand.
Filter papers.
Wash bottle.
Dropping bottles.
Tripod stand with plate of wire gauze.
Crucible stand with ring and clay-pipe triangle.
Crucible tongs.
Porcelain dishes and crucibles.
Watch glasses.

REAGENTS.

Sodium carbonate (Na_2CO_3).—Sodium carbonate melts easily in the blowpipe flame, and in this molten condition reacts with most mineral powders, forming soluble compounds of sodium which can be readily dissolved and examined in the wet way. Many minerals can be reduced to the metallic state by mixing with sodium carbonate and heating on charcoal (see p. 86).

Charcoal sticks.—These are small sticks of porous charcoal, about the size of a match, saturated with sodium carbonate. They cannot be recommended for general use instead of charcoal blocks in determinative mineralogy, but they are particularly useful when only very small fragments or grains can be used. In such cases it is not practicable to crush, and the particle can be picked up on the moistened tip of the stick and reduced in the blowpipe flame. One of the best examples of the utility of such a charcoal stick is the efficient way in which a small fragment of cassiterite can be reduced to a globule of metallic tin by means of it. Cassiterite is very refractory towards the blowpipe, and its powder can only be reduced easily in the ordinary way on charcoal by mixing with a little powdered charcoal and sodium carbonate, though a small grain can be readily reduced to a metallic globule on the tip of a charcoal stick. This is explained by the fact that a smaller surface is exposed than is the case with an ordinary charcoal operation, and the grain is therefore raised to a much higher temperature. In any case, however, the use of a charcoal stick is only recommended for small particles, for when there is plenty of material available the reduction by means of powdered charcoal and sodium carbonate in the ordinary way is very effective.

In the absence of a charcoal stick, this reducing operation on a small grain of cassiterite can be carried out on a charcoal block, using a thin layer of sodium carbonate to make the grain adhere to the surface of the block.

Borax ($Na_2B_4O_7 \cdot 10H_2O$) fuses readily to form a clear bead on a loop of platinum wire. Certain elements yield characteristic colours when the powder of a mineral containing them is fused in a borax bead (see p. 84).

Microcosmic salt or salt of phosphorus ($Na(NH_4)HPO_4$) is used in the same way as borax to yield bead reactions (see p. 84).

Cobalt nitrate ($Co(NO_3)_2$).—Certain mineral powders when heated alone on charcoal, then moistened with a drop of cobalt nitrate, and afterwards re-heated, yield characteristic colours (see pp. 85, 86).

Hydrogen potassium sulphate ($KHSO_4$), when fused in a platinum spoon or on platinum foil, forms a good solvent for powders of certain minerals, such as titanates, niobates and tantalates.

Potassium nitrate (KNO_3) is used as an oxidizing agent in certain cases.

Potassium iodide and sulphur ($KI+S$).—A mixture of these in equal proportions, when heated on charcoal with lead and bismuth minerals, gives characteristic sublimates.

Copper oxide, to test for chlorides.

Granulated zinc or tin, to produce a reducing agent (nascent hydrogen) when treated with hydrochloric acid.

Pure lead, free from silver, used in testing the silver content of lead ores.

Bone ash, used as an absorbent of lead oxide in the operation of recovering silver from a lead-silver alloy obtained by the reduction of a mineral powder.

Magnesium powder.—When the powder of a phosphate such as apatite or phosphorite is mixed with magnesium powder and ignited, the phosphate is reduced to a phosphide, which, when placed in water, generates a strong and characteristic odour of decaying fish due to the formation of phosphoretted hydrogen.

In addition to the foregoing, which are chiefly dry reagents, the following wet reagents are useful :

Hydrochloric acid.
Sulphuric acid.
Nitric acid.
Ammonium hydrate.
Ammonium carbonate.
Ammonium oxalate.
Ammonium molybdate.
Potassium ferrocyanide.
Barium chloride.
Platinic chloride.
Absolute alcohol.
Lime- or baryta-water.
Sulphuretted hydrogen.
Distilled water.

PROCEDURE IN CHEMICAL EXAMINATION OF MINERALS.

In carrying out the chemical examination of a mineral, the plan to be adopted will depend to some extent on the knowledge and experience of the person who is making the examination. If, as is often the case, the identity of a mineral is strongly suspected from a knowledge of its physical characters, then it is only necessary to select one or two distinctive chemical tests to decide the accuracy of the suspicion. The beginner, however, will do well not to strain in search of suspicions. It is safer to adopt a systematic course of procedure, and get together as many items of evidence as possible, especially as this can usually be done without much trouble. The following is a convenient order of procedure in making a chemical examination of a mineral:

1. Treatment with acid.
2. Flame coloration.
3. Heating in closed tube.
4. Heating in an open tube.
5. Borax bead test.
6. Microcosmic salt bead test.
7. Blowpipe reactions on charcoal without fluxes.
8. Blowpipe reactions on charcoal with sodium carbonate as a flux.
9. Fusion if necessary in a platinum spoon or crucible with sodium carbonate, or potassium hydrogen sulphate.

1. Treatment with acid.

The most convenient acid for general use is hydrochloric. It should be applied to the crushed mineral in a test-tube or on a watch-glass.

With carbonates a dilute solution of hydrochloric acid causes effervescence. Coarse fragments of calcite effervesce briskly in cold dilute acid, whereas fragments of dolomite, magnesite, and chalybite effervesce briskly only after heating. To prove that the gas is carbon dioxide, it should be passed into lime or baryta water, in which carbon dioxide produces a milkiness due to the formation of carbonate.

Many sulphides (*e.g.* galena), when treated with a solution of hydrochloric acid, yield sulphuretted hydrogen, which is readily identified by its characteristic odour, and the fact that it blackens a piece of filter paper which has been moistened with lead acetate.

Manganese oxides liberate chlorine gas (green and pungent) when treated with strong hydrochloric acid.

Certain silicates are effectively decomposed when boiled with strong hydrochloric acid. On evaporating the excess of acid, the silica forms a gelatinous residue in some cases.

Minerals containing iron yield yellow solutions with hydrochloric acid, due to the formation of ferric chloride, if the iron is present in a ferric state. If, as in chalybite, the iron is ferrous, it is necessary to add a few drops of nitric acid to develop the colour. This test for the presence of soluble ferrous compounds is sometimes of diagnostic value; but the widespread distribution of ferric oxide as an impurity in minerals makes caution necessary in drawing conclusions from the mere presence of this constituent.

2. Flame coloration.

Some of the elements impart characteristic colours to a Bunsen or a blowpipe flame. The observation of flame colours may be made when testing fusibility, by heating a splinter of a mineral in the blowpipe flame. After the observation on fusibility has been made, the tip of the splinter should be moistened with hydrochloric acid and re-heated in the oxidizing flame. In some cases prolonged heating is necessary. Another way of making a flame test is to pick up a little of the powdered mineral on a piece of platinum wire which has been already moistened with hydrochloric acid, and to heat this in the outer part of a Bunsen flame, or in the outer tip of a blowpipe flame (oxidizing). The colours should be observed on a black background. The following are the chief flame-colour tests :

CALCIUM.	Yellowish red.
STRONTIUM.	Red.
LITHIUM.	Crimson.
SODIUM.	Yellow.
BARIUM.	Yellowish green.
MOLYBDENUM.	Yellowish green.
BORON.	Bright green (use sulphuric acid).
PHOSPHORUS.	Dull green (do.).
COPPER.	Emerald-green ; but also azure-blue in the case of copper chloride.
LEAD.	Pale blue.
ANTIMONY.	do.
ARSENIC.	do.
ZINC.	do.
POTASSIUM.	Violet.

Flame colours are sometimes difficult to characterize, and it is desirable to have powders of known substances ready to hand for comparison in doubtful cases. The yellow colour due to sodium is not of much diagnostic value, owing to the abundance of sodium as an impurity, and the fact that a mere trace of it yields a strong yellow colour. Only when the yellow colour is very intense can it be inferred that sodium is present as an essential constituent of a mineral.

3. Heating in a “ closed ” tube.

The chief purpose of “ closed ” tubes (see p. 76) is to enable mineral powders to be heated without free access of air, so as to obtain sublimates of any unoxidized volatile products which may be given off. The most important of these sublimates are as follows :

WATER.—Collects as drops or a film of moisture in the upper part of the tube. Water is an essential constituent in many minerals, some of which yield much moisture when heated in a closed tube.

SULPHUR.—Given off freely by specimens containing native sulphur, and also by some sulphides. The sublimate is a reddish to yellow liquid when hot, and cools to a yellow solid.

MERCURY.—Deposited as a rule in small liquid globules when mercury minerals are mixed with a little sodium carbonate and heated in a closed tube. By rubbing off the sublimate with a piece of paper, larger globules can be obtained.

SULPHIDE OF MERCURY.—When sulphide of mercury (cinnabar) is heated alone in a " closed " tube, it volatilizes, and forms a shining black sublimate. When rubbed on a piece of paper, this sublimate yields a red streak.

ARSENIC is given off from certain arsenides, and forms a shining black sublimate.

ARSENIC SULPHIDE is volatile and is given off from certain minerals such as realgar and orpiment, which contain arsenic and sulphur. The sublimate is a dark red liquid when hot, and changes on cooling to a yellowish solid.

ANTIMONY OXYSULPHIDE is generally formed as a sublimate from minerals containing antimony and sulphur, *e.g.* antimonite. The sublimate is black when hot and reddish brown when cold.

ANTIMONY OXIDE AND CHLORIDE, OXIDE OF ARSENIC, LEAD CHLORIDE, and AMMONIUM SALTS all give a white sublimate.

4. Heating in an " open " tube.

An open tube (see p. 76) is used for the purpose of heating mineral powders in a current of air. The powder is placed in the shorter limb, and adjusted so that it lies near the bend of the tube. The tube can be held with the outer end of the longer limb in the hand. If now the bent portion of the tube is placed in a Bunsen flame, and the outer end of the short limb inclined slightly downward, a good current of air will pass over the heated powder, which may in this way be effectively roasted. Certain minerals, especially metallic sulphides, yield characteristic sublimates, which are deposited on the cool surface of the chimney-like longer limb. The odour of the escaping gases affords evidence of sulphur in the presence of sulphides. The garlic-like odour of arsenic fumes is also characteristic.

The following are the chief open-tube sublimates:

Arsenious Oxide (As_2O_3), from arsenic minerals, forms a white sublimate consisting in part of minute octahedral crystals. If the mineral is heated rapidly a black sublimate of arsenic or a yellow one of arsenic sulphide may be obtained, as in the closed tube experiment, through incomplete oxidation.

Antimonious Oxide (Sb_2O_3), given off by oxides of antimony. This also is a white crystalline sublimate, but it forms two varieties of crystals, one being octahedral, like those of arsenious oxide, whilst the other consists of prisms. Moreover, it is less volatile than the arsenious oxide, and is consequently deposited lower down the tube.

Antimonate of Antimony (Sb_2O_4), a white amorphous sublimate, non-volatile, deposited chiefly on the under side of the tube, from compounds containing antimony and sulphur. Thus sublimate is pale yellow when hot, and white when cold. Mixed with it there is usually some of the antimonious oxide sublimate.

Molybdenum Trioxide (MoO_3), formed near the assay as a white crystalline sublimate (pale yellow when hot), from molybdenite and molybdic ochre.

Lead Sulphate, mixed with lead sulphite, is formed in small amount as a white non-volatile sublimate from lead sulphide. It is deposited near the mineral, on the lower part of the tube.

Mercury gives a grey volatile deposit of small globules, which can be made to form larger globules by rubbing with a piece of paper, as in the closed-tube experiment.

5. Borax bead test.

In making this test, the borax powder should be picked up by the heated looped end of the platinum wire, and fused to a clear, colourless bead. A little of the powdered mineral, which has previously been placed on a clean porcelain plate, can then be picked up by the hot borax bead, to which the powder readily adheres. With different minerals, different amounts of the powder are required to give good bead reactions. Care should be taken to avoid picking up too much at the first trial, otherwise the bead may be rendered opaque by excess of the mineral. Time is saved, and the best results obtained, by first taking up a small amount of the mineral, and afterwards adding further small amounts, if necessary.

The bead should be first heated in the oxidizing flame and the colour of the bead noted after cooling. It should then be reduced thoroughly in the reducing flame, and the colour again noted after cooling. In observing the colour of the bead it is best to flatten it a few seconds after removing from the flame ; otherwise the bead acts like a lens, and is apt to yield effects which interfere with the observation of the colour when the bead is examined in transmitted light.

The following are the chief metals which produce characteristic colour effects in borax beads, and the colours produced by them in cold beads :

Metal.	Oxidizing flame.	Reducing flame.
Iron - -	Yellow (red when hot).	Dull greenish to brownish.
Manganese -	Deep red.	Colourless.
Titanium -	Colourless.	Brownish colour.
Tungsten -	Colourless.	Yellow.
Copper - -	Sky-blue.	Opaque and light red.
Nickel - -	Brownish colour.	Greyish colour.
Cobalt - -	Deep blue.	Deep blue.
Chromium -	Bright green (slightly yellowish).	Emerald-green.
Molybdenum -	Colourless (yellow hot).	Brownish colour.
Uranium -	Pale yellow.	Yellowish green.
Vanadium -	Greenish (yellow hot).	Green.

6. Test with microcosmic salt (salt of phosphorus) bead.

This test is carried out in the same way as that with the borax bead. The results obtained with microcosmic salt differ somewhat from those obtained with borax. In some instances microcosmic salt yields more definite results. This is notably the case with nickel, uranium, and molybdenum. A microcosmic salt bead is not so readily made as one of borax owing to the greater mobility of the former, and the large

Metal.	Oxidizing flame.	Reducing flame.
Iron - -	Pale brownish colour.	Pale brownish colour.
Manganese -	Violet.	Colourless.
Titanium -	Colourless to pale yellow.	Violet (deep red when iron present).
Tungsten -	Colourless to pale yellow.	Blue (deep red when iron present).
Copper - -	Blue.	Opaque and light red.
Nickel - -	Yellow.	Yellow.
Cobalt - -	Deep blue.	Blue.
Chromium -	Bright green (slightly yellowish).	Emerald-green.
Molybdenum -	Yellowish green.	Green.
Uranium -	Yellowish green.	Emerald-green.
Vanadium -	Yellow.	Green.

amount of water it gives off when fused. For this reason it is advisable to work with a rather smaller bead in the case of microcosmic salt. In preparing the bead it is better to take up a little at a time and fuse gently, than to take up a large quantity which is almost certain to drop from the wire when heated.

The lower table on the previous page gives a list of the chief metals which produce characteristic colours in salt of phosphorus beads, and the colours produced by them in cold beads.

7. Blowpipe reactions on charcoal without fluxes.

Certain minerals yield characteristic sublimates when roasted alone on charcoal. One of the best examples of the utility of this operation is the charcoal test to distinguish molybdenite from graphite, which it closely resembles. Molybdenite, unlike graphite, yields a white sublimate, which is converted to a characteristic deep blue colour when touched with the reducing flame. Sulphides yield the unmistakable smell of burning sulphur when roasted on charcoal; and arsenic minerals give the odour of garlic. It is usually preferable to carry out these roastings on coarse fragments rather than on powder, as the powder is scattered by the blowpipe blast.

The following are the more important of the sublimates produced by roasting minerals alone in the oxidizing flame on charcoal:

ARSENIOUS OXIDE (As_2O_3), a white and very volatile sublimate, the formation of which may be accompanied by the odour of garlic.

ANTIMONY OXIDES (Sb_2O_3 and Sb_2O_4) also form a white sublimate, which is, however, less volatile than that of arsenious oxide, and is therefore deposited in closer proximity to the roasted mineral.

LEAD OXIDE (PbO).—This sublimate is deep yellow when hot and pale yellow when cold, and forms near the assay. When galena and some other lead minerals are heated intensely on charcoal, a dense white sublimate consisting of a mixture of lead oxide, lead sulphite and lead sulphate is formed further from the assay. If a mixture of potassium iodide and sulphur (1 : 1) is added to the assay and the roasting repeated, a characteristic bright yellow sublimate is obtained.

BISMUTH OXIDE (Bi_2O_3).—This sublimate is orange yellow, both hot and cold. On re-roasting after the addition of a mixture of sulphur and potassium iodide to the assay, a characteristic vermilion-coloured sublimate is obtained.

ZINC OXIDE (ZnO).—This sublimate is yellow when hot and white when cold. After moistening with cobalt nitrate and re-roasting, it turns green.

Tin Oxide (SnO_2).—When metallic tin is heated in the oxidizing flame on charcoal it yields a white sublimate which turns bluish green when moistened with cobalt nitrate and re-roasted. This test may be applied to the globules of metallic tin obtained by the reduction of cassiterite (see below).

Molybdenum Oxide (MoO_3).—This sublimate is white, and is formed when a fragment of molybdenite is roasted alone on charcoal. On touching the white sublimate with the reducing flame, a characteristic deep blue colour is obtained due to the formation of a lower oxide. This test requires a fairly substantial fragment of the mineral. If only a small flake or a little powder is available, the flame test should be applied, or the nitric acid test mentioned on p. 222.

8. Blowpipe reactions on charcoal with sodium carbonate as a flux.

In preparation for this operation a little of the powdered mineral should be mixed with three or four times as much sodium carbonate, and made into a thick paste with a drop or two of water. This paste is most conveniently made on the palm of the hand, by manipulation with a clean spatula or penknife. When properly managed, a fairly compact admixture is obtained, which permits of vigorous treatment in the reducing blowpipe flame on charcoal. Many minerals yield metallic globules when reduced with sodium carbonate on charcoal in this way. The following are the properties of the principal metals obtained in blowpipe work :

Lead.—Greyish white in colour ; soft, malleable, and marks paper. Its formation on charcoal is accompanied by a yellow incrustation of lead oxide. The metal dissolves in a hot solution of hydrochloric acid, forming lead chloride which is soluble in hot water, but precipitates on cooling. A little of the fused mass should be left on the charcoal, and re-treated in the blowpipe flame after adding a little of the mixture of potassium iodide and sulphur, to obtain the characteristic and brilliant incrustation of lead iodide.

Bismuth.—Greyish white in colour, but rather brittle, and does not mark paper. Gives a yellow incrustation ; but in this case re-treatment in the blowpipe flame after adding a little potassium iodide and sulphur results in the formation of a bright vermilion-coloured incrustation.

Tin.—Metallic globules of tin are bright when hot and freshly reduced, but become dull on cooling, through oxidation. When the fused mass is hammered, however, the tin, being malleable, yields white metallic plates. By treating the metal in the oxidizing flame on a fresh piece of charcoal, a white incrustation of tin oxide is obtained, and this turns bluish green when moistened with cobalt nitrate and re-heated in the oxidizing flame. Another test to which a small piece of metallic tin can be conveniently submitted is that of treating it with one or two drops of fairly strong nitric acid and heating gently. This converts the tin into a comparatively bulky mass of white tin oxide.

Cassiterite (tinstone), the ore of tin, does not readily yield metallic tin when reduced on charcoal with sodium carbonate alone. If, however, in preparing the mixture for treatment on charcoal, a little powdered charcoal be added, the reduction takes place without difficulty.

COPPER.—This metal is malleable, and has a characteristic red colour. Large beads of the metal are not so readily obtained as in the case of the more fusible metals such as lead, bismuth and tin. The reduced mass should be crushed in an agate mortar, and the lighter material washed off. In this way the copper can often be obtained in the form of fine-red scales even when its presence is not obvious during reduction on charcoal. This treatment can be applied advantageously in other cases of malleable metals, as a means of separating the metal from the fused mass in which it is embedded.

SILVER.—White and malleable. Dissolves in dilute nitric acid, yielding a solution which gives a white precipitate of silver chloride on adding a few drops of hydrochloric acid.

In addition to the examination for metals, there are two or three other tests that may be applied to the fused mass obtained on charcoal with sodium carbonate.

MAGNETIC CHARACTER.—The mass obtained by fusion with sodium carbonate may be black and highly magnetic. This is notably the case with minerals containing a large amount of iron.

TEST FOR PRESENCE OF SULPHUR.—If a little of the fused and reduced mass is placed on a silver coin in a few drops of water, a black stain due to the formation of silver sulphide indicates the presence of sulphur in the mineral.

TEST FOR IRON, TITANIUM, AND TUNGSTEN.—If the fused mass is treated with a strong solution of hydrochloric acid, a deep brownish yellow solution will be obtained if much iron is present in the mineral. This colour is due to ferric chloride, and can be destroyed by adding a little granulated tin or zinc and heating for some time, the ferric chloride being reduced to colourless ferrous chloride. At the same time, if much titanium is present, a violet-coloured solution of titanium chloride will be obtained. In the presence of tungsten, a deep blue colour is produced, and this changes to a greenish colour on dilution with water.

9. Fusion in platinum spoon or crucible with sodium carbonate or potassium hydrogen sulphate.

Insoluble silicates may be fused with five or six times as much sodium carbonate, or fusion mixture, to which a little potassium nitrate has been added. If manganese is present the fused mass will be pale green in colour. Chromium yields a yellow mass. After fusion is complete, the mass should be dissolved in hydrochloric acid, evaporated to dryness, and kept for an hour or so at a temperature of about 105° C. On treating the mass with dilute hydrochloric acid, any silica present will remain insoluble, and on filtering this off the bases in solution can be tested in the wet way.

In some instances it is preferable to carry out the fusion with potassium hydrogen sulphate ($KHSO_4$). This is notably the case with columbite and other niobates. Rutile dissolves very readily in fused hydrogen potassium sulphate, and yields a good titanium reaction (violet colour) when the fused mass is digested in hydrochloric acid and reduced by adding a scrap of metallic tin.

CHAPTER VI.

THE PHYSICAL ANALYSIS OF CRUSHED ROCKS AND LOOSE DETRITAL SEDIMENTS.

General.

THE student of economic mineralogy will find it very useful to acquire a knowledge of the characters of crushed fragments of minerals. For some purposes it is necessary to examine rocks and minerals in sections; but it is remarkable how often, for ordinary practical purposes, an examination of splinters and crushings gives all the information that is necessary. The realization of this fact is important in the every-day work of anyone who has to take a severely practical interest in mineral studies. It applies to some extent to the study of textures as well as to the study of the minerals themselves.

It is indeed frequently possible by deftly chipping off a few splinters to determine both the texture and mineral composition of a specimen as effectively as one would be able to do it by the examination of sections, whilst avoiding the oft-times inconvenient delay, trouble and expense that the examination of sections involves. At any rate, even where sections are required, there is every reason why one should avail himself of the advantage offered by the readier method of examining splinters and crushed fragments. Moreover, this method of examination often yields useful information that cannot be got by merely examining sections, imprisoned as these usually are in a conventionally mounted slide.

A few pages may therefore be here conveniently devoted to a description of various simple methods whereby rocks, and mineral admixtures generally, may be separated into their different constituents, or concentrated to some extent even where complete separation is not possible. This work of separation and concentration, as carried out on a large scale in ore-dressing operations, fills an important place in the mineral industry. A simple course of laboratory study in methods of mineral separation and concentration therefore serves a double purpose. It equips the student with a knowledge of methods that are very important in determinative mineralogy, and it also furnishes him with a knowledge of the principles involved in methods of ore-dressing.

It is noteworthy that the mineral fragments of crushed rocks exhibit a variation of form which depends largely on the presence or absence of cleavage, and on the nature of the cleavage. Moreover, weathering and attrition operating on rocks and rock-detritus develop the cleavage and fracture-forms of the constituent minerals in much the same way as artificial crushing, though in detrital material the points and edges of the grains tend to become rounded. The prolonged abrasion of non-cleavable minerals rounds off the asperities of fragments completely. This is especially noticeable in grains that have been abraded by wind action, as under desert conditions, and in some cases the grains take on a pronounced polish. The softer minerals, such as monazite, require little abrasion to yield well-rounded grains (see fig. 247). Harder minerals, such as quartz, zircon, and tourmaline, suffer abrasion less readily, though well-rounded grains of these minerals are found frequently.

Those minerals that occur frequently in igneous rocks in the form of very small and well-formed crystals, are generally found in loose sediments in much the same condition, *e.g.* tourmaline (fig. 203) and apatite (fig. 175). Minerals with one perfect cleavage, *e.g.* mica and topaz, yield forms that are almost invariably platy. When two good cleavages are present, and two only, we get prisms, *e.g.* kyanite (fig. 192). When three or more good cleavages are present, we may still get characteristic forms in microscopic fragments. Thus calcite, with its rhombohedral cleavage, yields rhomboidal forms (fig. 213), and fluorite, with its octahedral cleavage, yields triangular plates (fig. 225).

Hence the mineral grains of crushed rocks and loose detrital sediments have on the whole a much greater constancy of appearance than have the minerals observed in rock slices; and this is especially true of minerals with cleavages. Kyanite, for instance, shows constancy of extinction-angle in fragments, since the grains are usually lying on the best cleavage face; whereas in rock sections the extinctions are very variable. The same holds true of pleochroism, refractive index, birefringence and compensation tests.

Preparation of material for examination.

The course of procedure to be adopted in examining crushed mineral fragments depends to some extent on the circumstances of the case.

In some instances one or two observations only are necessary, for the purpose of confirming conclusions suggested by one's experience; and in such instances only a few small fragments require to be examined. To this end a few splinters can be scraped off the specimen with a file directly on to a slide, and mounted in cedar oil. It is more often preferable, and it takes very little time, to crush one or two grams with hammer and steel anvil, transfer the small pieces to a small agate mortar, and reduce them to a suitable degree of fineness by crushing with an agate pestle. It is then convenient to place the crushings in a watch-glass, wash off the dust, and dry the residue, which is then ready for separation or direct examination with the microscope.

The dust is a nuisance in every way; not only does it interfere with separation of one mineral from another, it also adheres to the coarser grains and makes optical examination less satisfactory than when the washed grains are examined. This is especially the case with volcanic rocks, crushings of which usually contain a large amount of dust; and this dust may completely mask the crystalline granules present, if the crushed material is mounted for optical examination without the crushings being previously washed.

When it is necessary to take comparatively large amounts to represent more accurately the material being examined, it is advisable to avoid the production of dust as much as possible, especially when this arises from the powdering of crystalline matter. The production of dust can be minimised by frequent sifting during the crushing operation, the sieve used being determined by the fineness of grain required. A twenty-gram sample of crushings, which in special cases may represent a quartered-down sample of much larger bulk, is conveniently washed in a small porcelain dish or clock-glass.

When, instead of a compacted aggregate of minerals, a sand or some other loose detrital material has to be examined, the operation is less troublesome, as crushing is unnecessary. Under these considerations, if much clayey matter is present it is best to dry the material fairly thoroughly in a water oven, and then disintegrate by placing in water in small pieces, washing off the mud as dust is washed from rock crushings.

The chief methods available for the laboratory separation of crushed fragments or loose detritus are sifting, elutriation, decantation, panning, heavy-liquid separation, magnetic separation, electrostatic separation, and separation by chemical means. No attempt will be made here to give a complete account of the numerous ways in which these methods have been applied by different workers. Only a brief account will be given to show how, by comparatively simple means, this work of mineral separation can be carried out in the laboratory.

Sifting.

When, as is sometimes the case, there is a substantial difference in the grain-sizes of two minerals in a detrital sediment or crushed rock, concentration can be effected by mere sifting. For many purposes a set of three sieves with respectively 30, 60 and 90 meshes to the linear inch is sufficient; but sieves ranging up to 200-mesh can be obtained and are useful for some purposes.

When sifted, a natural gravel or sand consisting chiefly of quartz, and containing small amounts of zircon, tinstone, monazite, or other heavy minerals, generally shows some degree of concentration of the heavier minerals in the finer siftings. This is owing to the fact that, with minerals differing substantially in specific gravity, the hydraulic value of a comparatively light grain of any given size corresponds to that of a smaller grain of a comparatively heavy mineral. Consequently in a natural sand, the average diameter of the quartz grains as a rule substantially exceeds that of the heavier mineral such as monazite, zircon, or tinstone.

Again, where there is a difference in shape, concentration can often be effected by sifting. It is a familiar fact in petrology that, in a micaceous sandstone, the diameter of the mica flakes exceeds that of the quartz grains. This is due to the fact that platy and faceted grains have a greater surface in relation to their mass than have rounded grains, and are consequently more readily agitated in moving water, or settle more slowly in still water, than rounded grains of the same mass. Hence when a micaceous sand is sifted, the mica becomes concentrated in the coarser portion of the siftings.

In this connection it is worthy of note that mica can often be concentrated very effectively in a micaceous rock by crushing and sifting. For instance in a quartz-schist that owes its foliation to the presence of a small amount of mica, the tough plates of mica resist crushing, whereas the brittle quartz is readily powdered, after which sifting results in a very substantial concentration, or even approximate isolation of the mica. The isolation in this case can be made still more complete by placing the concentrate on a smooth inclined surface of paper or cardboard and tapping gently, when the quartz grains will roll down whilst the mica plates lag behind.

A specimen of practically pure platy mica can often be separated from a quartz-schist in this simple mechanical way. The operation is especially to be recommended as a striking and effective means of concentration in the case of the green variety of avanturine, which is a quartz-schist coloured by flakes of the green chromium-bearing mica fuchsite (see p. 312).

For some purposes more elaborate sieves can be used with advantage in sizing or grading both the coarser and finer grains of crushed minerals and detrital sediments. For sizes of 0·5 mm. diameter and over, sieves with circular apertures can be obtained. If it is desired to carry out a fairly accurate quantitative grading of the finer material of a crushed sample or a detrital sediment, it is usual to adopt the method of mechanical analysis by elutriation.

Mechanical analysis.

Mechanical analysis is the operation of classifying a mass of loosely aggregated particles into various grades according to the size of the particles, in order to ascertain the texture of the mass. By thus classifying or grading particles according to size, and ascertaining the relative proportions of the different grades present, important inferences can be drawn as to the physical properties of the mass, such as, for instance, its permeability to water or other fluids, its porosity, and its capillarity. The importance of mechanical analysis as a means of study has long been recognized by practical scientific workers, notably in agriculture, ceramics, and petrography. It has indeed a very wide sphere of usefulness in the investigation of crushed rocks, slimes, sands, clays, and other sediments, including refractory clays, glass sands and moulding sands.

Classification of grades.—There has always been some difference of opinion as regards the limiting sizes that should be adopted for grading purposes, and the choice of limits is necessarily to some extent an arbitrary matter.

The adoption of 1 mm. as a unit, with decimal multiples and subdivisions, gives a very convenient set of limits for the broad classification of grades, and perhaps no other broad grouping of grades has such a strong claim to recognition, whether on grounds of general utility or of international usage. This mode of grading gives us the following broad grades :

Large stones - - - - - - -	>10 mm. diameter.
Gravel - - - - - -	10 mm.—1 mm.
Sand - - - - - - -	1 mm.—0·1 mm.
Silt - - - - - - -	0·1 mm.—0·01 mm.
Mud - - - - - - -	<0·01.

The extent to which these grades should be subdivided depends on the special requirements of the work in hand. Much could be said for the plan of further subdivision by doubling the number of grades, adopting decimal multiples and subdivisions of 0·3̇ mm., and thus making a coarse and fine subdivision for each of the above-mentioned grades. This plan, however, has not been widely adopted. The custom has been to adopt limits of 0·5 mm., 0·25 mm. and 0·05 mm. diam. for subdividing the sand and silt grades. If, out of deference to established custom, we adopt these limits, using decimal multiples and subdivisions of 0·5 mm., we get the following further grading :

	Diam. in mm.		Diam. in mm.
Gravel	10—1	Coarse gravel	10 — 5
		Fine gravel	5 — 1
Sand	1—0·1	Coarse sand	1 — 0·5
		Medium sand	0·5 — 0·25
		Fine sand	0·25—0·1
Silt	0·1—0·01	Coarse silt	0·1 — 0·05
		Fine silt	0·05—0·01
Mud	<0·01	Mud	<0·01.

Further subdivisions, where necessary for special purposes, can be made according to requirements ; but in making such further subdivisions one should consider whether any practical purpose is to be gained by so doing. The mere multiplication of grades, apart from any knowledge we may have of its physical significance, is of no value. As regards the physical characteristics of the grades mentioned above, it is noteworthy that sand and gravel possess a high degree of permeability, whilst the mud grade is impermeable. The silt grade is intermediate in its properties and exercises a moderating effect. It possesses a high degree of capillarity, and this property attains its maximum development in the fine silt grade.

Methods of grading.—The coarse grades are separated by sifting, the finer grades by hydraulic treatment, preferably by elutriation. For sand and coarser grades, close grading can be carried out quickly and accurately by means of sieves, and the separation of these therefore presents no difficulty, as sieves corresponding to the 0·25 mm. limit are made with fair accuracy. The finest sieve made with any considerable measure of accuracy is the 120-mesh sieve, which corresponds closely to the 0·1 mm. limit. Sieves of such fineness are apt to clog, but many workers prefer to wet-sift at the 0·1 limit, as they distrust the results of elutriation on such coarse particles.

These facts as to the limited applicability of sifting in mechanical analysis define clearly for us the scope of the elutriation method, which is quite necessary for effective and accurate separation at the 0·01 mm. and 0·05 mm. limits, and which is applied with advantage even at the

0·1 mm. limit. The serious problem in mechanical analysis, therefore, is how to make a quick and fairly accurate separation at these limits, *i.e.* how to separate fine sand, coarse silt, fine silt and mud.

In what follows, it will be assumed that the sand and coarser grades should be separated from each other by sifting; that sand, coarse silt, fine silt and mud should be separated from one another by subsidence or preferably by elutriation; and that grading by elutriation cannot be carried out with any substantial measure of accuracy beyond the 0·01 mm. limit.

Hydraulic values corresponding to grade limits.—In making a mechanical analysis by hydraulic methods we need to know something of the relation between rates of subsidence and sizes of grains. In general the rates of subsidence of grains in still water vary with the size, shape, and density of the grains. The density factor diminishes in importance with the size of the grain, and this is a feature of considerable importance in mechanical analysis. For sand grains density is a significant factor in determining rates of subsidence; for silt grains it is less important; and in the mud grade there is a limit beyond which particles of the same size and shape are affected similarly in spite of considerable differences in density, owing to the insignificance of gravitational differences as compared with surface resistance.

The shape of a grain is also an important factor in determining its behaviour in either still or moving water. A faceted grain offers a greater surface resistance than does a rounded grain of the same mass, and consequently subsides more slowly in still water, or rises more rapidly in an upward-moving current. Platy particles are very erratic in their behaviour. The effect of shape on rate of subsidence can be observed very readily by comparing rounded quartz grains with cleavage fragments of calcite, or with flakes of mica.

In fact, mechanical analysis does not yield results of a very high order of accuracy for a mixture of grains of widely different densities, and this is especially true of the 0·1 and 0·05 mm. limits. It is for this reason necessary to adopt some empirical standard of hydraulic values, or rates of subsidence, based on elutriation results under known conditions, and use these as a basis of measurement. It is clear from the foregoing considerations that mineral composition must be taken into account, and any serious departure in mineral composition from that corresponding to the standard adopted makes it desirable to separate at the 0·1 mm. limit by sifting.

Now as a rule, the sand, silt, and coarse mud portions of a sediment consist almost entirely of quartz and other minerals having much the same density. For the mechanical analysis of ordinary sands, loams and clays, it is therefore desirable to standardize hydraulic values in terms of rounded or granular particles of quartz.

Careful elutriation tests carried out with quartz grains show that granular particles of about 0·01 mm., 0·05 mm., and 0·1 mm. diam. have approximately the following hydraulic values :

Size of particle.	Hydraulic value.
0·1 mm. diam.	7·0 mm. per sec.
0·05 ,,	2·0 ,, ,,
0·01 ,,	0·15 ,, ,,

In accordance with the classification of particles recommended above (p. 94), 0·01 mm. diam. is the limit separating the mud and silt grades, 0·05 mm. diam. the limit between fine and coarse silt, whilst 0·1 mm. diam. is the limit separating silt and sand. It is unnecessary for most purposes to have more than two silt grades ; but should a medium silt grade with a limit of 0·025 mm. be required, it may be noted that this limit corresponds to a hydraulic value of about 0·5 mm. per second.

The liability to flocculation in the mud grade makes it difficult to produce further subdivision in this grade with any measure of accuracy, and for most purposes it is well to be satisfied with the 0·01 limit. If it is required to separate the mud into two grades this is best done by subsidence and decantation, by placing in a large cylinder, filling up to the 24 cm. level, stirring thoroughly and allowing to stand for 24 hours. By repeating this until the supernatant water remains clear the coarse mud or comparatively quick settling portion can be separated from the fine mud, which is mostly clay, and which remains an indefinitely long time in suspension. In making this separation of mud into two grades, one should not delude himself into thinking that the results are or can be very accurate. It is better not to pretend that there is any definite size limit between the coarse and fine mud grades thus obtained. It is at times useful to compare clays by subdividing the mud grade in this way, but when this is done great care must be taken to disintegrate the clay thoroughly, and to deflocculate effectively by the use of ammonia or carbonate of soda.

We have just seen that the operation of mechanical analysis, below the limit at which sifting is practicable, is concerned chiefly with separation at the silt-grade limits, viz., 0·01 mm. diam., 0·05 mm. diam., and 0·1 mm. diam., corresponding to hydraulic values of 0·15 mm., 2·0 mm., and 7 mm. per second respectively. This separation can be effected in two ways : (1) by subsidence, the particles being allowed to subside for a time in water after agitation ; (2) by elutriation in rising currents of water moving at definite speeds.

Subsidence and decantation.—Subsidence methods are very simple and easily applied, as they involve the use of beakers and cylinders only. The deflocculated sediment is first thoroughly stirred and then allowed to stand until particles of the hydraulic value in question have had time to settle to the bottom and the supernatant liquid with its suspended matter is then decanted or siphoned off.

It is convenient to have marks on the beaker indicating the heights at which the water level is allowed to stand in timing the subsidence. Convenient heights are 9 cm., 12 cm. and 14 cm. above the base of the beaker. To carry out the operation place 20 or 30 grams of the deflocculated sediment in a beaker and fill up to the 9 cm. level. Stir thoroughly and allow to stand for 10 minutes. In this time all the particles having a rate of subsidence of 0·15 mm. (0·01 mm. diam.) will have settled to the bottom. Siphon off or decant the water with muddy matter in suspension. Repeat the operation, and continue until water siphons off free from suspended matter.

Having siphoned off all the mud, fill to the 12 cm. level, and after thorough stirring, allow to stand for 1 minute, after which time particles having a rate of subsidence of 2 mm. per second (0·05 mm. diam.) will have settled. Then decant. Repeat until all the fine silt (0·01 diam.—0·05 mm. diam.) is decanted off.

Now fill up to the 14 cm. mark, stir thoroughly, and allow 20 seconds for the time of subsidence, corresponding to a rate of subsidence of 7 mm. per second (0·1 mm. diam.). Then decant and repeat until no more coarse silt (0·05 mm. diam. to 0·1 mm. diam.) remains.

The residue of sand remaining behind can be separated by sifting into coarse, medium, and fine sand grades. By this operation then, we have obtained six grades from the sand and finer material, viz., three sand grades, two silt grades, and one mud grade.

Elutriation.—By this method the particles are graded in an upward-flowing current of water. The method can be applied conveniently to material that has passed a sieve with circular apertures about 1 mm. in diameter ; and it serves very well to separate such material into the four grades sand (1 mm. to 0·1 mm. diam.), coarse silt (0·1 mm. to 0·05 mm. diam.), fine silt (0·05 mm. to 0·01 mm. diam.), and mud ($<$0·01 mm. diam.).

If a particle subsides in still water at a certain speed, it will remain suspended in a water-current rising upward at that speed, whereas all particles with a slower rate of subsidence will be carried upward in the current. In order to separate sand, coarse silt, fine silt, and mud by elutriation, an apparatus is required in which fairly uniform speeds of 0·15 mm., 2 mm., and 7·0 mm. per second can be obtained, these being approximately the hydraulic values for particles of quartz having diameters of about 0·01 mm., 0·05 mm., and 0·1 mm. respectively. The following is a simple apparatus by means of which these speeds can be obtained.

It consists of two glass vessels (shown on the left side of fig. 99), having in their cylindrical portions internal diameters of 1·4 cm. and 9·6 cm. respectively, *i.e.* the internal cross-section of the upper cylinder is about 47 times that of the lower. Therefore if water is passed through these cylinders under constant pressure, and the outflow regulated so as to maintain a speed of 0·15 mm. per second in the upper cylinder, a speed of 0·15 × 47 = 7·0 mm. per second will be obtained in the lower cylinder.

The upper cylinder is about 5 cm. long, and is drawn out conically above and below. The lower conical portion is about 20 cm. long and is prolonged at its lower extremity as a plain tube about 1·4 cm. in diameter and about 2 cm. long; this tubular lower extremity is connected with the upper extremity of the lower cylinder by a piece of strong rubber tubing of not less than 1 cm. internal diameter, which carries a screw-pinch clip. The upper conical portion is about 5 cm. long and is terminated above by a thickened cylindrical neck into which fits a two-holed rubber stopper. This stopper carries a thin bent outlet tube and a pressure gauge, consisting of a glass tube, about thirty or forty centimetres in length, open at both ends.

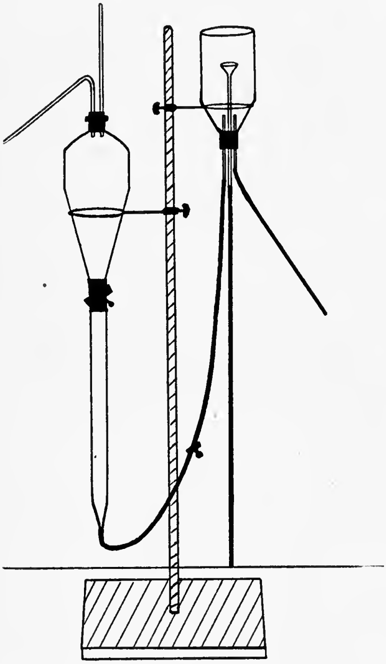

FIG. 99.—Elutriator.

The outlet tube is constricted at the outlet by being drawn out after the fashion of a wash-bottle outlet tube. The outlet should have a diameter of about 1 mm.

The lower cylinder is about 30 cm. in length, or longer if desired, and is uniform throughout, except at the lower extremity, where it has a conical constriction.

A small reservoir supplies water at constant pressure. It can be supported on a retort-stand, as shown on the right side of fig. 99, and the level fixed as required for any given outlet tube. The neck is fitted with a tight-fitting rubber stopper, carrying three holes. A long-necked funnel is inserted in one of these, and is connected with a tube leading to the sink. This serves as an overflow, and fixes the level. Each of the other holes is fitted with a plain tube. One of these is connected with the water-supply; the other supplies water to the cylinders by a rubber-tube connection with the lower extremity of the lower cylinder. This connecting tube should be narrow (about 3 mm. internal diameter) so as to produce a current sufficiently strong to keep the sand from choking it, and to maintain the sediment in a state of agitation in the lower cylinder. A screw-pinch clip on this tube permits the flow of water to be generated or checked as required; or as an alternative to this the tubular lower extremity of the lower cylinder may be provided with a glass stop-cock.

If the apparatus is so arranged that there is a head of water of about 25 cm., water will flow out at the rate of about 100 cc. in 92 seconds. If the rate found by experiment is slightly more or less, the head of water can be modified accordingly until the required outflow is obtained. With cylinders having internal diameters of 1·4 and 9·6 cm., an outflow of 100 c.c. in 92 seconds yields speeds of 7·0 mm. per second and 0·15 mm. per second respectively.

To standardize for the 2 mm. speed in the large cylinder detach the constricted outlet tube with its rubber fitting, and, using the 4 mm. outlet aperture, adjust the head to obtain an outflow of 250 c.c. in 17 seconds, which corresponds to the speed required.

When the required rate of outflow has been obtained, the position of the top of the water-column in the pressure-gauge should be marked, this mark serving as a constant with the particular outlet-tube used; and care should be taken to see that the pressure-gauge and head of water are properly adjusted when making an analysis. The heads required to secure these levels in the pressure-gauge depend to some extend on the nature of the sediment, the obstructive effect of which varies according to its mechanical composition.

The only part of the apparatus that requires to be specially made is the upper cylinder. The rest of the apparatus can be easily put together from materials usually kept in stock in laboratories.

Once fixed up there is, with ordinary care, little or no risk of breakage.

To use the apparatus, let the upper screw-clip be open, and the lower one closed, and let the lower cylinder be filled with water. Disconnect the rubber stopper and pour the 20 grams of boiled deflocculated sediment into the upper cylinder through a funnel. It is convenient to take 20 grams of material that has passed the 1 mm. sieve. Alternatively a suitable amount of the material that has been dry-sifted on the 5 mm. sieve can be wet-sifted on the 1 mm., 0·5 mm. and 0·25 mm. sieves, the material passing the last being placed in the elutriator.

Allow the sediment to settle as much as possible into the lower cylinder, and pour water into the upper cylinder till practically full. Insert the stopper, open the lower screw-clip, and proceed with the elutriation.

Grains having a hydraulic value of less than 7·0 mm. per second are carried into the upper cylinder; and particles having a value of less than 0·15 mm. per second escape at the outlet tube. When the upper cylinder has run fairly clear, pinch the upper screw-clip slightly so as to increase the speed in the connecting tube and allow the upper part of the lower cylinder to clear. The lower cylinder will then contain the sand, the upper the silt, and the mud will have been carried over.

Close the upper screw-clip, then the lower, and disconnect the lower cylinder from the rubber connection with the upper one. The sand can then be washed into a porcelain dish by inverting the cylinder and opening the lower screw-clip to secure a flow of water. If wet sifting on the 0·5 mm. and 0·25 mm. sieves has not already been done the sand can be dried and separated into coarse, medium, and fine by means of these sieves.

To separate the silt in the upper cylinder into coarse and fine grades, re-connect the two cylinders, and continue the elutriation after detaching the 1 mm. outlet tube, operating with the 4 mm. outlet aperture so as to obtain a speed of 2 mm. per second in the upper cylinder, readjusting the head as required. In this way the fine silt is quickly carried over into a separate vessel, leaving the coarse silt in the cylinder.

The sand and silt grades are readily collected and weighed. The collecting and weighing of the mud is a more tedious operation. It can be best done by flocculating the sediment, allowing to settle, drawing off the supernatant clear water, evaporating the remainder to dryness on a water-bath, and collecting and weighing the dried residue. But in view of the length and uncertain accuracy of this operation, it is perhaps permissible to adopt the alternative method of devoting scrupulous care to the collecting and weighing of the sand and silt grades, and estimating the mud by difference.

The problem of elutriation is simplified considerably by wet-sifting at the 0·1 mm. limit, and elutriating in a single cylinder with speeds corresponding to the 0·01 and 0·05 mm. limits. There is much to be said in favour of this procedure, though it is more tedious.

In preparing a muddy or clayey sample for elutriation, it is desirable that the material should be disintegrated by boiling and gentle pestling, a little sodium carbonate or ammonia being added afterwards to produce deflocculation.

Some idea of the usefulness of elutriation as a means of grading the finer particles may be gathered from a consideration of the approximate sizes of the apertures of fine sieves. These sizes for 60-, 90-, 120- and 200-mesh sieves are roughly 0·25 mm., 0·15 mm., 0·1 mm. and 0·065 mm. diameter respectively. From these figures it is clear that the 200-mesh sieve, which at best is not a reliable one to use, is far too coarse to separate silt from mud, as these grades have been defined above. The significance of this failure of sieves to secure a satisfactory grading of fine particles may be seen from the fact that the average limit of effective mechanical concentration is somewhere near the 0·01 value. If we also take into consideration the fact that 0·01 mm. diameter is about the limit at which impermeability begins to develop, it becomes evident that the 0·01 mm. limit is a very useful one for demarcating silt from mud or slime. Indeed, this limit varies somewhat for different minerals, chiefly in accordance with density and shape ; but the grade here defined as mud corresponds very closely to the true slime of the cyanider and ore-dresser generally, or would do so if the term "slime" were used with more precision.

Concentration by panning.

The object of the familiar panning operation as carried out by the prospector is to separate as far as possible the particles of one mineral from those of another. This separation depends chiefly on the density factor, and is based on the fact that, when a mixture of grains of substantially different densities are agitated under water, the lighter grains arrange themselves in the upper, and the heavier in the lower layers. In this operation the best results are obtained with sand, *i.e.* with grains ranging from about 0·1 to 1 mm. in diameter. Indeed, the operation is inapplicable to dust or fine mud, since for this fine material the factor of relative density is insignificant compared with that of the surface resistance offered by the grains to movement in water.

Consequently, in the process of concentration by panning, any slow-settling mud or dust that may be present is necessarily washed off.

A convenient pan for use is one made of iron, about three inches deep, having a circular base about eight inches in diameter, and sides sloping outwards to a thickened upper margin about a foot in diameter. With such a concentrating dish two or three kilograms of sediment can be conveniently treated at one operation.

The conical *batea* also gives good results, and by some is much preferred to the flat-bottomed pan.

The object of a panning operation is to wash away the particles of quartz and other light ingredients, and obtain a residue of the heavy minerals which are almost invariably present, though they usually constitute only a very small percentage. Care having been taken in the first place to have the pan thoroughly clean and free from grease, the sediment is placed in the pan, covered with water stirred until the particles are thoroughly wetted, and freed from mud by decantation. The sand is then gently agitated by to-and-fro, side-to-side, and horizontal circular movements, which cause the heavier grains to settle towards the bottom of the pan. After a minute or two the uppermost layer can be washed over the margin of the pan, and the operation continued until the heavier minerals, if present, have been concentrated in the last portion remaining in the pan, in which they can as a rule be readily distinguished from the quartz. When as much of the quartz as possible has been eliminated, the heavy residue can be washed into a watch-glass or porcelain dish by means of a wash-bottle, and dried.

If the operation is carried out carefully, most of the rounded grains having a density greater than 3 will be left in the residue. Platy fragments with a density substantially exceeding 3 may be washed off. If the amount of sediment available is comparatively small, and it is desired to obtain as much as possible of the heavier grains, the first washings should be saved by washing them into a second pan or other receptacle, and the operation repeated on them, when a little more of the heavy residue will usually be obtained.

A concentrating dish used in this way is a very economical and excellent qualitative method of obtaining in a small bulk the heavy minerals scattered through a large volume of sand, of which they frequently constitute much less than 0·1 per cent.

When the sample to be concentrated is small, a wooden batea is convenient; and a watch-glass or clock-glass can often be used with advantage.

Heavy-liquid separation.

The most important heavy liquids for use in making mineral separations are as follows (the three which are most used being italicised):

Liquid.	Density.	Melting-point.	
1. *Bromoform*	2·85	—	Dilution of liquid and washing of grains to be effected by means of benzene. Liquid at ordinary temperatures.
2. Acetylene tetrabromide	3·0	—	
3. *Methylene iodide*	3·33	—	
4. Methylene iodide + iodine	3·6	—	
5. Mercury potassium iodide	3·20	—	Dilution of liquid and washing of grains to be effected by means of distilled water. Nos. 5, 6, and 7 are aqueous solutions.
6. Cadmium borotungstate	3·25	—	
7. Barium mercury iodide	3·5	—	
8. *Mercurous nitrate* (*crystalline*)	4·3	70° C.	
9. Thallium silver nitrate	4·5	75° C.	
10. Thallium mercury nitrate	5·3	76° C.	

By the use of these liquids, quantitatively accurate separations of minerals can be made in many cases. Perhaps the most useful and convenient are the organic liquids, viz. bromoform, acetylene tetrabromide, and methylene iodide. They are very mobile, evaporate without leaving a residue, are non-corrosive, and do not attack carbonates. The readiness with which grains can be washed with benzene after separation, the absence of residue on the grains, and the rapidity with which they dry, are considerable practical advantages.

For general use, and especially for the quantitative estimation of the total amount of heavier minerals present, bromoform, which is comparatively cheap and effective, can be strongly recommended.

The chief disadvantage of methylene iodide is its expense. It tends to darken through the separation of iodine, but can be cleared by shaking with a little copper wire. For special use the density of methylene iodide can be increased to 3·6 by adding iodine, though the solution thus obtained has the disadvantage of being very dark-coloured.

The corrosive action on the skin and the extremely poisonous character of a solution of mercury potassium iodide make it objectionable. Cadmium borotungstate is rather viscid, has an acid reaction, and crystallizes out very readily; these are serious drawbacks to its use. Barium mercury iodide is rather unstable, and is not required if methylene iodide is used.

Mercurous nitrate, thallium silver nitrate, and thallium mercury nitrate, unlike the previously mentioned salts, are used in a state of fusion. On account of its cheapness, its lower melting point, and its superior mobility, mercurous nitrate ($HgNO_3 \cdot H_2O$) should be used where possible. As far as detrital minerals are concerned, it will be found in practice that most of the separations for which the thallium salts are usually recommended, can be made quite as well with mercurous nitrate.

On account of their expensiveness, the thallium salts should only be used in separations that cannot be made in any other way. It is important to remember that thallium silver nitrate attacks pyrite, whilst the mercury salt does not; but against this advantage of the latter is to be placed the fact that it is less stable.

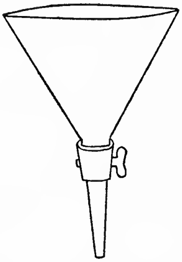

FIG. 100.—Open funnel separator.

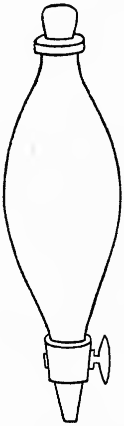

FIG. 101.—Closed separating vessel.

The simple and well-known separating funnel (fig. 100) is the best form of separator for use with media such as bromoform, which are liquid at ordinary temperatures; and it can be adapted to meet all requirements. For general use with large amounts of sand, it is convenient to have a funnel the diameter of which is about 10 cm. at the upper margin, the neck having an internal diameter of about 5 mm. The bore of the glass stopcock should have the same or nearly the same diameter as that of the neck-tube.

Some prefer to use a closed separating vessel of the type shown in fig. 101. There is a large variety of separating vessels, sufficient to suit all tastes, but the simpler forms are the best.

By means of a funnel such as the one described above, a large sample of sand or crushed rock can be examined, and the proportion of heavier minerals quickly and quantitatively estimated. The bromoform or other liquid used is first poured into the funnel, after which a weighed amount of dry sediment is placed in it and thoroughly stirred ; and the heavier minerals can then be drawn off by opening the stopcock. If the proportion of heavy minerals is small, as in the case with ordinary unconcentrated sediments, a large amount of material, say about 100 grams or so, can be added at once. When the amount of heavier minerals is large, as in concentrated sediments and in many crushed igneous rocks, the mixture should, if necessary, be added in several portions, the stopcock being opened each time, to prevent accumulation of too much material in the neck of the funnel.

It is convenient to have the heavy-liquid bottle at hand provided with a filtering funnel fitted with filter paper, and to allow the heavy minerals to drop on the filter paper. After the heavy liquid has drained off, the filter paper can be detached and opened, and the heavy grains washed off by placing the paper face downwards in a watch-glass or porcelain dish containing benzene or distilled water, according to the heavy liquid used. The washings thus obtained can be kept in a separate bottle and used over again. Ultimately, the amount of heavy liquid in the washings will become considerable, and can be recovered if it is thought worth while. If it is desired to recover the heavy liquid systematically from the washings, a series of bottles containing washings of different strengths should be kept. It is possible, however, to waste a great deal of valuable time in recovering a comparatively worthless amount of heavy liquid. In this respect the use of the more expensive liquids naturally calls for most care.

Should a funnel with a glass stopcock not be available, an ordinary filtering funnel, fitted with a rubber tube and a pinch-cock, can be used.

For a rough qualitative separation of a small amount of material in bromoform, a small cylindrical and flat-bottomed specimen tube placed in a flat-bottomed porcelain dish can be used ; half fill the tube with bromoform, introduce the sand, and stir ; then add liquid till the tube is full, and allow the lighter grains to collect at the surface. By causing the liquid to flow quietly down a glass rod into the tube, the lighter minerals will be collected in the porcelain dish. A small amount of material can often be quickly and effectively treated in this way. But where possible, the use of separating funnels is preferable.

Separation by means of liquid fusions, such as mercurous nitrate, is best made by using a test-tube, and fusing in a water-bath, or over a flame. After separation has been effected, the tube is allowed to cool, and broken so as to recover the solid mass, the fragments of the tube being carefully removed ; the solid column containing the separated minerals can then be cut across near the ends, or in the middle, if necessary, to recover the separated grains.

Magnetic separation.

Detrital minerals show a wide range of variation in magnetic permeability, and in consequence of this, one mineral can often be separated from another by virtue of its greater or less susceptibility in a magnetic field. It is customary and convenient to call minerals magnetic when they are attracted by the poles of a magnet, and non-magnetic when they remain unattracted.

Only a few minerals are affected in the field of an ordinary horse-shoe magnet, the poles of which are blunt and not in close proximity to one another. Magnetite is a well-known example of such a mineral. Other examples are titaniferous magnetite (magnetitic ilmenite), magnetitic hæmatite, and pyrrhotite. All these minerals appear to owe their extreme permeability to the presence of ferrous iron.

Many other minerals are magnetic, but in a much smaller degree, and are only affected in a strong field, in which the magnetic lines of force are concentrated by reducing the area of the adjacent portions of the poles and bringing the poles close together. In such a strong magnetic field a large number of minerals are attracted to the poles of the magnet. Most of these are ferro-magnetic, *i.e.* they owe their magnetic character to the presence of iron. But some magnetic minerals contain no iron, *e.g.* monazite and xenotime; these two minerals owe their magnetic character to the presence of cerium and yttrium respectively.

The best way to secure a strong magnetic field is to have two adjustable pole-pieces attached to the poles of a magnet as illustrated in fig. 102. By varying the distance between the pole-pieces, the intensity of the magnetic field can be varied. The adjacent portions of the adjustable pole-pieces should be bent down, not vertically, but at about 45°, and should thin out somewhat towards the tips. Provided with such adjustable pole-pieces, a strong permanent horse-shoe magnet can be made to lift many minerals, *e.g.* garnet and monazite, which are quite unaffected by a magnet of the ordinary type, in which the pole-ends are too blunt and widely separated to give the necessary strong field.

The best results, however, are obtained with an electromagnet, such as that illustrated in fig. 103. For laboratory use a small electromagnet, having an iron-core about an inch in diameter, and limbs about 4 inches long, on which are wound seven layers of 16-gauge wire, each layer having about 40 turns, is quite sufficient. The two adjustable pole-pieces should be about $1\frac{1}{4}$ inches wide, and about $\frac{1}{3}$ of an inch thick. They should be slotted so as to move over screw clamps by which they can be secured against the ends of the poles and adjusted in any desired position. In this way a strong field of variable intensity is obtained, and it is much better to vary the intensity of the field by adjusting the pole-pieces than by varying the current.

The magnet can be actuated by a portable 8-volt secondary battery, by an ordinary battery of four cells of the Bunsen type, or by a small dynamo. Better still, electricity installed on the premises for lighting purposes may be used to excite the magnet, provided that a suitable resistance is inserted.

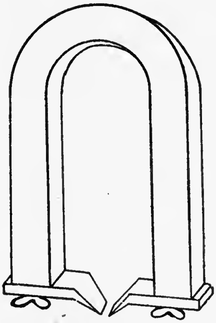

FIG. 102.—Permanent magnet.

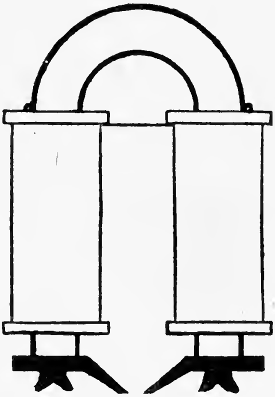

FIG. 103.—Electromagnet.

The wire connecting the electricity supply with the electromagnet should be furnished with a lever-switch arrangement, by means of which the current can be turned quickly on and off as required. It is convenient to have the magnet suspended on a wooden frame, and to place a small cardboard tray below the pole-pieces.

To make a separation, place the mixed grains on a piece of stiff paper or cardboard, and first of all remove, by means of an ordinary horse-shoe magnet, any highly-magnetic minerals, such as magnetite, that may be present. Then with the tips of the poles of the electromagnet about a centimetre apart, bring the grains into the vicinity of the pole-tips, and switch on the current. The first portion of the more magnetic grains will enmesh some non-magnetic grains, and it is advisable therefore to let the grains fall back by switching off the current, and to repeat the operation several times before letting the attracted grains fall into the tray. In this way a group of moderately magnetic minerals represented by ilmenite can be separated. When the separation of this group is complete, reduce the interval between the tips of the pole-pieces to about 5 mm. and continue the separation as before to separate another group of minerals, represented by monazite, which are only weakly magnetic. It frequently happens that monazite is alone or mixed with only traces of rutile in this group, and under these conditions it can be isolated with a fair degree of quantitative accuracy from the minerals that sink in bromoform. The residue remaining after the monazite group has been extracted is non-magnetic, or practically so, and among sediments, almost invariably if not invariably, contains zircon. Rutile usually remains behind in the non-magnetic group, as also does cassiterite; but grains of these minerals may also be lifted with monazite. Indeed, slight amounts of ferriferous impurity may make many otherwise non-magnetic minerals slightly magnetic, and it is impossible to give for guidance rules to which there are no exceptions. If the ferriferous impurity is merely a cementing material coating the grains, it can be eliminated by acid treatment; but if, as sometimes happens, the impurity exists as microscopic enclosures or as an impregnation of the non-magnetic grains, a good result cannot be hoped for, and at the best the separation can only be imperfect.

Minerals can as a rule be separated into the following four groups:

1. *Highly magnetic minerals*; *e.g.*, magnetite, magnetitic ilmenite, magnetitic hæmatite, and pyrrhotite.
2. *Moderately magnetic minerals*; *e.g.*, ilmenite, chromite, garnet, hæmatite, siderite, wolframite.
3. *Weakly magnetic minerals*; *e.g.*, monazite, tourmaline, columbite, ferriferous rutile, ferriferous cassiterite, and ferriferous zinc-blende.
4. *Practically non-magnetic minerals*; *e.g.*, zircon, corundum, galena, fluorite, pyrite, cassiterite, rutile, barite, and most minerals free from iron.

Electrostatic separation.

The possibility of electrostatic separation depends upon the fact that minerals differ in electrical conductivity. Generally speaking, opaque minerals, such as ilmenite and pyrite, are good conductors, whilst transparent minerals, such as quartz, monazite, and zircon, are bad conductors. Owing to the fact that ilmenite is rather lighter than monazite, a mixture of grains of these two minerals perhaps affords the best example of electrostatic separation.

If a mixture of ilmenite and monazite grains is placed on a good-conducting surface, such as a copper plate, dried thoroughly, and a flattened stick of sealing-wax which has been previously excited by rubbing is brought near to them, the ilmenite grains will be attracted to the sealing-wax, and can thus be separated from the monazite grains. This is due to the fact that the ilmenite grains, being good conductors, suffer a ready separation of charges on their surfaces under the inducing effect of the sealing-wax, the remote negative charges on the grains escaping quickly into the copper plate, leaving the unhampered positive charges on the grains to be attracted by the negative charge of the sealing wax. Owing to their bad conductivity, the monazite grains are practically inert under the influence of a charged rod if they are thoroughly dry, and they remain unattracted. Thorough dryness of the surface of the grains is an essential condition if separation is to be effected, as the charges reside on the surfaces of the grains, and a film of moisture is sufficient to convert a bad conductor into a good one.

As regards mode of separation, various methods of procedure for laboratory use will occur to the mind of the operator ; but the method of using a copper plate and a flattened stick of sealing-wax as described above is convenient, especially when a small amount of a good conductor is mixed with a large amount of bad conductors.

In the reverse condition of things, when a large amount of good conductors has to be separated from a small amount of a bad conductor, it is convenient to use two copper plates, one of which has had a surface coated with a layer of shellac, this layer being continued over the edges of the plate to form a narrow strip around the margin of the other surface. Two pieces of shellac-coated glass (portions of microscope slips) should be placed on the shellac-covered surface near the opposite edges, so that this face can be superimposed on the uncovered copper plate in close proximity to, but not touching, the grains. The upper surface of the upper plate can then be charged by a small electrophorus.

It will be found that such an arrangement gives a good control over the intensity of the charge ; and since the attracting surface is larger, the separation can be made more quickly.

The possibilities of the electrostatic method of separation are much more restricted than those of magnetic separation, owing to the fact that electrical conductivities are not so well graded as are magnetic permeabilities. In electrostatic separation, moreover, the presence of moisture on grains is an obstacle, and it is not sufficient as a rule to have the grains merely air-dried, though the separation naturally works much better in dry than in humid air. Magnetic separation, on the contrary, depending as it does upon the permeability of the mass of the grains to the lines of force, works quite well on air-dried material.

The electrostatic method, therefore, cannot claim to be so useful as the electromagnetic method of separation, though the occasions for its use frequently arise. Several cases of its aptness as a method of separation in laboratory work have arisen in the experience of the writer, *e.g.* the separation of xenotime from a mixture of ilmenite, wolframite and xenotime obtained by electromagnetic separation. Ilmenite and garnet can also be separated. Again, in the weakly magnetic group small amounts of ferriferous cassiterite, rutile, and chrome-spinel can often be largely eliminated from monazite in this way. In the non-magnetic group again, gold or pyrites can be lifted; and small amounts of cassiterite and other moderate conductors can often be concentrated, when mixed with a large amount of zircon, by the electrostatic method. In this way a sufficient degree of concentration can be effected to make possible a decisive blowpipe test for tin, a test which would yield no satisfactory result unless the comparatively large amount of zircon were previously separated or greatly reduced in amount.

Flotation.

Minerals with a metallic or adamantine lustre have an affinity for oily or greasy substances and are antipathetic towards water. On the other hand minerals with a vitreous lustre are antipathetic towards oily or greasy materials and show an affinity for water. An instance of this fact is very familiar to the gold prospector, who finds it necessary to have his pan free from grease if he wishes to avoid the loss of gold particles when panning to obtain a concentrate from sand or gravel. Another instance is the use of grease tables to trap diamonds in the process of separating this mineral from the other minerals with which it is obtained after washing off the weathered earthy matrix or yellow ground in which the diamond occurs.

It is upon this fact of the more wettable nature of minerals having a vitreous lustre, as compared with minerals having a metallic or adamantine lustre, that the principle of flotation in the concentration of minerals depends. A mineral fragment that will not wet, tends in consequence of the high surface tension of water to float on that medium; and even if by virtue of its mass and high specific gravity it sinks in the water, it carries air with it, whereas a fragment of a mineral with vitreous lustre tends to sink, owing to the fact that it is easily wetted and therefore does not suffer from the buoying tendency by which through air-adhesion, particles with a metallic lustre are affected. Consequently when a mixture of these two sorts of particles of suitable size are agitated so as to get plenty of air entangled with them, the air bubbles tend to adhere to the particles with metallic or adamantine lustre, and in spite of their greater density these particles tend to float whilst the gangue particles tend to sink.

This tendency can be accentuated by adding certain oily matters to the mixture so as to diminish the wettability of the particles with metallic lustre, and certain acid or alkaline matters to augment the wettability of the particles with non-metallic lustre. This is made possible by the fact that oil and water are more antipathetic than metallic-lustred minerals and water, whilst the wetting effects of water are accentuated by reducing its surface tension.

In recent years the flotation principle has been adopted extensively in metallurgical practice for the separation of ore minerals from gangue. The principle has long been known, but in this, as in many other instances that could be quoted, the evolution of suitable apparatus for applying the principle in practice has been a tardy process. Only since suitable machinery and reagents for the production and control of frothing action have been introduced, has the application of the principle made rapid progress.

Minerals can be separated or concentrated in the laboratory by using this principle, but not so readily as by the other methods already described. On account of its great importance as a method of ore concentration, however, it is well worthy of experimental practice by workers who are interested in the physical methods of separating and concentrating minerals.

Chemical separation.

Chemical separation involves the destruction of one or more of the ingredients present. The commonest and simplest example of this mode of separation is that of isolating such minerals as ruby, emerald, and spinel, when these occur embedded in a matrix of calcite or limestone, by treatment with dilute hydrochloric acid to dissolve the calcium carbonate. Hydrochloric acid is frequently useful in this way for dissolving the calcareous and ferruginous cements that bind together the grains of many detrital sediments, whereas sulphuric acid can be used effectively in decomposing argillaceous cements. Other solvents which can at times be used with advantage in the isolation of minerals are, nitric acid for decomposing sulphides, and hydrofluoric acid for dissolving quartz and many silicates.

CHAPTER VII.

THE GEOLOGY OF ECONOMIC MINERAL DEPOSITS.

The student of economic mineralogy should cultivate a knowledge of dynamical geology and petrology in order that he may understand the broader aspects of mineral occurrences. Economic mineral deposits are rocks, and the study of their modes of genesis comes properly within the purview of the science of petrology. It is beyond the scope of this book to enter at length into a consideration of rock genesis, or to study the nature of rocks in general. It seems worth while however, to review briefly the salient features concerning the structure of the earth's crust and to note origin of the chief varieties of rocks, so as to explain in an elementary way the genesis and modes of occurrence of minerals.

ROCKS AND ROCK-FORMING PROCESSES.

The rocks that build up the accessible portion of the earth's crust can be arranged in several groups according to their origin, *i.e.* according to the processes by which they have been formed. The rock-forming processes, considered geologically, and the rocks produced by them, may be enumerated as follows, beginning with the surface processes, the operations of which are more open to observation than are the processes that arise from deep-seated causes.

1. Weathering residues.—The surface of the land is in most places occupied by a layer of loosely aggregated material formed by the action of weathering agencies on the subjacent rocks. Loose surface sands and gravels lying on or near the rock from which they have been derived by weathering are termed eluvial deposits, to distinguish them from alluvial deposits transported by rivers. Where rocks are exposed to the atmosphere they are continually though slowly being eaten into by the action of temperature changes, the solution effect of rain water, and various other agents (fig. 104). The nature of the surface in some places does not allow the disintegration products to accumulate, but this state of things is exceptional, and in most places a portion of the weathering products accumulates to form soil.

Except in desert regions, where the climatic conditions allow only of scanty xerophytic growths, the surface soil maintains innumerable forms of plant life, notably the grasses. This surface soil is usually not more than a foot in thickness and it is as a rule black or dark brown in appearance, owing to the accumulation in it of organic matter resulting from the decay of plant tissues. Under it is found a variable thickness of material which is called sub-soil. As a rule the sub-soil, at least in its upper layers, does not differ mineralogically from the soil, the chief difference between their natural conditions being that the sub-soil is lighter-coloured due to the absence of decayed organic matter. The colour of the sub-soil is usually yellow or reddish due to ferric oxide, which is an important colouring agent in nearly all weathering products that are free from organic matter.

FIG. 104.—Soil-formation by the weathering and disintegration of granite.

The sub-soil has for its foundation the firmer rocks of the earth's crust proper. These rocks vary considerably in the readiness with which they furnish soils by weathering. Some of them, particularly the metamorphic varieties, are hard and resisting ; they disintegrate slowly, and yield no binding ingredient by which the disintegrated particles can be held together to furnish a footing for plant growth ; hence the bareness of such rocks, which are the bane of the agriculturist, but the delight of the geologist and prospector. Others, such as many sedimentary and igneous rocks, are either already capable of affording root-hold or readily weather into such a condition; and in areas occupied by these rocks the geologist and prospector has to depend largely on stream or cliff sections and quarry workings for the outcrops which he studies.

Departures from the typical relation of soil to sub-soil are found in some places, as in arid climates, where there is insufficient moisture to secure a covering of vegetation. Such areas may be occupied by drifting sand; or may otherwise exhibit marked differences from those of moist temperate climates.

A characteristic feature of tropical as compared with temperate regions, is the greater thickness of the mantle of weathering residues in many tropical areas. They are typically of a red colour, owing to the presence of iron oxide; but they often also contain free hydrated alumina, and are then known as *laterite* (from the Latin '*later*,' a brick), a name that was originally given to them on account of their peculiar property of setting hard when exposed to the atmosphere. They are often quite soft when fresh, and their property of setting on exposure permits them to be used as a rude substitute for bricks. This thick accumulation of lateritic weathering residues is especially characteristic of those parts of the tropics that have a long dry season alternating with one of heavy rains. Its formation is apparently due to the discontinuous drainage and is probably connected with the accumulation of alkali salts in the surface deposits.

Where the climatic and other conditions are such that the ground water is kept free from these salts by a fairly constant precipitation of moisture and a continuous drainage, the decomposition of felspars and other rock silicates results in the formation of hydrated silicate of aluminium, lithomarge, etc., which is amorphous and colloidal, and which constitutes the plastic ingredients of common rock-clays. This plastic amorphous clay plays a very important part in retaining moisture in many surface soils, and in rendering impermeable to water the mudstones and other argillaceous rocks of which it is the chief ingredient.

The explanation of this difference between the weathering residues of tropical and those of temperate climates is probably to be found in the action of the alkali salts in decomposing the colloidal hydrated silicate of aluminium in many tropical and sub-tropical areas, and forming colloidal hydrated alumina. This colloidal hydrated alumina is the mineral bauxite, which is usually found in admixture with other amorphous materials, especially the hydrated oxides of iron, titanium and manganese, together with various minerals from the parent rock that have resisted decomposition, such as rutile, ilmenite, zircon, and often quartz. The rock made up of this complex admixture of minerals is known as laterite. When dominantly ferruginous, as indicated by their deep reddish-brown colour, laterites are often used as iron ores. The remarkable nickeliferous and chromiferous hydrated iron-ores of Cuba (see p. 229), and the garnierite nickel-ores of New Caledonia (see p. 228), are laterites. Iron oxide is sometimes present in comparatively small amount, as in the bauxites of commerce, some of which are greyish or pale brown in colour.

On account of the abundance of iron oxide in most laterites, the term laterite is commonly used in a wider sense, so as to include all superficial ferruginous masses found in the tropics; but though it is convenient to use the word loosely and popularly in this wide sense as a vague field-term, it is preferable for scientific purposes to restrict the meaning of the term in the manner indicated above (see also p. 152).

In addition to the minerals already mentioned, gold, tinstone, and other minerals are sometimes found in surface weathering residues, and the fact that these deposits are often in a loose state of aggregation is one of considerable importance as bearing on the economy with which they can be worked.

2. Transportation of rock detritus.—The earthy mantle of surface weathering products in temperate climates is continually being washed by the rains. Its mineral ingredients consequently find their way into streams and rivers, and are in part carried out to sea. The materials thus mechanically carried and deposited by water are spoken of as detrital sediments.

Rivers add to the weathering detritus by eroding material from the channels along which they flow; and the sea adds a further quota by the effective work of coast erosion. The boulders, gravel, and coarse sand are largely laid down along river valleys and sea coasts, and form what are known among miners as *alluvial* or *placer* deposits. Much of the finer sand, silt, and mud is deposited in estuaries or is carried out to sea for some distance, forming deposits which, when compacted, yield sandstone, siltstone, and shale or mudstone.

Placer deposits are of special interest on account of the occurrence in them of such valuable heavy minerals as gold, platinum, cassiterite, and monazite, sometimes in a concentrated condition. The various rock materials including quartz that form the matrix of heavy minerals, usually have a specific gravity ranging from about 2·6 to 2·9. Boulders, pebbles, and grains of these matrix minerals are readily buoyed up in a strong current of water, owing to the anti-gravitational effect of liquids on the solids immersed in them. This buoyancy effect is comparatively greater with a mineral like quartz than with the heavier minerals. Some idea of its importance can be formed by comparing the apparent or effective weights in water of equal volumes of quartz and cassiterite. Cassiterite has a specific gravity about 2½ times that of quartz. The apparent or effective weight in water of a cubic centimetre of quartz, however, is only just over 1½ grams; whereas that of a cubic centimetre of cassiterite is about 6 grams. The apparent weight of cassiterite in water is therefore about 4 times that of an equal volume of quartz. The disparity of apparent or effective weights is still more striking when quartz is compared with the much heavier metals gold and platinum.

We see then, that although quartz and other comparatively light minerals and rocks are readily buoyed up and carried forward in a current of water, even in large boulders, heavy minerals such as monazite, cassiterite, wolframite, tantalite, gold, platinum, and iridosmium sink heavily in the moving stream, and tend to concentrate near the source from which they have been derived. Small grains of these heavier minerals find lodgment among the boulders and pebbles, and in the rock crevices on the floor of the stream, as can be very well seen where schists or slaty rocks lie with the strike of their foliation at right angles to the course of the stream.

The sluice box used by the miner in working placer deposits is a simple device by means of which he imitates the process of stream concentration. By this device he seeks to generate, on an inclined surface, a stream sufficiently strong to buoy up and carry off the comparatively light quartz and other rock materials, whilst leaving behind, trapped on the riffled or coarse-canvas floor of the sluice box, a concentrate of the gold or other heavy minerals that were previously mixed with a large amount of valueless gravel.

A process of natural concentration also operates in tidal and wave action on beach deposits. The black sands of many beaches and rivers such as those of the Pacific coast of North America, the Taranaki sands of New Zealand, and the black sands of the River St. Lawrence in Quebec, owe their blackness to the presence of a large proportion of ilmenite and magnetite concentrated in this way. The monazite sands of Brazil and Ceylon, the monazite and garnet sands of Travancore in India, and the diamond-bearing sand of South-West Africa, are notable examples of concentration in modern beach deposits.

When freshly deposited, transported detritus is usually in a loosely-aggregated condition, and it may continue to exist in a non-cemented condition long after deposition. More commonly, however, the long-continued gentle pressure of superincumbent beds and the interstitial deposition of binding materials such as iron oxide, carbonate of lime, and silica, result in the formation of strongly cemented masses of stratified rock. Most of the geologically-old detrital deposits are in this compacted condition.

3. Solution and deposition by surface waters.—The waters that flow from the land into streams, rivers, lakes, and seas carry salts in solution, notably those of lime, magnesium, and sodium. The lime is being continually appropriated by organisms that build up calcareous shells. The calcareous remains of these organisms accumulate on the sea floor, forming limestones. Calcium carbonate is by far the commonest material used by the lower types of organisms in building up their shelly parts; but some organisms secrete silica, *e.g.* radiolaria and diatoms, and their remains accumulate to form siliceous deposits. In addition to the calcium carbonate that is deposited from solution indirectly through organic agents, a large amount is deposited directly both from sea water to form oolitic and other limestones, and from fresh water to form travertine where streams are flowing over limestones.

After deposition in the sea, calcium carbonate is liable, under the action of the magnesium compounds dissolved in sea water, to change into dolomite, especially under comparatively shallow-water conditions. Many dolomitic limestones and massive dolomites have arisen in this way, through the action of sea water on freshly deposited calcium carbonate; and many of the coral reefs of the Pacific are dolomitized in this way during growth. By this process much of the magnesium in sea water becomes deposited to form dolomitic limestone.

The sodium chloride, on the contrary, accumulates in the sea water, of which it constitutes by far the chief saline ingredient. It is only when a portion of the sea becomes isolated, and dries up, that the sodium chloride is deposited from sea water to form beds of rock-salt and gypsum, sometimes also potassium chloride and other potassium salts.

The salts carried in the surface solutions of arid regions consist largely of sodium carbonate and sodium sulphate as well as sodium chloride; and sodium carbonate is sufficiently abundant in some lake waters to form thick and extensive crusts of almost pure trona (see p. 352). More often, however, the lake waters of arid regions contain a mixture of sodium chloride, carbonate, sulphate and other salts, and a mixture of salts is then often formed when the lake-waters are dried up.

The formation of bog iron-ore furnishes an interesting case of deposition from surface solutions. The iron is carried in solution in the drainage waters as bicarbonate and oxidizes at the surface of the water to form hydrated oxide which is precipitated and accumulates at the bottom of lakes or marshes. Essentially similar to the bog iron-ores in their mode of origin are the "iron-pans," consisting of a hard layer of hydrated iron oxide, that form at or near the surface of the soil in many localities and require to be broken up before the soil can be cultivated.

Other instances of deposition from surface solutions are those of hydromagnesite, and the borates colemanite, ulexite, and borax (see pp. 335, 346).

4. Solution and deposition by descending waters.—A portion of the water that falls on the land seeps into the pores and divisional planes of the rocks at and near the surface. Where the rocks are sufficiently porous this water accumulates to form an underground reservoir, the surface of which is known as the "water-table." This water-table rises and falls with the contour of the land, but it is nearer the surface as a rule in valleys than in hills. Its level is variable and depends on the rainfall and seasonal changes.

This underground water of surface origin exerts an important influence on the rocks with which it is in contact. It is being continually fed with mineral matter derived from the surface rocks through which the water percolates in its descent. The soluble salts arising from surface decomposition, a portion of which as we have seen accumulate in surface waters, in part descend into the earth for some distance, and influence the rocks they traverse. When the surface drainage is not continuous, especially as in many hot countries where there is a protracted season of drought, the action of these seepage waters with salts in solution is comparatively intense, and is probably, in part if not altogether, the cause of laterization. A pre-eminent function, in this respect, should perhaps be allotted to sodium carbonate and sodium sulphate, which as we have seen are produced in surface soils, and are frequently deposited in lake waters.

Numerous other materials are carried down in solution by these descending waters, notably magnesium and iron salts, and sulphates of the numerous metals that occur disseminated or segregated among rocks in the form of sulphides. The seepage waters are thus continually supplied with mineral matter, and their effects on the rocks, partly by interaction with replacement of the rock substance itself (metasomatism), and partly by deposition in pores and larger cavities, lead to many important petrological changes. Solutions carrying magnesium act on limestones and transform them into dolomites, the transformation being accompanied by a reduction in volume and the consequent production of a cellular texture in the resulting dolomite. Silica, iron oxide, and calcium carbonate are among the commoner materials deposited, sometimes in the interstices of the rocks, and sometimes as a replacement of their substance, and some important deposits of iron ore have arisen in this way.

Where veins rich in metallic sulphides are acted on by surface-seepage waters, important secondary changes take place, and this is especially important in many copper-ore districts. The sulphides are readily oxidized at and near the surface, above the water-table, and the sulphates are carried down into the deeper portions of the veins where they suffer reduction and enrich the veins by fresh deposition of copper sulphide, largely in the form of chalcocite. Gold is also carried downward in these descending sulphate solutions and redeposited from them, often in conjunction with the sulphides. Some of the richest copper-ore deposits have arisen in this way by a process of secondary enrichment.

5. Igneous action.—By the term igneous are described all those rocks that have crystallized or solidified from a molten condition. As we know from the evidence provided by volcanoes, parts of the earth's crust are at times subjected to such conditions of temperature and pressure that the rocks are in a molten condition. These molten materials may be injected into rocks near the surface or ejected at the surface as lava flows, in which case they cool comparatively quickly and are either very imperfectly crystallized or not crystallized at all. On their way towards the surface, which they may or may not reach, the molten rocks traverse cracks in the solid crust, and on cooling they solidify in the cracks to form dykes and sills. Dyke rocks generally cool more slowly than volcanic rocks, and are therefore more definitely crystalline, though their crystalline grains are often too small to be visible to the unaided eye. At greater depths large reservoirs of molten rock occur; these cool very slowly and crystallize more completely, yielding coarse-grained rocks such as granite, in which the individual granules can be clearly distinguished without the use of a lens. Such deep-seated igneous magmas often give rise by segregation to important ore deposits in themselves; they also exude liquids and vapours from which valuable minerals are deposited in the form of vein-fillings in the surrounding rocks (see below).

According to the depth at which they have solidified, then, we can sub-divide igneous rocks in a three-fold manner as follows:

(*a*) *Plutonic rocks,* which have crystallized at considerable depths; they are entirely crystalline and generally coarse-grained in texture. Examples: granite, granodiorite, syenite, monzonite, diorite, gabbro, olivine-gabbro, and peridotite.

(*b*) *Volcanic rocks,* which have solidified after ejection at the surface of the earth; they may or may not contain crystals of noticeable size (porphyritic crystals), but they generally possess a groundwork of non-crystalline or imperfectly crystalline material. Examples: obsidian, rhyolite, trachyte, phonolite, andesite, basalt, and olivine-basalt.

(*c*) *Dyke or hypabyssal rocks,* which are intermediate in texture between plutonic and volcanic rocks. They have crystallized at shallow depths. They may or may not have large (porphyritic) crystals, but they generally have a compact groundwork which, though as a rule entirely crystalline, is made up of small microscopic crystals. Occasionally, hypabyssal rocks are suddenly chilled and then yield rock-glass of the pitchstone and tachylite type. Examples: porphyry, elvan, pitchstone, porphyrite, dolerite, olivine-dolerite, tachylite.

The student of economic mineralogy should familiarize himself with these commoner types of igneous rocks, of which he should obtain specimens. A brief account of the mineral composition and texture of the more important of them is given under "building stones" on p. 336.

6. Deposition from igneous exudations.—Igneous magmas and especially acid magmas often contain a large amount of water and metallic material. Much of the metallic material separates out during the crystallization of the rock itself, sometimes in small crystals disseminated through the mass of the rock, and sometimes in the form of large segregated masses. During or after the act of intrusion, metalliferous solutions and vapours may find their way into the surrounding rock masses, and deposit their burden of metalliferous matter in the immediate vicinity of the intrusion, forming what are known as contact impregnations. Magmas often give up much mineral matter in solution in this way to the rocks into which they intrude, forming new minerals and in some instances producing ore deposits of importance, partly in the form of veins and stringers and partly as a more uniformly distributed impregnation or replacement of the rock mass invaded by the magma.

In addition to this impregnating and metasomatic action of exudations escaping from intrusive magmas, and on the whole far more important, a large amount of metalliferous mineral matter is deposited from the solutions that ascend towards the surface along fissures. Pegmatite veins containing tinstone, wolframite, molybdenite and other important ore minerals are instances of this. Such pegmatite veins, though not always ore-bearing, are almost invariably associated with granitic intrusions. Numerous vein-systems have arisen in this way, and instances of these will be given later.

Another type of deposit by igneous exudations is that arising by sublimation from vapours escaping from igneous rocks at the surface in fumaroles and solfataras; but this type is not of much economic importance.

7. Thermodynamical alterations of rocks.—Many rocks owe their mineral composition and texture to the fact that they have been influenced by thermodynamical conditions without the addition of extraneous material; *i.e.* the new minerals that have developed are due entirely to re-adjustment arising from increased temperature and pressure. Igneous intrusions frequently produce thorough changes in the characteristics of the rocks into which they intrude, simply by the transforming influence of the high temperature to which they raise the surrounding rocks; but similar changes may be produced by rocks being buried at great depths, and subjected to thermodynamical changes without the aid of igneous intrusion.

By these agencies sandstones are converted into quartzites and quartz-schists; shales and slates into phyllites and mica-schists; compact and earthy limestones into calciphyres or coarsely crystalline marbles; granites into gneisses; dolerites and basalts into hornblende-schists.

When the changes can be clearly seen to have taken place along the margin of an intrusive rock they are usually referred to as "contact metamorphism." Where gneisses and schists occur over large areas in which there is little or no evidence of igneous intrusion, their formation is attributed to "regional metamorphism." Many so-called regionally metamorphosed areas are doubtless large-scale instances of contact metamorphism. Others appear to have suffered alteration, not by the effect of igneous intrusion, but by thermodynamical changes unaccompanied by intrusive activity, and it is to these that the term "regional metamorphism" is most aptly applied. These two types of metamorphism merge into one another, however, and they produce similar effects.

THE GENETIC CLASSIFICATION OF ROCKS.

To a geologist, and especially to a mining geologist, rocks are the building stones of the outer earth's crust, and minerals are the homogeneous substances that enter into the composition of rocks. To anyone who looks at petrology from this point of view, it is necessary to correlate rocks and rock-forming processes, and to make this correlation the basis of rock-classification. Such a classification is termed genetic.

In rough accordance with this principle, it has long been the custom to divide rocks into three groups, viz. igneous, sedimentary, and metamorphic. By igneous rocks are meant those that have solidified from a fused condition. Sedimentary rocks are those that have been deposited from suspension or solution in rivers, lakes, and seas. Metamorphic rocks, in the narrow sense of the term, are those igneous and sedimentary rocks that have been altered by thermodynamical agencies so as to produce a new mineral composition, or a new texture, or both.

This threefold subdivision of rocks is in some ways convenient; but it is a makeshift rather than a truly scientific scheme of genetic classification. It is based on a rather restricted view of the scope of petrology. It lacks completeness and does not correspond with any definite grouping of rock-forming processes.

In order to surmount this difficulty, and to frame a scientifically genetic grouping of rocks, it is necessary to take a wider survey of rock-forming processes. If we do this, and consider the processes briefly outlined in the preceding section, we see that these fall naturally into two broad geological groups. The processes of weathering, mechanical transportation and deposition, transportation by and deposition from solution, either from surface solutions or from solutions descending into the crust, constitute a natural large geological group of processes which may be aptly termed *exogenetic* or *supragenetic*. The corresponding group of exogenetic or supragenetic rocks includes sedimentary rocks, but it also includes others to which the term sedimentary cannot properly be applied. It comprises all rocks formed by processes that are connected with atmospheric agencies, and these rocks subdivide naturally into weathering residues, detrital deposits, deposits from surface solutions and deposits from descending solutions.

The second group of processes comprises those connected with the action of the earth's internal heat, either by the thermodynamical changes at a considerable depth in the crust or by the intrusion of molten magmas at shallow depths. This group of processes may be aptly termed *endogenetic* or *infragenetic*. The corresponding group of endogenetic or infragenetic rocks includes igneous rocks proper, rocks arising from the action of igneous exudations, and those rocks that are styled "metamorphic" in the restricted sense of the term, *i.e.* rocks that owe their composition and texture to thermodynamical changes.

We may tabulate this geodynamical grouping of rocks as follows:

I. ENDOGENETIC OR INFRAGENETIC ROCKS, formed by processes of internal origin, which processes operate deep-seatedly or from within outwards. High-temperature effects constitute the prevailing characteristic and the water taking part as an agent has been affected by igneous action, *i.e.* it has either been exuded from igneous magma or heated thermodynamically.

1. IGNEOUS ROCKS.
2. IGNEOUS EXUDATION PRODUCTS.
   - (*a*) Contact impregnations and rocks metasomatized by contact.
   - (*b*) Hydrothermal vein-rocks.
   - (*c*) Solfataric deposits.
3. THERMODYNAMICALLY ALTERED ROCKS; BUT UNFUSED AND NOT MODIFIED BY EXUDATION.

II. EXOGENETIC OR SUPRAGENETIC ROCKS, formed by processes of external origin, which processes operate superficially or from without inwards. These rocks are formed at ordinary or comparatively low temperature, and the water taking part in their formation is of atmospheric origin.

1. WEATHERING RESIDUES, including eluvial gravels.
2. DETRITAL ROCKS, comprising aeolian, alluvial, and marine sediments, loose or cemented.
3. SOLUTION DEPOSITS.
   - (i) *Surface solution deposits.*
     - (*a*) Organic deposits.
     - (*b*) Inorganic deposits.
   - (ii) *Descending solution deposits.*
     - (*a*) Certain vein deposits.
     - (*b*) Rocks metasomatized by descending solutions.
4. SUBAERIAL PLANT ACCUMULATIONS.

THE GENETIC CLASSIFICATION AND PARAGENESIS OF ECONOMIC MINERALS.

The problem of the genetic classification of minerals should be approached with a knowledge of the basis of genetic classification as applied to rocks. Mineral deposits are rocks; and economic mineral deposits are those rock masses which contain useful minerals in such quantities that it is practicable to extract them for use in the arts.

In some instances, a mineral in itself constitutes a rock. Masses and beds of iron ore, chromium ore, manganese ore, corundum, rock-salt, phosphorite, and other minerals afford examples of this. More commonly, however, the mineral is, from a quantitative standpoint, a comparatively insignificant constituent of the rock in which it occurs; and there are all possible gradations between instances in which an economic mineral in itself forms the chief part of a rock mass, and those in which it is disseminated through a large amount of useless rock matrix; but in all cases the deposit as a whole is essentially a rock.

Petrology and the study of ore deposits have, however, developed as two separate branches of science; and it has been the custom to classify rocks and ore-deposits differently. Petrologists have not hitherto regarded vein deposits as coming properly within the purview of rock studies; and the persistence of the roughly genetic three-fold grouping of rocks as igneous, sedimentary, and metamorphic is largely due to the incomplete view of classification adopted by petrologists.

Those rocks that the petrologist has found it convenient to ignore have been closely studied by scientific workers interested in mineral deposits from the economic point of view. It is therefore interesting to note that, corresponding to the narrowness of the petrologist's outlook as regards rocks, there was for long a narrowness of view as to the scope of economic mineral studies; for until recent years it has been the custom to limit the study of economic mineral deposits to "ore deposits."

So long as that view prevailed there was naturally much reluctance to adopt a genetic classification of ore deposits; but the widening of the scope of this study to embrace economic mineral deposits generally has made the adoption of a genetic grouping of these deposits practically inevitable for the purpose of the study of formative processes. It is therefore noteworthy that authorities on economic mineral deposits have not found it convenient to adopt a three-fold grouping of these deposits into igneous, sedimentary, and metamorphic.

One of the supposed genetic modes of grouping that has been most widely adopted by writers on ore deposits has been that of a two-fold grouping into (1) *Syngenetic deposits*, or those that have been formed contemporaneously with the enclosing rock; and (2) *Epigenetic deposits*, or those formed at a time subsequently to that at which the enclosing rocks were formed. It is a curious fact that this conception of relativity of age between an ore deposit and the enclosing rock has been widely accepted as the basis of a supposed genetic mode of grouping. It is indeed not genetic at all in the true sense of the term; as may be seen from the fact that it brings igneous segregations, surface solution deposits, and thermodynamically altered deposits all into one group, and in the other group brings together such unrelated types of deposits as contact impregnations and descending solution deposits.

A genetic scheme of classification, as pointed out in the last chapter, implies the possibility of a classification of formative processes. It has already been shown that on this principle a division of rocks into igneous, sedimentary, and metamorphic is not a satisfactory genetic scheme; and the same reasoning applies to economic mineral deposits, which as we have seen is only another name for rocks that contain useful minerals.

It is, moreover, as already remarked, to the science of petrology that the study of economic mineral deposits properly belongs; and if this be admitted it follows that the grouping of processes required in a genetic classification of economic mineral deposits is a geodynamical grouping. Such a grouping is that already adopted for rocks in the preceding section, and in its broad features this is apparently the mode of grouping best suited to the requirements of the genetic classification of economic mineral deposits.

The importance of the genetic classification of mineral deposits lies in its bearing on the association of minerals, a subject of great practical importance to the student of economic mineralogy. If minerals associate in characteristic groups, a knowledge of the nature of these groups, their relation to one another, and to the conditions of occurrence, becomes a matter of great practical significance to the prospector and those interested in the development of mineral resources. It has long been the custom of mineralogists to deal with mineral associations under the heading of *paragenesis*, without endeavouring to secure a petrological basis for the study of these associations. It is clear, however, that paragenesis cannot be treated adequately apart from the study of geodynamical processes, and a scheme of paragenesis is essentially the same thing as a genetic classification of minerals. To illustrate this fact, a list of some of the commoner associations of economic minerals is given below, under the genetic sub-groups of rocks or deposits in which they occur:

I. ENDOGENETIC OR INFRAGENETIC DEPOSITS.

A. IGNEOUS SEGREGATION DEPOSITS.

(*a*) *Acid-magma associations.*

Cassiterite, topaz, fluorite, and tourmaline in granite.
Corundum, orthoclase, and hornblende in syenite.
Magnetite, hornblende, and apatite in syenite.

(*b*) *Basic-magma associations.*

Magnetite, ilmenite, rutile, and apatite in gabbro.
Pyrrhotite, pentlandite, chalcopyrite, and hypersthene in gabbro.
Corundum and olivine in peridotite.
Chromite, chrome-spinel, and olivine or serpentine.
Platinum, osmiridium, chromite, and olivine or serpentine.
Diamond, garnet, ilmenite, and enstatite in peridotite dykes and pipes.

B. IGNEOUS EXUDATION DEPOSITS.

(*a*) *Contact impregnations.*

Cassiterite, tourmaline, and quartz.
Chalcopyrite, pyrite, pyrrhotite zinc-blende, garnet, and epidote.
Magnetite, chalcopyrite, garnet, and epidote.

(*b*) *Hydrothermal veins.*

Cassiterite, wolframite, tourmaline, and quartz.
Cassiterite, topaz, and quartz.
Cassiterite, columbite, tantalite, and quartz.
Cassiterite, chalcopyrite, arsenopyrite, fluorite, and quartz.
Samarskite, muscovite, and quartz.
Uraninite, muscovite, and quartz.
Monazite, felspar, and quartz.
Amblygonite, spodumene, triphylite, and quartz.
Chalcopyrite, pyrite, galena, zinc-blende, and quartz.
Chalcopyrite, molybdenite, bismuthinite, and quartz.
Graphite, apatite, pyrite, and quartz.
Gold, pyrite, galena, zinc-blende, arsenopyrite, and quartz.
Phlogopite, apatite, and pyroxene.

(*c*) *Solfataric deposits.*

Sulphur and cinnabar.

C. THERMODYNAMICALLY ALTERED DEPOSITS.

Hæmatite, magnetite and quartz (itabirite beds).
Corundum, mica, and quartz in schists.
Ruby, sapphire, spinel, phlogopite, and dolomite in crystalline limestones.

II. EXOGENETIC OR SUPRAGENETIC DEPOSITS.

A. WEATHERING RESIDUES.

Amorphous clay (lithomarge, etc.).
Bauxite and laterite.

Garnierite and serpentine.

Gold, cassiterite, wolframite, quartz, flint and various other minerals occurring separately or associated in eluvial gravel, sand, clay, or laterite.

B Detrital Deposits.

Gold, ilmenite, zircon, rutile, and quartz.

Monazite, ilmenite, zircon, rutile, and quartz.

Gold, platinum, osmiridium, chromite, and quartz.

Diamond, garnet, ilmenite, and quartz.

Ruby, sapphire, spinel, and quartz.

C. Solution Deposits.

(*a*) *Surface solution deposits.*

Halite (rock-salt) and gypsum.

Halite, sylvite, and carnallite.

Halite, trona, and glauber's salt.

Halite, epsomite, and mirabilite.

Gypsum and celestite.

Bog iron-ore (limonite).

(*b*) *Descending solutions* (*infillings, enrichments and replacements*).

Calcite, ankerite, zinc-blende, galena, barite, and pyrite in joints and fault planes.

Magnesite veins in serpentine.

Chalcocite, covellite, chalcopyrite, and bornite in secondarily enriched copper veins.

Gold and pyrite.

Sulphur, calcite, and gypsum.

Phosphorite and limestone.

Concretionary iron carbonate and limestone.

A study of these paragenetic groups from the petrological point of view leads to important generalizations as regards the distribution of minerals in the earth's crust, and tells the prospector the economic possibilities of the various rock types.

Tin ores, tungsten ores, molybdenum and bismuth ores, tantalum, uranium, lithium and thorium minerals are invariably associated with granitic intrusions and their exudations. On the other hand platinum, iridium, chromite, and diamond find their home in intrusions of peridotite. Nickeliferous pyrrhotite of economic importance is an igneous segregation product and is found in hypersthene-gabbros (norites).

The mineral ilmenite shows a much greater affinity for basic than for acid magmas, and masses of segregated magnetic iron ore in gabbros are usually titaniferous (ilmenitic) in a much higher degree than those associated with the syenites. The iron ores of exogenetic solution deposits are as a rule comparatively free from titanium, which tends to remain behind in the weathering residues; and when after having passed through the exogenetic phase they become thermodynamically altered and dehydrated, they yield high-grade hæmatite or hæmatite-magnetite ores that are often almost free from titanium and phosphorus and on that account much more valuable than the phosphatic and titaniferous magnetites of the igneous segregation sub-group.

These instances will serve to show the practical importance of a petrological study of paragenetic groups of economic minerals.

THE TECTONIC FEATURES OF THE EARTH'S CRUST.

By the term "tectonics" in geology is meant the broad structural conditions and relations exhibited by the stratified and other rock masses of which the earth's crust is built.

A large part of the outer rind of the earth in continental areas consists of stratified rocks. These rocks, as we have already seen, consist of materials derived from the waste of the land. They are formed largely in shallow seas and estuaries, where they are deposited in practically horizontal beds. If the earth's crust were stable, the result of this process would be the total disappearance of the land and the complete conquest of the sea. The sea is easily able to swallow the material of the continents, and would soon do so, were it not that earth movements are continually affecting the relative levels of various parts of the land surface and the ocean floor.

The movement of the crust is due to shrinkage of the earth's nucleus, consequent upon continual loss of heat. Shrinkage of the nucleus develops stresses in the crust; and the crust adapts itself by a process of radial contraction or collapse and wrinkling which results in a relative change of level at different parts of the surface. In this way portions of the earth's surface which have been long buried under the sea, and on which large masses of stratified rocks have accumulated, become uplifted into land areas; and so we find that land areas are largely built of stratified rocks.

Horizontal disposition of strata.—In the process of emergence whereby a portion of the sea floor becomes dry land, a large region may be affected in such a way that the stratified rocks retain over wide areas the horizontal or approximately horizontal arrangement under which they were deposited (fig. 105).

Dipping and folding of strata.—Very frequently, however, strata suffer some displacement from the horizontal as a consequence of the disturbances that have affected them since they were laid down. In beds which are not horizontal, the inclination of the plane of bedding is called the *dip* (fig. 106). In such beds, the direction of a horizontal line in the plane of bedding is called the *strike* of the beds. The angle between the plane of bedding and the horizontal is called the *angle of dip*.

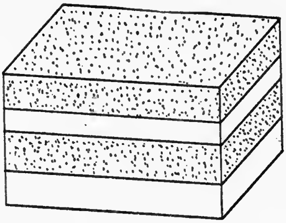

FIG. 105.—Horizontal strata.

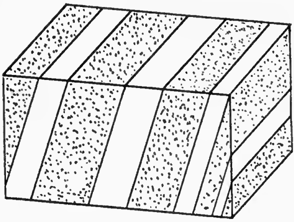

FIG. 106.—Dipping strata.

Departures from the horizontal arrangement are well seen in many mountain regions, and the worn-down stumps of such regions, where the strata have been severely crumpled and folded under great pressure. The resulting arrangements of the strata are very various. In some instances dome-shaped elevations, and in others basin-shaped depressions are produced. Most commonly, however, the folds have a linear arrangement and yield ridges or mountain chains as the result of weathering and denudation.

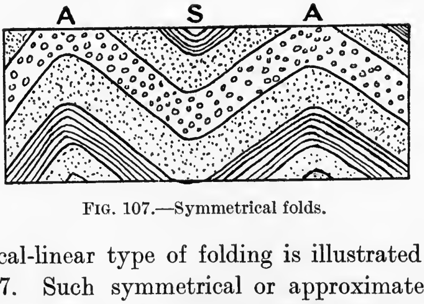

FIG. 107.—Symmetrical folds.

The symmetrical-linear type of folding is illustrated by the section shown in fig. 107. Such symmetrical or approximately symmetrical folds are termed *anticlines* when they are bent upwards, as in the crest of a wave (*A* in the fig.) and *synclines* when they are bent downwards as in the trough of a wave (*S* in the fig.).

Folds often vary in their disposition from point to point in a mountain group as shown in fig. 108, which illustrates the fan-shaped arrangement of the Alpine type of folding. An asymmetric fold in which the axial plane of the fold becomes horizontal or nearly so (fig. 109) is termed an *overfold*.

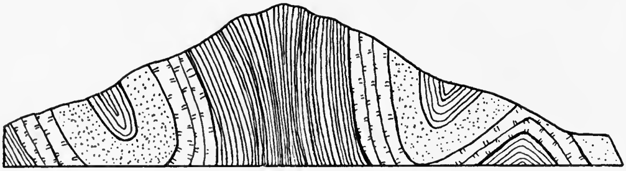

FIG. 108.—Fan-shaped folds.

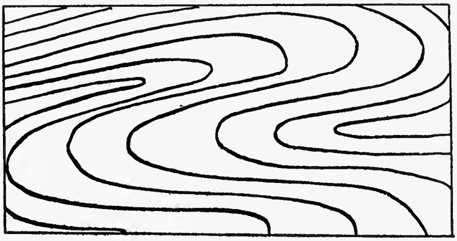

FIG. 109.—Overfold.

Faults.—In extreme cases the strata are fractured as the result of excessive overfolding, and there may be an extensive displacement of the beds on either side of the plane of fracture (fig. 110). Such a plane of fracture is called a *reversed fault* or *plane of overthrust.*

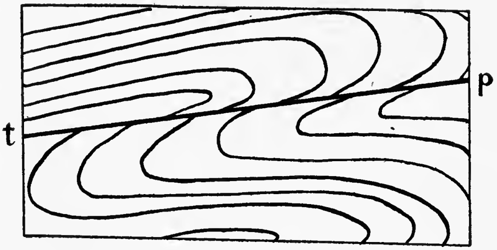

FIG. 110.—Overthrust or reversed fault.

When instead of compression, which develops folds and overthrusts, we have tension in the strata, planes of fracture are developed such as those represented in section in fig. 111. These planes of fracture are called *normal faults.*

When two adjacent normal-fault planes dip towards each other, as in fig. 112, they yield what is called a *trough fault*, in which a wedge-shaped mass of strata is depressed between the two faults. If successive fault planes dip in the same direction as shown in fig. 113 they produce what are called *step faults*.

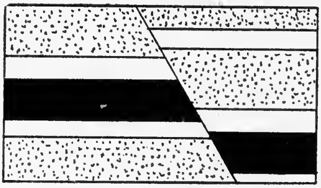

FIG. 111.—Normal fault.

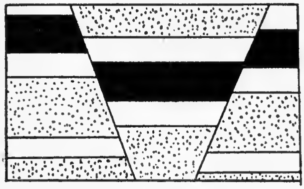

FIG. 112.—Trough fault.

The inclination of a fault plane to the horizontal is called the *dip of the fault*. The side of the fault on which the beds have been depressed is called the *downthrow* side; that on which the beds have been relatively elevated is called the *upthrow* side. In the case of the overthrust or reversed fault mentioned above, the fault plane dips towards the upthrow side. In normal faults, on the contrary, the fault plane dips towards the downthrow side.

The distance between the two corresponding parts of a faulted bed or vein is named the *throw* of the fault; and the horizontal distance is termed the *width, heave* or *offset* of the fault.

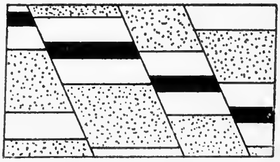

FIG. 113.—Step faults.

The terms used in describing faults, as defined above, apply only to displacements of horizontal or nearly horizontal beds, and are not intended to give an exact description of fault movement. The exact nature of the movement of rock surfaces on the two sides of a fault plane can seldom be ascertained. It is well known that in some cases fault movement results only in horizontal displacement, with practically no vertical displacement. In such cases it is customary to refer to the lateral " shift " rather than to the " throw " of the fault. It is clear that there must be variation between the extreme of a fault movement which is entirely a lateral shift and one in which it is a vertical throw.

When the facts concerning fault movement can be fully ascertained, which is rarely the case, it is possible to state the total displacement and resolve this into its component lateral shift and vertical throw. As a rule, however, one has to be satisfied with a less complete knowledge of the movement; but this should be remembered when reference is made only to the vertical throw as shown in section or the lateral shift as shown in plan.

The rock surfaces along a fault-plane are often striated and polished as a result of movement. Such surfaces are named *slickensides.* Fault-fissures often contain fragments of rock which have been broken from the edges of the strata and re-cemented to form *fault-breccia.* The broken edges of faulted strata are often curved with their free ends turned away from the direction of movement. This, and the direction of the striation-marks on slickensided surfaces, are often useful as indicating the whereabouts of the displaced bed, and the nature of the fault-breccia sometimes furnishes help in the same way.

Small normal faults are often abundant in strata that are only slightly disturbed by folding, especially among strata consisting of alternations of sandstone and shale with coal seams, as in the English coal measures. These small faults are doubtless due to tension set up as a result of gradual desiccation of the strata and consequent shrinkage in volume, a state of things highly favourable for the production of normal faults.

Large faults of the same type, due to tension in the earth's crust on a grander scale, have sometimes a throw of several thousand feet, and are continuous over large tracts of country, producing in some instances enormous scarps or precipices (fault scarps) that contribute in a large way to the formation of the major surface features. Perhaps the best examples of these are the extensive fault scarps that dissect the surface of eastern Africa, where they form the eastern precipitous boundary of the central plateau highlands, and cut up the surface in many places by the formation of large valleys of depression (the so-called rift-valleys or sunk-lands) that are merely enormous trough faults.

Dip- and strike-faults.—The trend of faults in relation to the strike or dip of the strata cut by them is variable. A fault the strike of which coincides with the strike of the strata is known as a *strike-fault.* If the fault strikes at right angles to the strike of the strata it is called a *dip-fault, i.e.* it trends in the same direction as the dip. A fault the trend of which is intermediate between these two directions is sometimes termed an oblique fault.

Fracture-zones.—Instead of being fractured along a simple fault plane, rocks are frequently broken by numerous fractures through a zone of considerable thickness in which there has been extensive shattering as a result of crustal movement. These fracture-zones, like simple faults, have often provided channels along which solutions rich in mineral matter have flowed, and in which this mineral matter has been deposited. Lodes of copper ore and other metallic ores in some instances consist of fracture-zones that have been mineralized in this way by the solutions that have traversed them.

Joints.—In consequence of irregularities in deposition, stratified rocks usually exhibit divisional planes parallel to the bedding, or split readily along these planes. In addition to these bedding planes, stratified rocks as well as igneous and other rocks that do not exhibit bedding, usually show other divisional planes called joints, by which the rocks are split up into quadrangular blocks of variable size (fig. 114).

FIG. 114.—Joints in sandstone (Coal Measures).

Joints arise from various causes. In some instances they are due to shrinkage. A notable instance of this is the columnar jointing in basalts, as shown by the well-known columnar basalts of Giants' Causeway in Co. Antrim and many other localities. Another instance of jointing is the tabular jointing frequently seen in granite, in consequence of which weathered outcrops of this rock often assume a form resembling the bedded appearance of stratified rocks.

In stratified rocks the joints are usually at right angles to the bedding, and there are frequently two systems of planes at right angles to each other, one of which, sometimes known as the *master-joints*, is the better developed of the two, and determines the predominant outcrop-face when the strata are exposed by denudation. In dipping strata, joints that are parallel to the strike of the beds are called *strike-joints*, whilst those that trend at right angles to this direction are called *dip-joints*.

A notable feature about joints is the way in which these divisional planes frequently persist with a uniform trend over large areas of country.

This is very well shown by the so-called " cleat " or chief joint-plane in coal seams.

As already mentioned, some joints are due to the direct effects of contraction. In some instances, it is clear that torsional stresses have accompanied tension due to contraction and that these stresses have affected the rocks uniformly over large areas after the consolidation of the rocks. This is shown by the nature of the joint faces, and by the way in which, as in the Old Red Sandstone conglomerates, joints sometimes cut clean across the pebbles.

Joints are of importance from a physiographical or scenical point of view on account of their effect in determining the outlines of a rock mass under the action of denuding agents, especially in coast erosion. From an economic point of view they are important because they make quarrying operations more practicable. They also serve as channels along which solutions can travel and deposit mineral matter. The " gash veins " in limestones are instances of this (see p 138). Perhaps one of the most familiar instances, however, is that provided by the ankeritic infillings of the major joint cracks (cleat) of coal. The white patches frequently seen on the bright joint faces of English coal consist usually of ankerite, with small amounts of calcite, barite, blende, galena, and pyrite, and have been deposited in the joint cracks by solutions percolating from above.

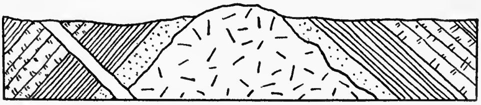

FIG. 115.—Granite intrusion in core of an anticline.

Igneous intrusions.—Associated with earth movements, especially those of the mountain-building type, we often find intrusive activity. Large masses of plutonic igneous rock are frequently found at the core of huge domes and anticlines (fig. 115). The granite masses of many mountains are such fold-cores that have been exposed by denudation and have stood out in relief in consequence of their superior powers of resistance to weathering and denudation. An instance of this is the granite axis of Cornwall which forms the high ground of the county, and is flanked on the north and south by the less resisting argillaceous sediments (" killas ") and other sedimentary rocks.

Domes and ridges of igneous rocks are often found to have a floor of sediments as illustrated by the diagrammatic section in fig. 116. Such intrusive masses are termed *laccolites* (Gr. *lakkos*, cistern, and *lithos*, stone) from their cistern-like form. Laccolites are formed as reservoirs of molten rock injected from dykes into spaces produced by the arching-up of superincumbent strata. Intrusive sheets which are of fairly uniform thickness, and wide in extent as compared with their thickness, are called *dykes* when they cut across the bedding of stratified rocks, and *sills* when they are parallel to the beds. Dykes are usually vertical or nearly so, and sills horizontal, as shown in fig. 117.

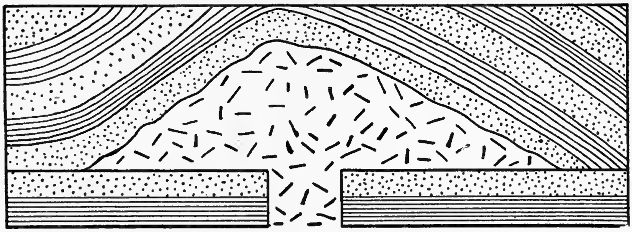

FIG. 116.—Laccolite.

Volcanic rocks are sometimes ejected from cracks and fissures, and spread over the surface in large sill-like sheets. As a rule, however, the eruption is more local, and the rocks accumulate to form cone-shaped masses around the vent.

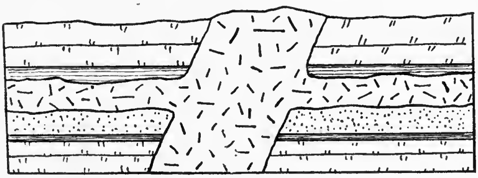

FIG. 117.—Dyke and sill.

Dykes, sills and surface flows of igneous rock often show columnar jointing.

Unconformity.—Sedimentary strata that have been deposited in the same sea, and during a given epoch of accumulation, exhibit a regular and comparatively uninterrupted sequence, as illustrated by fig. 105. Such a sequence is described as *conformable*.

When accumulation is interrupted at any place by the emergence of the sea floor, the beds are, as we have seen, often folded. But whether folded or not, their emergence exposes them to the denuding action of atmospheric agencies, and when during another period of depression, they again become immersed in the sea, the beds that are laid down are deposited on an eroded surface of the older strata, as shown in fig. 118. This discordant relation between rocks formed at different times is called *unconformity.* It furnishes valuable evidence in the study of the relative ages of deposits, and often enables the geologist to distinguish between intrusive rocks of different ages. In such a case as that illustrated by fig. 118, for example, a set of intrusives which pierced the older sediments but not the newer, would clearly be older than the latter; whereas a set which pierced both older and newer sediments would be younger than the newer sediments. In two such sets of intrusions of different ages, one set is sometimes found to have been the cause of the deposition of valuable minerals, whilst the other set has been barren.

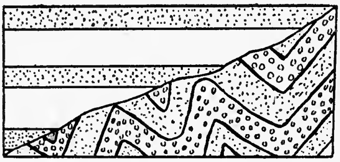

FIG. 118.—Unconformity.

We have seen, moreover, that valuable minerals are often concentrated in surface deposits; and an enrichment of ore deposits often takes place for some distance below the surface, due to the action of solutions percolating downwards. The discovery of an unconformity in mining operations is therefore, in certain cases, not without significance in its bearing on ore deposits, since it indicates the presence of an old surface on or below which enrichment may have taken place.

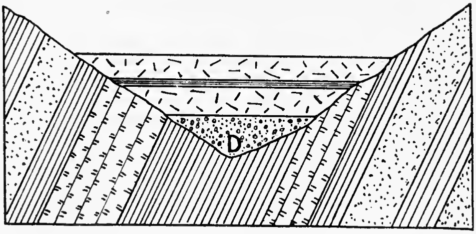

FIG. 119.—Deep lead (*D*) under a cover of basalt.

The bauxite deposits of Arkansas occur on an old syenite rock surface, and are covered by Tertiary sediments. The bauxite deposits of Co. Antrim in north-east Ireland occur on an old basaltic land surface that was exposed to weathering during Eocene times, and covered by a later flow of basalt.

In this connection the alluvial deposits known as "deep leads" are worthy of note (fig. 119). Deep leads are former surface gravels that have become buried, generally under sheets of basaltic lava. Important gold-bearing gravels of this type have been worked in Victoria and other parts of Australia and also in California.

MORPHOLOGICAL TYPES OF ECONOMIC MINERAL DEPOSITS.

Economic mineral deposits exhibit a great variety of shapes and conditions of occurrence. The chief morphological types may be enumerated as follows :

1. Fissure veins or lodes.
2. Bedded veins.
3. Saddle reefs.
4. Gash veins.
5. Pipes.
6. Stockworks.
7. Bedded sediments and their metamorphic equivalents.
8. Irregular masses.

1. **Fissure veins or lodes.**—These are the infillings of extensive fractures, commonly fault cracks, which may extend downwards to great depths. They may, and commonly do, consist of layers of mineral matter deposited successively. The rock traversed by a vein is called the *country rock*. Fissure veins are occasionally vertical; but as a rule they are obliquely inclined. The upper wall of the country rock bounding a vein is called the *hanging wall*, and the lower one the *footwall* (fig. 120). The walls of a vein are in some cases unaltered; in others they have been extensively replaced (metasomatized) by mineral matter deposited during the filling of the vein. In some veins, the vein-stuff or wall-rock or both have been broken into

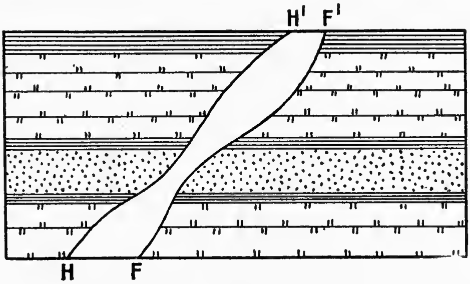

FIG. 120.—Hanging wall (*HH'*) and footwall (*FF'*) of a vein.

angular fragments and the fragments have been re-cemented by vein-stuff subsequently deposited. Such re-cemented vein-stuff is called *vein-breccia* or *lode-breccia.*

A fissure vein may be simple or compound ; in the latter case there are numerous parallel or intersecting small veins in close juxtaposition. The term *lode* is by some authors restricted to such compound fissure veins.

The term *strike* and *dip* can be used to describe veins in the same sense as they are used in the description of strata and faults.

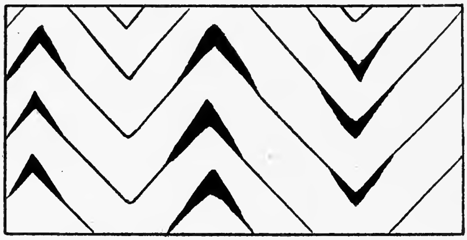

FIG. 121.—Saddle reefs.

2. **Bedded veins.**—Fissure veins usually cut across the stratification or foliation of the rocks in which they occur. Occasionally, however, they coincide with the planes of bedding or foliation, and are then called bedded veins.

3. **Saddle reefs.**—Where strata are folded, the crests of the anticlines and sometimes also the troughs of the synclines, are occupied by ore deposits as shown in fig. 121. Such bedded veins are called saddle reefs.

4. **Gash veins.**—These are formed in limestone joints that have been widened by solution prior to the deposition of the vein-stuff (fig. 122).

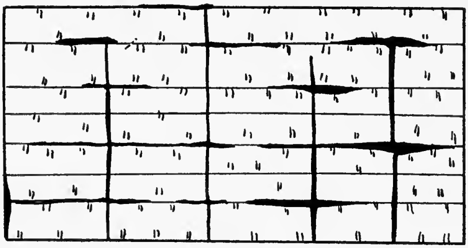

Fig. 122.—Gash veins in limestone.

Galena and blende are commonly found in such veins ; and where limestones and shales are interbedded, the gash veins are limited to the joints of the limestone.

5. **Pipes.**—Ore channels are sometimes more or less cylindrical or pipe-like in shape. Examples of this are the pipes of tin ore in the crystalline limestone of the Federated Malay States, and the pipes of tin ore in granite in the neighbourhood of Zaaiplaats, Transvaal. Other examples of pipes are the diamantiferous peridotite pipes of South Africa, and the pipes of nickeliferous pyrrhotite ore of the Sudbury district, Ontario. Lead and other ores are sometimes found in infillings of solution pipes in limestone.

6. **Stockworks.**—A stockwork is an irregular mass of interlacing veins. The rock interstices of such a mass are sometimes impregnated with ore, especially in stanniferous deposits, and stockworks thus grade into disseminated masses in which little or no evidence of vein structure is to be seen. The constituent veins of a stockwork are sometimes extremely thin, and not more than a millimetre or so in thickness, as in the case of the *Zwitterbander* of the German tin-ore miners.

Examples of stockworks are to be found among the stanniferous granite of Altenberg in the Erzgebirge, and among the tin-ore deposits in the granite and killas (slate) of Cornwall. Gold, silver, and copper deposits sometimes also furnish examples of stockworks.

7. **Bedded Sediments.**—Under bedded sediments are included all those deposits of sedimentary origin which have been formed *pari passu* with the beds in which they occur. Examples of these are the gold-placer or "banket" deposits of the Witwatersrand and the Gold Coast, in which detrital gold occurs in the interstices of conglomerates. Other examples are beds of bog iron-ore, manganese ore, gypsum, rock-salt and many other kinds of salt beds, all of which have been precipitated from solution.

8. **Irregular masses.**—In addition to the foregoing types of ore deposits, which, excepting stockworks, are more or less regular in shape, there is a varied assortment of deposits of irregular shape. These include *cave deposits*, notably those in limestone which sometimes become infilled by mineral matter deposited from the ore-bearing solutions that traverse them. Other examples of irregular masses of ore are many igneous segregations, contact impregnation deposits of metasomatic origin, and residual weathering deposits.

EARTH-HISTORY IN RELATION TO THE ORIGIN OF ECONOMIC MINERALS.

A study of the earth's crust has revealed the fact that the existing order of phenomena as regards weathering, denudation, earth movement and igneous activity has prevailed on the earth for many millions of years. As far back as we can go stratigraphically in tracing the earth's history, it appears that rock-forming processes were operating, and that the tectonic changes of the earth's crust were proceeding in much the same way as at the present day.

The history of the earth is imperfectly, yet wonderfully, recorded in stratified rocks by the fossil remains entombed in them, and by the nature and tectonic relations of rocks of different ages. The study of fossils shows that there has been a gradual evolution of forms of life during the earth's history, from the simpler invertebrates of the earliest times up to the highly organised vertebrates of the present day; and that each system of strata carries a characteristic assemblage of fossil remains by which it can be distinguished from older and newer systems. And so, by a combination of tectonic and palæontological evidences, geologists have been able to delineate, in a fairly successful manner, all except the earliest phases of the earth's history.

The earliest strata that contain relics of a definite fauna are those of the Cambrian system, which were deposited probably several hundred million years ago. Stratified rocks were deposited before Cambrian times, and some of these pre-Cambrian strata contain fossil remains; but on the whole these earlier strata have been so extensively metamorphosed that their fossil contents have been obliterated; and although there are indications of several systems of strata separated by unconformities in times preceding the Cambrian, these systems cannot be correlated in a satisfactory manner, and they are therefore conveniently arranged together under the name pre-Cambrian. Since the commencement of the Cambrian, however, the record is fairly clear, and by a study of unconformities and life changes, geologists have divided the fossiliferous stratified rocks into groups, sub-groups, and systems as follows:

Groups.	*Sub-groups.*	*Systems.*
Neozoic	Kainozoic or Tertiary	Post-pliocene
		Pliocene
		Miocene
		Oligocene
		Eocene
	Mesozoic	Cretaceous
		Jurassic
		Triassic

Groups.	*Sub-groups.*	*Systems.*
Palæozoic	Upper Palæozoic	Permian
		Carboniferous
		Devonian
	Lower Palæozoic	Silurian
		Ordovician
		Cambrian
Eozoic or pre-Cambrian.		

The above groups and sub-groups and in many cases the systems also, are marked off from one another by pronounced unconformities indicative of earth movement. A closer study of these earth movements enables us to take a much simpler view of the geological record, and one which, from the standpoint of the economic mineralogist, is of great interest. This will become clearer if we review briefly and broadly the history of earth-movement and igneous activity, and refer to some of the more important deposits of economic minerals in relation thereto.

Pre-Cambrian cycles.—The pre-Cambrian group of rocks gives evidence by several unconformities that repeated oscillations of the crust took place during the time when they were being formed. The orogenic earth-movements of pre-Cambrian times are often described as the Huronian movements, from the fact that their effects are best seen in the Huronian strata of Canada. As already mentioned, however, there are no means of correlating the systems of this group, and little is known concerning the comparative duration of the periods involved in their formation. Intrusions and metamorphism took place on an extensive scale in pre-Cambrian times, and many of the world's important deposits of economic minerals were formed during those early geological times. Indeed, instances of such deposits can be mentioned from most of the regions where pre-Cambrian rocks are found extensively. In Europe we have the valuable iron ore deposits of Sweden. In South Africa the banket gold deposits of the Witwatersrand and the chromite deposits of Rhodesia are of this age. In India the Kolar gold deposits, the primary ores of manganese, and the mica-pegmatites may be mentioned; whilst in Ceylon and Madagascar, the important deposits of graphite are of this age. Other deposits of this age are the iron and copper ores of Lake Superior, the nickel and cobalt ores of Ontario and the primary gold deposits of Western Australia.

Lower Palæozoic cycle.—Europe was largely submerged beneath shallow seas during Lower Palæozoic times. Some other parts of the earth show substantial evidence of Lower Palæozoic submergence, which led to the deposition of sedimentary strata over extensive areas unconformably on the pre-Cambrian formations. Eastern and western North America, eastern and western Australia, and large parts of Asia show clear evidence of submergence during Lower Palæozoic times, and show a large accumulation of Cambrian, Ordovician and Silurian strata. Equally widespread over the earth is the evidence of volcanic activity during this submergence.

In Europe there was little or no evidence of igneous activity during the Cambrian period; and the Cambrian strata of eastern and western America are equally free from evidence of igneous activity. Elsewhere, however, there was intense igneous action during Cambrian times, notably in north-western Australia, where there is one of the most extensive outflows of basic lava of Cambrian age. The igneous activity in the European region took place during the early part of the Ordovician and was one of the most intense outbursts of volcanism of which the geological record shows any evidence.

The strata of the Silurian system in Europe, like those of the Cambrian, show sedimentation under quiet conditions with very little evidence of igneous action; but in eastern North America the Silurian sediments are largely interbedded with volcanic rocks.

Orogenic earth movements (*i.e.* movements due to tangential compression, which folds stratified rocks and frequently gives rise to plutonic intrusions) took place at the close of Lower Palæozoic times. In eastern North America the movement asserted itself at the close of the Ordovician. In Europe it took place at the close of the Silurian, and led to the development of the folds known as Caledonian from their occurrence in Scotland, though they constitute a well-marked feature in the tectonic geology of western Europe generally. Numerous plutonic intrusions of granite were injected along the anticlines of Caledonian folds, and these plutonic intrusions have since been exposed by denudation. The eastern United States shows much evidence that folding and plutonic intrusion took place in that region about the same time. It is, moreover, interesting to note that the close of the Silurian in eastern Australia was marked by orogenic activity and plutonic intrusion on a large scale, much as it was in Europe.

According to the theory that plutonic igneous action is a factor of large importance in ore deposition it might be expected that the rocks affected by the earth movements and intrusions at the close of the Ordovician in eastern North America, and again at the close of the Silurian in western Europe, would show much evidence of ore deposition.

Few of the world's important ore deposits, however, can be attributed to this period.

The Wabana iron ores occurring as extensive bedded deposits in Newfoundland are of Cambrian age. The Clinton iron ores of the eastern United States are of Silurian age. The chromite and asbestos deposits of Quebec occur in a serpentine to the intrusion of which an Ordovician age is attributed. The galena limestone of S.E. Missouri is Cambrian. Many of the eastern Australian ore deposits are attributable to deposition during movement and intrusion at or just subsequent to the close of the Lower Palæozoic; but on the whole it appears that, as compared with the pre-Cambrian, the Lower Palæozoic geodynamic cycle does not show an important list of igneous ore deposits.

Upper Palæozoic cycle.—The orogenic earth movements already referred to under the name Caledonian as having asserted themselves in Europe at the close of the Silurian period, continued their activity into the Devonian, and the emergence resulting therefrom culminated in Middle Devonian times. As a result of these movements extensive mountainous tracts had been formed over areas previously covered by the Lower Palæozoic seas, and it was these mountainous lands that provided the coarse conglomerates of the Old Red Sandstone strata.

In Upper Devonian times a movement of submergence set in, and the Lower Carboniferous sea spread over wide areas. It was on the floor of this sea that the valuable limestones of Lower Carboniferous age were deposited in the English area, and during their deposition there was much volcanic activity. The Scottish oil-shales are of Lower Carboniferous age.

In Upper Carboniferous times the sea began to get shallower; ultimately it became silted up, and in the swamps that developed there was an abundant growth of vegetation under genial climatic conditions. The remains of this vegetation accumulated to form what are now the coal beds of western Europe and eastern America, which altogether, including as they do large deposits of anthracite, as well as bituminous varieties of coal, constitute one of the world's most valuable assets of mineral fuel.

At the close of the Carboniferous another period of important orogenic earth-movement opened, the effects of which in western Europe and eastern America were profoundly important. They seriously affected the regions over which Carboniferous strata had been deposited, folding these strata and raising them above sea level over extensive areas. It is in the synclines of the folds thus formed that many of the important coalfields have been preserved, the anticlines having been denuded away. The folds formed at this time are known by the names Hercynian, Armorican, Pennine and Mendipian in western Europe. In eastern North America they are known as the Appalachian folds, from the Appalachian mountains the formation of which is attributed to Permian folding.

Just as the early Devonian orogeny in western Europe gave rise to the formation of the Old Red Sandstone strata under somewhat arid conditions, so the orogeny of late Carboniferous and early Permian times gave rise to desert continental tracts over which the " New Red Sandstone " strata of Permian and Triassic times were deposited. It was in the salt lakes of these Permo-Triassic desert areas that some of the most valuable of the world's deposits of common salt and potash salts were formed.

The tin, tungsten, copper, and other ore deposits of Devon and Cornwall were due to the igneous activity that accompanied Hercynian or Armorican earth-movements; and it has been suggested that the zinc-lead ores of the British Isles are largely due to the igneous activity of these times.

The Gondwana coal deposits of India are regarded as of Permian age, and it seems highly probable that the coal beds of eastern Australia are largely of Permian age.

Mid-Mesozoic cycle.—The close of the Upper Palæozoic geodynamic cycle is marked in Europe by the Rhætic submergence. This submergence ushered in a marine phase which was dominant in western Europe throughout the Mesozoic. The Jurassic submergence was of a widespread character. The strata deposited in Jurassic times include the very important low-grade iron ores of England, France, and Germany, notably those of Lorraine in France and Cleveland in England. Useful deposits of clay and limestone were also formed. The extensive coal deposits of the Karroo beds in South Africa are regarded as being of Jurassic age.

The Jurassic closed with orogenic movements of large significance in the Coast Range area of western North America, and these were accompanied by extensive basic eruptions. The magnesite and chromite deposits of California and other parts of the Coast Range belt occur in serpentines formed from intrusions of peridotite of this age. Extensive basic eruptions took place during the Jurassic in Australia (especially in Tasmania) and South Africa. The nickel-copper pyrrhotites of Insizwa in south-eastern Africa occur in one of these basic intrusions.

Cretaceous-Tertiary cycle.—The orogenic activity at the close of the Jurassic did not attain a magnitude comparable with that of the orogeny of the Upper Palæozoic, and it was soon followed by the Cretaceous submergence which was more widespread and important than even the Jurassic submergence had been. During this submergence the valuable chalk deposits of western Europe were laid down. The bauxites of southern France are of this age, and are supposed to have been formed from argillaceous beds which, after having been deposited in the Cretaceous sea, were temporarily elevated and subjected to laterizing influences. The valuable coal deposits of the Rocky Mountain regions are Cretaceo-Tertiary. The diamond pipes of South Africa are regarded as Lower Cretaceous intrusions.

Extensive basic eruptions took place towards the close of the Cretaceous, and the Deccan traps of India, which represent one of the largest outpourings of basic igneous rock known in geological history, were erupted at this time. The chromite serpentines of Baluchistan in India as well as the chromite and nickeliferous serpentines of New Caledonia are portions of Cretaceous eruptives.

At the close of the Cretaceous there set in a period of orogenic activity which continued through the Tertiary and which has had more pronounced effects on the existing relief features of the continents than any which preceded them. The Rocky Mountains and the Andes, the Alps and the Himalayas, which represent the largest mountain tracts in the world, are due to Tertiary orogeny. Some of the most valuable of the world's ore deposits are products of Tertiary igneous action and were connected with these orogenic movements. Ore deposits of gold, silver, copper, lead and zinc are very abundant in association with Tertiary igneous rocks in the Rocky Mountain and Andean regions. Other important Tertiary deposits worthy of note are those of tin and bismuth in Bolivia, quicksilver in Texas, bauxite in Arkansas, phosphate in Florida, manganese ore in Russia, and last but not least the valuable petroleum deposits of Tertiary strata in California, Mexico, and eastern Europe.

Recent deposits.—Among deposits that owe their importance to processes now operating, mention may be made of alluvial deposits of gold, monazite, tinstone, diamonds, and other minerals in many localities. The phosphate deposits of oceanic islands are also worthy of mention, whilst bauxite, manganese ore, limestones and clays may be mentioned as instances of other useful minerals and rocks that are in course of formation at the present time.

It will be seen from the foregoing account of earth history in relation to the origin of rocks, and mineral deposits generally, that the geodynamical arrangement of the leading events in earth history for any region is of great interest and importance in connection with the study of economic mineral deposits. It is known that earth-movements, especially those of the orogenic or mountain-building type, are usually accompanied by the intrusion of acid igneous rocks, and that these igneous intrusions are in some cases the direct causes, in others the indirect causes, of the formation of important metalliferous and other mineral deposits.

Much remains obscure concerning the relation of ore deposition to igneous activity. The data available for consideration are in many cases very meagre ; but we have to bear in mind the fact that, in his mining operations, even of the deepest, man has hitherto been merely scratching the outer skin of the earth. Already, however, a geological classification of economic mineral deposits is feasible, and one may reasonably hope that before long it will be possible to say with some measure of exactness how the formation of these deposits in the earth's crust stands related to the various igneous, dynamic, and climatic changes through which the earth has passed.

CHAPTER VIII

THE ECONOMIC CLASSIFICATION OF USEFUL MINERALS

In the classification of minerals several methods are available. Of these there are three of chief importance, viz. (1) *the chemical method*; (2) *the genetic method*; (3) *the economic method.*

(1) *The chemical method* is the one adopted in works on scientific mineralogy, and is the one best suited for the description of minerals as a whole. In this method the order of arrangement usually adopted is as follows: Elements; Sulphides, etc.; Haloids; Oxides; Carbonates; Silicates; Phosphates, Vanadates, etc.; Nitrates; Borates; Sulphates, etc.; Tungstates; Molybdates; and minerals of organic origin. So far as the mineral world in its entirety is concerned there is much to be said for this method, but it is not a suitable means of classification for useful minerals considered apart from minerals generally.

(2) *The genetic method* brings together all those minerals which have had a similar mode of origin, irrespective of their chemical composition or other characters. It is in some ways a mode of classification very valuable to the student of economic minerals, inasmuch as it is natural and tells him which minerals are associated together. It is a method well suited for petrology, which aims chiefly at the study of rocks and the processes by which minerals are formed. Reference has already been made to this important aspect of the subject in the section dealing with the geology of economic mineral deposits; and we shall have occasion to note associations of minerals in dealing with the occurrence and distribution of economic minerals. It is an aspect of the subject which every student of economic minerals should study closely; but the genetic method of classification is not the best method of classifying economic minerals for descriptive purposes.

(3) Lastly we have *the economic method* of classification, in which minerals are grouped as far as possible according to their uses: a mode of procedure which is frankly at variance with the more academical groupings based on chemical or genetic principles. It is perhaps as

well to make a full confession of its comparative crudity as a method of classification, and to admit that, in adopting it, one aims solely at utility as the basis of arrangement. With this object in view we shall in this book divide economic minerals into three groups, viz., (1) Ore minerals; (2) Gem minerals; (3) Miscellaneous economic minerals. Ore minerals will be arranged according to the metals concerned, and the metals will be taken in alphabetical order. Gem minerals will be arranged alphabetically. Miscellaneous economic minerals will be arranged as far as possible according to uses, and for the rest according to their chemical nature; but the order of description of the groups will be alphabetical, with the object of facilitating reference and making the use of the index less necessary.

By ore mineral is meant a metalliferous mineral which owes its economic value to the fact that it is smelted to obtain a metal. Gem minerals and miscellaneous economic minerals are not used to any considerable extent as sources of the metals, and are generally used in their natural chemical condition. A large mumber of economic minerals however, require to be concentrated (*i.e.* separated from the matrix) before the minerals are available for smelting to obtain the metal or for use in other ways.

CHAPTER IX

ORE MINERALS

ALUMINIUM

ALUMINIUM is an important constituent of a large number of minerals, notably corundum (Al_2O_3), bauxite ($Al_2O_3 + xH_2O$), diaspore ($Al_2O_3 \cdot H_2O$), hydrargillite ($Al_2O_3 \cdot 3H_2O$), cryolite ($3NaF \cdot AlF_3$), alunite $\{(K, Na)(Al \cdot 2HO)_3(SO_4)_2\}$, and a large number of silicates. Of these minerals, bauxite, hydrargillite (gibbsite), and cryolite are of economic importance as ore minerals of aluminium, though bauxite is by far the most important.

Corundum is the mineral richest in alumina, and might be expected to be the ore of aluminium, especially as it occurs abundantly in certain igneous rocks, and is obtainable in a high degree of purity for commercial uses (see p. 323). Corundum, however, is too valuable for abrasive purposes to be available for use as an aluminium ore in competition with bauxite, which, as it does not require to be dressed, is a very cheap ore.

Felspar of the labradorite variety, which occurs extensively in Norway, has been experimented with recently to test its suitability as a source of metallic aluminium. The felspar can be decomposed by a 30 per cent. solution of nitric acid. After separating the iron from solution and evaporating to dryness, the ignition of the residue yields alumina from which the nitrates of calcium and sodium can be separated for use in agriculture.

The commonest aluminium compound is hydrated silicate of aluminium, which is present in large amounts in ordinary rock-clays and mudstones. Kaolin or China clay also consists of hydrated silicate of aluminium. Already a method has been introduced for the extraction of aluminium from clay on a commercial scale, and it may be that in the future clay will become the chief ore of aluminium. For the present, however, bauxite is the ore mineral in demand.

Aluminium is used largely in the manufacture of domestic articles, and conducting-wires for electrical purposes; and it yields various useful alloys with zinc, copper, and magnesium. "Duralumin" is aluminium alloyed with small amounts of copper, iron, or manganese and magnesium. "Magnalium" is an alloy of aluminium and magnesium. Aluminium powder is used for welding by the thermit process whereby oxides are reduced to metals. The best instance of this is the use of a mixture of aluminium powder and iron oxide ("thermit"), for welding iron and steel. When the mixture is ignited the iron oxide is reduced, and yields molten steel.

Bauxite (named after Baux, near Arles, in southern France, where it occurs).

General.—Amorphous and earthy; shows no crystalline form, but frequently possesses a concretionary (pisolitic) structure, like that of pisolitic limonite (fig. 123). Hardness variable though frequently low and about 2. The hardness of the pisolitic concretions may be as high as 6. Specific gravity frequently about 2·5, but higher in the less hydrated forms and in varieties containing much iron oxide.

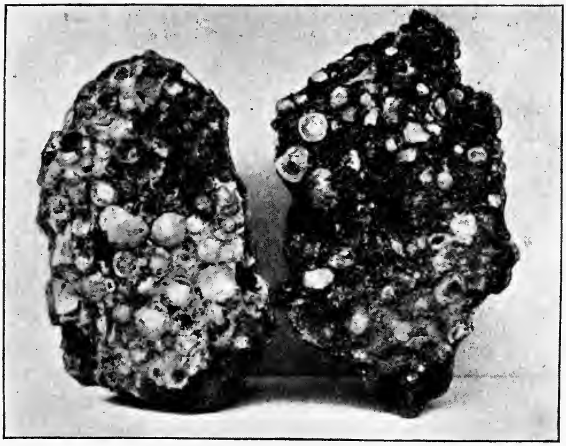

FIG. 123.—Pisolitic bauxite, India (× ½).

Optical.—Colour variable, according to the amount of iron oxide present; greyish or yellowish white when the amount of iron oxide is small, but brownish or reddish when this impurity becomes considerable in amount. Opaque, except in microscopically small particles, which are isotropic and have a refractive index about 1·57.

Chemical and blowpipe.—Bauxite consists essentially of hydrated alumina, the amount of water being variable. It varies between extremes corresponding to the formulæ of diaspore ($Al_2O_3 \cdot H_2O$) and hydrargillite ($Al_2O_3 \cdot 3H_3O$). Pisolitic concretions having the hardness, composition, and specific gravity of diaspore should perhaps be regarded as imperfectly crystalline diaspore. Other hydrated compounds are usually present, notably iron oxide, titanium dioxide, and silicate of aluminium. When the amount of hydrated alumina is small in comparison with the iron oxide and other ingredients the material should be called laterite (see below). For use as aluminium ore, bauxite should not contain more than two or three per cent. of silica. The following generalized analyses show the variability of composition among bauxites:

	Co. Antrim.	France.	Arkansas.	Central Provinces, India.
Alumina - -	42	63	54	55
Ferric oxide - -	2	9	9	7
Silica - - -	13	3	3	2
Titanium dioxide -	6	4	2	10
Combined water -	21	16	28	25
Moisture - -	16	5	4	1

Bauxite yields water when heated in a closed tube. It is infusible before the blowpipe, and becomes blue when re-heated after moistening with cobalt nitrate. It is difficultly soluble in hydrochloric acid.

Origin of bauxite and laterite.—The action of atmospheric influences on rocks containing felspars and other aluminium silicates containing various bases, results in the decomposition of these silicates, and the formation of hydrated products. In regions where the climate is temperate, and the rainfall frequent, the alkaline products of decomposition are largely carried off in solution in the abundant surface waters, and amorphous hydrated silicates of aluminium, the plastic ingredients of rock-clays and mudstones, remain as an end-product of weathering, usually mixed with quartz and other resistant minerals.

In those hot countries where a long dry season alternates with a wet season, the change goes a step further. Under these conditions the hydrated silicate of aluminium and free silica are attacked, and hydrated alumina is the end-product of weathering. The explanation of this is probably to be found in the fact that, under such climatic conditions alkaline salts accumulate in the soil, and yield solutions that can attack silica and aluminium silicates.

The tropical weathering products thus produced are laterites; and though these are characterized by the presence of amorphous hydrated alumina, they usually contain other amorphous hydrated oxides in large amount, especially ferric oxide and titanium dioxide. More rarely they contain manganese oxide, chromium oxide, and nickel silicate, whilst there may be a residue of undecomposed hydrated aluminium silicate and quartz, together with ilmenite, rutile, zircon, gold, cassiterite, and other minerals that have resisted decomposition.

It is therefore convenient to use the term laterite in a broad petrographical sense, and to apply the term bauxite in a mineralogical sense to the amorphous hydrated alumina which is the characteristic ingredient of laterites, and which in a more or less impure condition constitutes the bauxite of commerce.

Laterite manifests a tendency to segregation. Segregated masses of iron oxide and bauxite in pisolitic forms are commonly found among laterites. As already mentioned the pisolitic concretions are stated to have in some cases all the essential characteristics of diaspore. Hydrargillite (gibbsite) is frequently present in the cracks and cavities of laterite and bauxite, and bauxite may become completely changed into hydrargillite.

Uses.—Bauxite is used for a variety of purposes other than as an ore of aluminium. It is fused in the electric furnace to form artificial corundum, which is used as an abrasive under various trade names, including "aloxite" and "alundum." Varieties containing a considerable amount of silica, but not much iron oxide, are used for the manufacture of aluminium sulphate, and also for making refractory bricks. The ferruginous bauxite of Antrim is used as a flux in smelting the hæmatite iron ores of Cumberland in England, which are siliceous and deficient in alumina. Another use is for oil-refining.

An electrical furnace process (the Serpek process), involving the fixation of atmospheric nitrogen, was invented some years ago, for the purpose of obtaining aluminium nitride from high-grade bauxite. By treating the aluminium nitride with caustic soda, sodium aluminate and ammonia are formed. From these pure alumina and ammonium sulphate can be obtained, the former useful as a source of aluminium, the latter as a fertilizer.

Occurrence and distribution.—Bauxite is widely distributed, but the chief countries in which it is mined are France, United States, British Guiana, Ireland, and Italy. Large deposits occur in Rumania, India, Dutch Guiana, and West Africa, and some of these are likely to become of economic importance in the future.

France.—Bauxite occurs extensively and is mined in the Departments of Var and Hérault in southern France. At Baux, from which locality the mineral takes its name, it occurs in a sedimentary series of

Cretaceous age associated with beds of limestone, sandstone, and clay. In this and other cases where bauxite is found in sedimentary strata the bauxite represents an interruption of the stratigraphical sequence, and was presumably formed by the weathering of argillaceous material during a period of emergence. In Puy-de-Dôme, bauxite deposits occur in association with gneiss and basalt, from which they have arisen as products of decomposition.

United States.—Arkansas is the chief producer, but bauxite is mined also in Georgia, Alabama, and Tennessee. In Arkansas the bauxite deposits lie on decomposed syenite, and reach a thickness of 30 feet; they are overlain by Tertiary sands, gravel, and clay (fig. 124). In Georgia, the bauxite is associated with sands and clays of Cretaceous and Tertiary age; and the bauxite of Tennessee occurs in a limestone-dolomite-chert formation.

Ireland.—Bauxite is mined at various localities in County Antrim, where it has been formed by the atmospheric weathering of basalt and other volcanic rocks during early Tertiary times. It occurs associated with lithomarge forming a layer between the older and younger Tertiary basalts. Typical sections showing the relation of bauxite to basalt in Antrim are those seen at Irish Hill, Straid. One section at this locality shows a layer of bauxite from 3 to 7 feet thick lying on lithomarge, this in its turn lying on a mass of older basalt from which it has been derived; and overlying the bauxite layer is the younger basalt. Some sections at this locality show the bauxite interbedded with lignite, whilst in other sections the bauxite is missing, its place being taken by a layer of pisolitic iron ore.

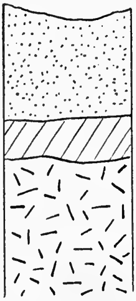

Fig. 124.—Vertical section of Arkansas bauxite, lying on syenite, with overburden of sand, etc.

Italy.—Bauxite is mined at Pescosolido in the Terra di Lavoro district of Abruzzi, where it occurs interbedded with Cretaceous limestone.

Other Localities.—Some of the laterite deposits of India consist of typical bauxite. Typical concretionary bauxites containing a low percentage of silica but a rather high percentage of titanium, occur at Katni in the Central Provinces (see analysis on p. 151). The Indian deposits have only been worked to a small extent hitherto, but they may become of great commercial importance in the future.

Bauxites of the ferruginous and non-ferruginous types, some of which are concretionary, occur in many parts of West Africa, in some places forming extensive deposits, as at Mt. Ejuanema in the Kwahu district of the Gold Coast Colony.

The bauxites of the Guianas in South America are stated to occur in extensive deposits, and some of them are of very good quality, containing low percentages of iron and titanium oxides and silica. The bauxite of Christianburg on the Demerara River in British Guiana contains up to 67 per cent. of alumina and is of excellent quality.

Large deposits of bauxite, estimated to contain about 20,000,000 tons of the mineral, occur in the Bihar mountains of Western Rumania, where they are associated with Jurassic limestones. These Rumanian bauxites are of the ferruginous type, containing from 50 to 65 per cent. of alumina, 20 to 30 of iron oxide, 2 or 3 of titanium dioxide, 1 or 2 of silica, and 11 to 12 per cent. of water.

Other deposits of note are those of Dalmatia (Sebenico, Dernis, and other localities) and Herzegovina, from which the Central Powers obtained supplies during the late war.

Hydrargillite (Gr. *hydor*, water, and *argillos*, clay. Also frequently called gibbsite, but the latter name is also applied to a hydrated aluminium phosphate).

General.—Monoclinic. Occurs in the form of small six-sided scales and scaly aggregates. Basal cleavage. Hardness, about 3. Specific gravity, about 2·35.

Optical.—Colour, white. Lustre, pearly on cleavage plates. Refractive index low, but variable, and about 1·56. Birefringence moderate, but variable; $\gamma - \alpha$ about 0·02. Optical sign, positive. Sometimes approximately uniaxial.

Chemical and blowpipe.—Hydrated alumina, with a composition corresponding to the formula $Al_2O_3 \cdot 3H_2O$. Infusible. Gives off water in a closed tube. Dissolves readily in a bead of microcosmic salt. Turns blue after moistening with cobalt nitrate and heating in blowpipe flame. Soluble in sulphuric acid, but not readily attacked by hydrochloric acid.

Occurrence.—Found most frequently as a crystalline alteration product of bauxite; and is often met with in the cracks and cavities of laterites. Bauxite may be completely altered to hydrargillite.

Cryolite (Gr. *kryos*, frost, and *lithos*, stone; so named from its resemblance to ice).

General.—Monoclinic, but usually massive. Cleavage good, and yields approximately cube-shaped fragments. Hardness, $2\frac{1}{2}$. Specific gravity, about 3.

Optical.—Colour, white or brownish. Lustre, vitreous. Refractive index very low, and about 1·36. This is an abnormally low refractive index for a mineral; and cryolite is one of very few minerals the microfragments of which show but a feeble relief when mounted in water, a fact which provides a simple and ready means of testing the mineral. Birefringence, very low. Optical sign, positive.

Chemical and blowpipe.—Fluoride of sodium and aluminium ($3NaF \cdot AlF_3$). Fusibility $1\frac{1}{2}$, fusing with extreme readiness to a white enamel. Flame coloration, intense yellow. When heated with potassium bisulphate in a closed tube, hydrofluoric acid is given off, and the glass tube is attacked, a white deposit of silica being formed. Decomposed by sulphuric acid, with evolution of hydrofluoric acid.

Uses.—Cryolite was formerly the only source of aluminium, but it has been superseded for this purpose by bauxite, which is cheaper. It is still used, however, in conjunction with bauxite, in the production of aluminium, but chiefly on account of its fluxing property. It is also used in making sodium salts, opaline glass, enamels for iron ware, and a white variety of Portland cement.

Occurrence and distribution.—Cryolite is not of frequent occurrence, and the only locality where it has been found in considerable quantity is at Ivigtut, an Eskimo village on the south-west coast of Greenland. It occurs there in the form of a vein-like band in gneiss, and is associated with galena, zinc-blende, chalybite, pyrite, arsenopyrite, fluorite, columbite and cassiterite. In the vicinity of the cryolite vein there are intrusions of porphyritic granite, associated with pegmatite veins, and these are supposed to be genetically connected with the cryolite deposit. The deposit has a length of 600 feet and a width of 200 feet at the surface, and has been quarried to a depth of over 150 ft.

ANTIMONY

The chief ore mineral of antimony is stibnite (Sb_2S_3), which is found in quartz veins of hydrothermal origin, and to some extent also as a metasomatic replacement of the country rock. Where these veins have been altered by oxidation at and near the surface, the minerals senarmontite (Sb_2O_3), valentinite (Sb_2O_3), and kermesite (Sb_2S_2O) frequently occur. The mineral jamesonite $\{7(Pb, Fe)S \cdot 4Sb_2S_3\}$ is sometimes found abundantly enough to play the part of an ore mineral of antimony, especially when associated with gold.

Antimony is a constituent of many useful alloys. *Antifriction metal* is an alloy of antimony with lead; so is *type metal*, but the latter usually contains some tin as well. *Britannia metal* is an alloy of tin, copper, and antimony. Antimony is also used in making shrapnel bullets on account of the brittleness it imparts. Antimony sulphide is used in vulcanizing rubber.

Stibnite (L. *stibium*, the old name of antimony; the mineral is also known as antimonite and antimony-glance).

General.—Orthorhombic. Crystals often large, and in the form of long prisms (fig. 125); the prism faces are as a rule conspicuously striated. Sometimes granular in texture. Perfect pinakoidal cleavage parallel to the prism edges. These cleavage surfaces show characteristic slip striæ which lie at right angles to the prism edge, and which are important as affording a means of identification. Hardness, 2½. Specific gravity, about 4·6.

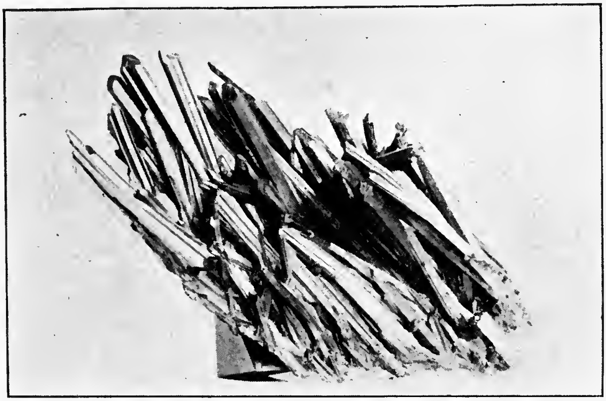

FIG. 125.—Stibnite, Japan (× ½). B.M.

Optical.—Colour, lead-grey. Streak, greyish black. Lustre, metallic and especially brilliant on a freshly cleaved surface. Opaque or nearly so, only the thinnest edges being translucent and of a red colour in microscopic splinters. Mean refractive index about 4. Double refraction extremely strong and negative.

Chemical and blowpipe.—A sulphide of antimony of a composition represented by the formula Sb_2S_3, and containing 71·8 per cent. of antimony. Fusibility, 1; fuses readily and gives a pale greenish flame. Readily volatile, yielding a white volatile incrustation near the mineral when heated before the blowpipe on charcoal. Heated strongly in a closed tube yields a sublimate of antimony oxysulphide, which appears black when hot, but becomes reddish brown on cooling. Roasted in an open tube, yields a white sublimate of antimony oxide, and gives off sulphur dioxide. Decomposed by strong hydrochloric acid, giving off sulphuretted hydrogen. If water is added before decomposition is complete, an orange-coloured precipitate of antimony sulphide is obtained (distinction from bismuthinite).

Senarmontite (named after H. de Senarmont).

General.—Cubic, usually showing octahedral form. No good cleavage. Fracture uneven. Hardness about $2\frac{1}{2}$. Specific gravity about 5·25.

Optical.—White or colourless. Lustre adamantine. Microfragments transparent or nearly so. Refractive index very high (2·01). Isotropic.

Chemical and blowpipe.—A sesquioxide of antimony (Sb_2O_3), containing about 83·5 per cent. of antimony when pure. Fusibility, $1\frac{1}{2}$. Readily volatile and yields a heavy white sublimate on charcoal.

Valentinite (named after Basil Valentine, a fifteenth century alchemist).

This mineral is a sesquioxide of antimony (Sb_2O_3) resembling senarmontite in its colour and chemical properties. It is distinguished from senarmontite by its crystalline form (orthorhombic), good cleavage, specific gravity (5·55), and anisotropic character.

Kermesite (Sb_2S_2O) is distinguished from both senarmontite and valentinite by its red colour, hardness (about $1\frac{1}{2}$), specific gravity (4·6), and by the fact that it gives off sulphur dioxide when heated in an open tube. It crystallizes in acicular prisms of monoclinic symmetry, is frequently found in radiating aggregates, and shows a good cleavage.

Jamesonite (named after R. Jameson of Edinburgh, who was a contemporary and disciple of Werner).

General.—Orthorhombic, usually in the form of acicular crystals or fibrous masses. Perfect cleavage at right angles to prism edge (distinction from stibnite). Hardness about $2\frac{1}{2}$. Specific gravity, about 5·8.

Optical.—Colour, greyish black. Streak, black. Lustre, metallic. Opaque.

Chemical and blowpipe. — Sulphide of lead and antimony $\{7(Pb, Fe)S \cdot 4Sb_2S_3\}$ containing when pure about 32 per cent. of antimony and about 40 per cent. of lead. Fusibility, 1. Reddish brown sublimate of antimony oxysulphide in closed tube. Yields metallic lead when fused with carbonate of soda on charcoal. Decomposed by hydrochloric acid, giving off sulphuretted hydrogen, and the solution deposits lead chloride on cooling.

Occurrence and distribution of antimony ores.—The leading producer of antimony ore is China. Considerable amounts are also produced by

Japan, Bolivia, Mexico, France, Algeria, Bohemia and Hungary, Australia, Turkey, Serbia, and Italy. The output of other countries is comparatively very small; but it should be mentioned that the United States produces a large amount of antimonial lead (hard lead), obtained by smelting silver-ores that contain lead and antimony.

China.—Antimony ore occurs abundantly in the southern provinces of China. The chief mining centres are situated in the provinces of Hunan, Kwangsi, and Kwantung. The ore mineral is generally stibnite. Valentinite, senarmontite and kermesite are found associated with the stibnite as alteration products; and at Fengyi in Kwangsi, ore composed chiefly of senarmontite has been mined.

The stibnite of Hunan occurs chiefly in quartz veins. The ore frequently carries about 50 per cent. of antimony, and ore containing over 60 per cent. has been mined. At some localities the stibnite is found in pockets in a dolomitic limestone of Carboniferous age, and is supposed to have been formed in these cases by replacement (metasomatism).

France.—Antimony is abundantly distributed in the Central Plateau area, notably in the departments of Puy-de-Dôme, Haute-Loire, Mayenne, and Cantal, where it is found in quartz veins that traverse the granites, gneisses, and schists. Zinc-blende and pyrites occur frequently in the veins, occasionally associated with calcite and barite. Lead and silver minerals are present in some of the veins. In some of the veins, as at Freycenet, there are lenticular masses of rich stibnite ore containing very little quartz.

Bolivia.—In Bolivia, rich vein deposits of stibnite traversing Palæozoic shales are mined at various localities, notably in the Potosi region and near Oploca. A little quartz is usually present in the veins; and sometimes also galena, which is detrimental. A large output of ore containing upward of 50 per cent. of antimony has been obtained from these deposits. Some of the Bolivian antimony ores are auriferous. Antimony is an important war metal, as is shown by the fact that the Bolivian exports rose from 186 metric tons of ore in 1914 to about 18,000 tons in 1915, and over 27,000 tons in 1916.

Mexico.—Stibnite vein deposits of the normal type, oxidized at and near the surface, have yielded large amounts of antimony ore in various parts of Mexico, notably in San Luis Potosi and in Queretaro. A less common type of deposit is that of La Sirena near Zimapan, where there is a large deposit of jamesonite occurring as a replacement of limestone. Associated with the jamesonite are the minerals arsenopyrite, zinc-blende, pyrrhotite, quartz, albite, fluorite, and apatite.

Bohemia and Hungary.—Antimony ore has been mined to a considerable extent in Bohemia and various parts of Hungary. In the Rechnitz Mts. of Hungary, stibnite occurs in quartz veins which traverse the crystalline schists ; and the veins are particularly rich where the schists are chloritic or graphitic. Calcite and auriferous pyrite are found associated with the stibnite in these veins. At Magurka, a granite is traversed by quartz veins containing stibnite associated with gold, pyrite, chalcopyrite, galena, zinc-blende, calcite and dolomite.

Australia.—Antimony ore is mined at various localities in Victoria, New South Wales, and other parts of Australia. In New South Wales, notably in the Hillgrove district, the ore mineral, which is chiefly stibnite, occurs in quartz veins. These veins traverse Palæozoic sedimentary rocks and various igneous rocks, including granite, that are intrusive in these sediments. The most productive veins are found in the sedimentary rocks near their contact with the intrusive granites.

At Costerfield in Victoria, quartz veins traversing Ordovician and Silurian shales, slates and sandstones contain an abundance of stibnite and the ore is auriferous. The antimony-ore concentrates obtained at Costerfield contain about 48 per cent. of antimony and from 2 to 2¼ oz. of gold per ton.

Japan.—In the island of Shikoku, veins of stibnite are found in sericitic schists. The vein-stuff associated with the stibnite is quartz and calcite, and in close proximity to the veins the enclosing schists are impregnated with pyrite. Fine groups of large crystals have been obtained from the Ichinokawa mine in the Iyo province of Shikoku island.

United States.—In the United States some antimony is obtained from antimonial lead (hard lead) produced in part as a by-product in working silver ores. In California, Idaho, and various other States, however, stibnite occurs in some abundance as a vein mineral, and has been mined at various places. At Pine Creek for example, in the Cœur d'Alene district of Idaho, there is a well-defined vein containing stibnite, which near the surface is oxidized to kermesite, valentinite, and senarmontite.

Other Deposits.—Among other antimony deposits mention may be made of those of Rhodesia, where stibnite and jamesonite occur in some abundance in gold ores, as at the Globe and Phœnix and other mines. Jamesonite, as well as stibnite, occurs in the antimony veins at Endellion (Cornwall) in England.

ARSENIC.

The chief arsenic minerals are arsenopyrite ($FeAsS$), orpiment (As_2S_3), and realgar (As_2S_2). Arsenic is a constituent of numerous other minerals, notably the metallic arsenides and sulpharsenides of which the more important are löllingite ($FeAs_2$, see p. 161); enargite ($3Cu_2S . As_2S_5$, see p. 175); smaltite ($CoAs_2$, see p. 170); cobaltite ($CoAsS$, see p. 170); chloanthite ($NiAs_2$, see p. 226); niccolite ($NiAs$, see p. 226); and gersdorffite ($NiAsS$, see p. 226).

Arsenious oxide, the white arsenic of commerce, is used in the manufacture of certain pigments, and in making glass and enamels. It is also used in medicine. About 0·3 per cent. of arsenic is alloyed with lead in the manufacture of shot. Large amounts of sodium arsenite are used in insecticides, as in sheep dips. Arsenic is used in Australia to destroy the prickly pear. Calcium arsenate is used in the United States to destroy the boll weevil, which does much damage to cotton crops.

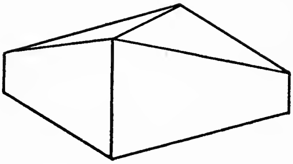

FIG. 126.—Arsenopyrite.

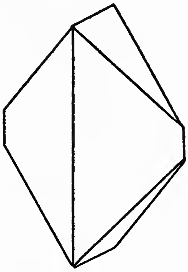

FIG. 127.—Arsenopyrite.

Arsenopyrite (also called mispickel and arsenical pyrites).

General.—Orthorhombic. Usually massive, but frequently also in crystals of a clearly orthorhombic type. These crystals are sometimes of an elongated prismatic habit; but dome forms often occur, sometimes in combination with a stumpy prism (see figs. 126, 127). Fracture, uneven. Hardness, $5\frac{1}{2}$. Specific gravity, about 6·1.

Optical.—Colour, steel-grey. Streak, greyish black. Lustre, metallic. Opaque.

Chemical and blowpipe.—A sulpharsenide of iron ($FeAsS$) containing 46 per cent. of arsenic. Fusibility, 2; fuses readily to a magnetic globule in the blowpipe flame, giving off fumes of arsenic. Heated in a closed tube gives a red sublimate of arsenic sulphide and a metallic sublimate of arsenic. Decomposed by nitric acid, the dilute solution giving a reddish brown precipitate of basic ferric arsenate when excess of ammonia is added.

Origin.—Arsenopyrite is of hydrothermal origin. It occurs frequently as a vein mineral associated with galena, zinc-blende, chalcopyrite, cassiterite, and wolframite.

Löllingite is closely similar to arsenopyrite, which it resembles in crystalline form and habit. It contains little or no sulphur and has a specific gravity about 7·2.

Orpiment (name derived from the Latin *auripigmentum*, meaning golden paint).

General.—Orthorhombic. Usually occurs massive, with a granular or foliated texture. Perfect pinakoidal cleavage. Hardness, $1\frac{1}{2}$. Specific gravity, about 3·5.

Optical.—Colour, lemon-yellow. Lustre, pearly. Refractive index very high, and greater than that of a solution of sulphur in methylene iodide. Birefringence, high.

Chemical and blowpipe.—Sulphide of arsenic (As_2S_3), containing 60·9 per cent. of arsenic. Fusibility, 1 ; fuses with extreme ease in blowpipe flame, giving off fumes of arsenic and sulphur dioxide. Heated alone in a closed tube gives a sublimate which is deep-red when hot and yellowish when cold. When mixed with plenty of sodium carbonate and a little charcoal powder and heated in a closed tube, yields a metallic deposit of arsenic. Heated in an open tube yields a sublimate of arsenious oxide, which is very readily volatile. Soluble in aqua regia, and caustic potash.

Realgar (name derived from the Arabic *Rahj al ghar*, meaning powder of the mine).

General.—Monoclinic ; but like orpiment with which it is usually found in intimate association, it generally occurs in a massive condition. Fairly good pinakoidal cleavage. Hardness, $1\frac{1}{2}$. Specific gravity about 3·5.

Optical.—Colour, red. Lustre, resinous. Under the microscope shows a very high refractive index, greater than that of sulphur in methylene iodide. The small fragments show a high birefringence, and are slightly pleochroic.

Chemical and blowpipe.—Sulphide of arsenic (AsS), containing 70·1 per cent. of arsenic. Fusibility and chemical reactions like those of orpiment.

Occurrence and distribution of arsenic minerals.—The chief countries concerned in the production of arsenic minerals are Silesia, United States, United Kingdom, France, and Canada. Nearly the whole of the arsenic of commerce is obtained as a by-product of the metallurgical treatment of lead, tin, and other ores.

SILESIA.—Arsenopyrite occurs abundantly in the Liegnitz and Breslau districts of Silesia. At Reichenstein the country rock consists of serpentine in contact with limestone. The arsenopyrite is disseminated through the serpentine, and also occurs in large compact ore-bodies; it is auriferous, and is associated with magnetite, zinc-blende, argentiferous galena, chalcopyrite, bornite, pyrrhotite, pyrite, and erythrite.

UNITED STATES.—White arsenic (As_2O_3) is obtained as a by-product in smelting lead and copper ores, chiefly in the States of Washington, Montana, Virginia and Utah. The lead ores contain arsenopyrite. At Butte, in Montana, enargite is an important constituent of the copper ore there mined.

UNITED KINGDOM.—Arsenopyrite occurs in large quantities with the tin and copper ores of Devon and Cornwall, from which it is obtained as a by-product.

FRANCE.—Arsenopyrite occurs abundantly in quartz veins at numerous localities, notably in the region of the Central Plateau, and is sometimes richly auriferous and argentiferous. In some veins it is associated with cassiterite and wolframite. Other minerals found variously associated with the arsenopyrite are stibnite, galena, chalcopyrite, barite, pyrite, smaltite, and native arsenic.

CANADA.—Arsenopyrite occurs abundantly in Hastings County and other parts of eastern Ontario, where it is auriferous, and is associated with pyrite and chalcopyrite. The ore occurs in large bodies in the Keewatin schists. The chief supply of arsenic in Canada at present is obtained from the famous silver-nickel-cobalt-arsenic ores of the Cobalt district (see p. 171).

OTHER COUNTRIES.—Among the less important occurrences of arsenic minerals, it is of interest to note that orpiment is mined near Talifu, in the Province of Yunnan, China, and is exported to Burma for use in lacquer work. Orpiment is also mined in Chitral, India. Realgar is mined at Matra in Corsica, where it occurs as a vein 13 feet thick traversing slates.

BISMUTH.

The chief ore minerals are native bismuth (Bi), and bismuthinite (Bi_2S_3). In the zone of weathering and oxidation, bismutite $BiO \cdot Bi(OH)_2 \cdot CO_3$, and bismite ($Bi_2O_3$) occur frequently.

Other bismuth minerals, of little or no significance economically, are numerous, and include tetradymite (Bi_2Te_3), chiviatite ($2PbS \cdot 3Bi_2S_3$), emplectite ($Cu_2S \cdot Bi_2S_3$), matildite ($Ag_2S \cdot Bi_2S_3$), eulytite $Bi_4(SiO_4)_3$, and pucherite ($BiVO_4$).

Although the ore minerals of bismuth contain high percentages of the metal, the ores as mined seldom contain more than about 10 or 20 per cent. of bismuth.

Metallic bismuth is an important constituent of various fusible alloys, notably those known by the names of Rose, Wood, Newton, and Lipowitz, in which it is alloyed with lead and tin and sometimes cadmium. It is also sometimes used in making stereotype plates. Bismuth compounds are used to some extent in medicine. The oxide (Bi_2O_3) is used in colouring porcelain.

Native Bismuth.—*General.*—Rhombohedral, but usually occurs in granular or dendritic forms. Basal and rhombohedral cleavages perfect. Hardness, 2½. Specific gravity, 9·8.

Optical.—Colour and streak, silver-white. Lustre, metallic. Opaque.

Chemical and blowpipe.—Consists of metallic bismuth (Bi). Fusibility, 1; fuses to a globule with extreme ease. Before the blowpipe yields a yellow incrustation of bismuth oxide; and when a mixture of potassium iodide and sulphur is added, yields a fine red sublimate. Lead minerals yield a fine yellow sublimate before the blowpipe with a mixture of potassium iodide and sulphur and are thus readily distinguished from those of bismuth. Bismuth moreover is brittle, whereas lead is easily malleable. Bismuth dissolves in nitric acid, yielding a white precipitate of bismuth oxynitrate $\{(BiO)NO_3\}$ when excess of water is added.

Bismuthinite (also called bismuth-glance).

General.—Orthorhombic. Usually massive and foliated; sometimes fibrous (fig. 128). Shows a perfect cleavage, often with a strongly striated cleavage face. Hardness, 2½. Specific gravity about 6·5.

Optical.—Colour, lead-grey. Streak, greyish black. Lustre, metallic. Opaque.

Chemical and blowpipe.—Sulphide of bismuth (Bi_2S_3), containing 81·2 per cent. of bismuth. Fusibility, 1. In open tube gives off sulphur dioxide and yields a white sublimate. On charcoal readily reduced to metallic bismuth, which is brittle as compared with lead, and yields a yellow incrustation. Yields the other charcoal reactions mentioned under metallic bismuth. Decomposed by strong hydrochloric acid, and gives off sulphuretted hydrogen. If water be added before decomposition is complete the brownish-black sulphide of bismuth is precipitated (distinction from stibnite).

Bismutite.—Amorphous, occurs almost always in the form of white, greenish or yellowish crusts. Hardness about 4½. Specific gravity, 6·9 to 7·6. Rarely shows a vitreous lustre. Chemical composition rather doubtful, and approximately represented by the formula $BiO \cdot Bi(OH)_2 \cdot CO_3$, with about 79 per cent. of bismuth. Fusibility, 1½. Yields good bismuth reactions on charcoal (see native bismuth).

Bismite (also called bismuth-ochre).—Orthorhombic; but in nature occurs massive only, and generally in an earthy condition. Specific gravity, about 4·4. Colour, greyish-white or yellowish. Consists of bismuth oxide (Bi_2O_3) with 89 per cent. of bismuth. Yields good bismuth reactions (see native bismuth).

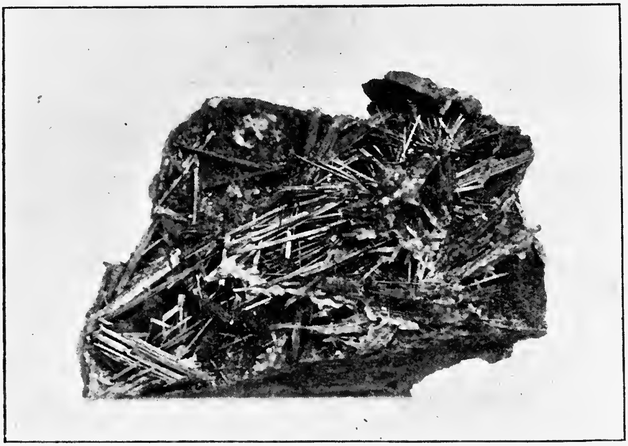

FIG. 128.—Bismuthinite, Cornwall. (× ¾). B.M.

Occurrence and distribution of bismuth ore.—The chief sources of bismuth ore are Bolivia, Germany, Australia, and Peru.

BOLIVIA.—Bolivia is the chief producer, and the most important deposits are at Tasna. The ores occur in quartz veins traversing slates. The ore minerals are native bismuth, bismuthinite, bismutite, and bismite. The ores carry from 20 to 30 per cent. of bismuth. The associated minerals are cassiterite, wolframite, barite, and chalybite, together with sulphides of iron, zinc, lead, and copper.

GERMANY.—An important deposit of bismuth ore occurs at Schneeberg in Saxony. The bismuth is found native in the cobalt-silver veins of that locality. The veins traverse schists and slates that have been invaded and metamorphosed by granite, and the ores have probably been deposited from exudations given off by the granite intrusion.

The associated minerals include quartz, cobaltite, pyrites, galena, native silver, and pyrargyrite.

At Altenberg, in Saxony, quartz veins contain native bismuth and bismuthinite associated with pyrite, chalcopyrite, cassiterite, wolframite, fluorite, and molybdenite.

Australia.—Important deposits of bismuth ore are found in Queensland, Tasmania, and New South Wales.

In the Biggenden district of Queensland, bismuth is associated with magnetite. At the Glen mines in the Herberton district, the ore occurs as veins of bismuth carbonate associated with native bismuth, wolframite, and topaz. Here the country rock is biotite-granite, which contains occasional small deposits of cassiterite and wolframite. In the Degilbo district of Queensland, bismuth ore forms a vein about a yard wide. The country rock is slate, with intrusive dykes of porphyry. In this vein the sulphide, carbonate, and tetradymite occur, associated with gold, silver, and copper minerals.

In the Middlesex district of Tasmania, quartz-topaz veins, containing bismuth ore associated with cassiterite and wolframite, traverse a metamorphosed limestone.

In New South Wales, bismuth ore is found at Kingsgate and Whipstick. The country rock consists of Carboniferous shales into which granite has intruded. The ore occurs in the form of pipe-like deposits near the junction of the granite and shale. The vein-stuff is quartz, or quartz and felspar, containing native bismuth, bismuthinite, molybdenite, wolframite, and arsenopyrite. Near the surface the bismuth sulphides are altered to oxide and carbonate.

Peru.—In Peru, bismuth ores have been worked near San Gregorio, Cerro de Pasco; but they occur also at several other localities.

CADMIUM.

The only mineral of note in which cadmium is an essential constituent is greenockite, a sulphide of cadmium (CdS) crystallizing in hemimorphic hexagonal crystals. Greenockite, however, is a rare mineral, and does not in itself constitute cadmium ore. The cadmium of commerce is obtained as a by-product in smelting zinc-blende and other zinc ores. Cadmium is usually present as an impurity in commercial zinc.

On the average, zinc ores contain perhaps about 0·1 per cent. of cadmium. Richer ores may contain as much as 0·5 per cent.; and zinc-blende sometimes contains over 1 per cent. of the metal, in the form of cadmium sulphide.

Cadmium is produced as a by-product of zinc smelting in Silesia, where the zinc minerals often contain a considerable amount of cadmium.

The zinc-blende of Joplin, Missouri, contains on the average about 0·35 per cent. of cadmium, which is obtained as a by-product by the zinc smelters in amounts quite adequate to meet the needs of the United States.

Cadmium finds one of its chief uses in the manufacture of fusible alloys, in conjunction with bismuth, lead, and tin. It can also with advantage replace bismuth in cliché metal, which is used in making stereotype plates. A cadmium amalgam containing a little bismuth is used in admixture with tungsten powder in the process of making the filaments of tungsten lamps.

CERIUM.

Cerium occurs as an essential constituent of a considerable number of minerals, the more notable of which are monazite (phosphate of the cerium metals), cerite (hydrated cerium silicate), and allanite (silicate of iron, calcium, aluminium, and the cerium metals). The only mineral of commercial importance as a source of cerium is monazite, a description of which is given on p. 426. As will be seen from a reference to that description, however, monazite is chiefly valuable as a source of thoria.

The ceria of monazite was for a long time practically a waste product. It was used to a small extent in the form of cerium oxalate as a medicine, but the amount thus used was negligible in proportion to the total ceria available. In recent years a use has been found for it in the manufacture of a pyrophoric alloy with iron (ferrocerium) in which cerium is an essential constituent; but so long as monazite continues to be the chief source of thoria, the ceria obtained from it as a by-product will probably supply all, and more than all, the cerium compounds required. Ferrocerium, of which sparking devices are made, contains about 30 per cent. of iron. A large amount of cerium fluoride was used during the late war in connection with naval searchlights; and by virtue of its inflammability through air-friction, ferrocerium was used to illuminate the paths of shells.

CHROMIUM.

The ore of chromium is chromite, the composition of which is represented by the formula $(Fe, Mg)O \cdot (Cr_2, Al_2)O_3$. The formula of the ideal chromite of the mineralogist is $FeO \cdot Cr_2O_3$, corresponding to 68 per cent. of chromic oxide; but as a consequence of the replacement of iron by magnesium, and chromium by aluminium, the chrome ores of commerce seldom contain more than 50 per cent. of chromic oxide.

Chromium yields with iron an important alloy (ferrochrome) which is used in making chromium steel. Chromium steel is used in the manufacture of those parts of crushing machinery (crusher-jaws, etc.) that are subject to severe abrasion. Rustless steel containing from 12 to 15 per cent. of chromium is used in the manufacture of rustless cutlery, and in many other ways. Chromium is alloyed with cobalt and tungsten to form the alloy known as "stellite," which has a remarkable acid-resisting property and is a valuable material for making cutting tools. Potassium bichromate and other chromium salts are obtained from chromite. Chromite is of value as a refractory material for use in making bricks for furnace linings.

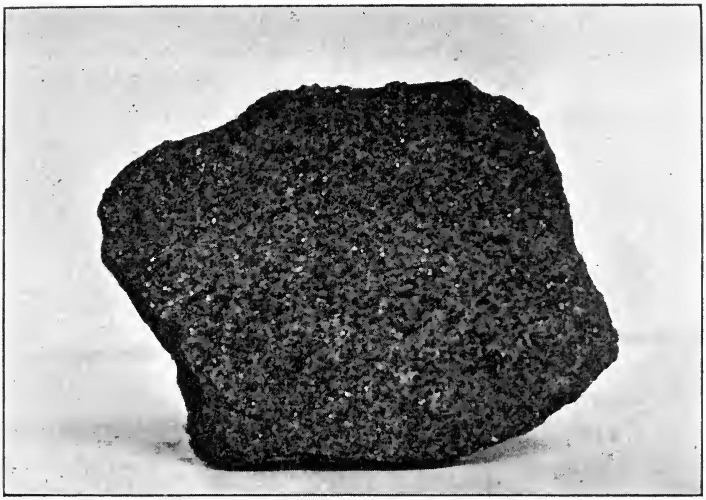

FIG. 129.—Granular chromite in matrix of serpentine, Unst, Shetlands. (× $\frac{5}{6}$). B.M.

Chromite.—*General.*—Cubic. The ore usually consists of compact masses; but can often be seen to be made up of small granules, sometimes octahedral in shape, embedded in a matrix of serpentine or chlorite, generally the former (fig. 129). Hardness, 6. Specific gravity about 4·5 when pure, but usually lower, and often 4·2, owing to admixture of ingredients referred to above.

Optical.—Black in the mass. Lustre, submetallic. Streak, dark brown. Fine microscopic splinters are translucent, dark brown in colour, and isotropic. Refractive index very high, and greater than sulphur in methylene iodide.

Chemical and blowpipe.—A chromate and aluminate of iron and magnesium, rich portions of the ore having a composition approximating to that represented by the formula $FeCr_2O_4$. Infusible. In bead tests with borax and microcosmic salt, yields a fine green colour in both oxidizing and reducing flames. Insoluble in acids; but is attacked by soda on fusion, yielding sodium chromate, which is soluble in water.

Origin.—Chromite is a frequent constituent of igneous rocks rich in olivine, *i.e.* peridotites. It is one of the first constituents to crystallize in very basic magmas, and segregates to form ore-bodies of considerable size during the consolidation of these rocks. Olivine becomes altered to serpentine; hence chromite is often found in serpentine.

Occurrence and distribution.—The chief producers of chromium ore are Rhodesia and New Caledonia, but large amounts are mined also in Russia, Asia Minor, Greece, Canada (Quebec) and India. The production in Bosnia and Herzegovina, Norway and Sweden, United States and various other countries was comparatively insignificant before the war, but the United States became the leading producer towards the end of the war.

RHODESIA.—Chromite is found at many localities in Southern Rhodesia, and is mined extensively at Selukwe, where it occurs in the form of numerous lenticular masses in a matrix of talc-schist and serpentine. The rock was originally a peridotite (olivine rock), in which the chromite was formed by magmatic segregation. Intrusive in the talc-schists and serpentines is an enormous boss of granite, and the rocks enclosing the chromite have been largely metamorphosed. The largest ore-bodies occur in talc-schist. Some of the ore lenticles exceed 400 feet in length. The ore as marketed contains from 42 to 51 per cent. of chromic oxide (Cr_2O_3), 8 to 15 per cent. of magnesia, and 14½ to 16½ per cent. of alumina. The best ore contains on the average about 50 per cent. of chromic oxide.

NEW CALEDONIA.—The chromite deposits of New Caledonia are found chiefly in the southern part of the island, where the ore occurs partly in the form of hard lenticular masses in serpentine, and partly in the form of soft and more easily worked masses lying in ferruginous clay. The ore is of good quality and is readily concentrated so as to contain over 50 per cent. of chromic oxide.

UNITED STATES.—Prior to the late war very little chromite was produced in the United States, but during the war a large output was obtained in the states of California and Oregon, where chromite-bearing serpentines are abundant in the Coast Range tract. The beach and river sands of this region are often rich in chromite.

CANADA.—Chromite has been mined extensively in the eastern townships of the Province of Quebec, notably in the area between Black Lake and Coleraine. In this area there are extensive peridotite intrusions of supposed Ordovician age, that have been altered to serpentine. The ore is of variable quality as mined, ranging up to 50 per cent. or more of chromic oxide, with an average of about 30 per cent.; but the low-grade ore can be readily concentrated to yield a product containing 50 per cent. or more of chromic oxide.

RUSSIA.—Chromite occurs abundantly among the serpentinized peridotites of the Ural region. It is among these rocks, as for instance at Nijni-Tagilsk, that platinum and iridosmine are found associated with chromite.

ASIA MINOR.—Important deposits of chromite are mined at Daghardi and other localities near Brusa, where the chromium ore occurs in irregular masses embedded in serpentine. Ores of exceptionally good quality have been obtained abundantly in this area.

GREECE.—Chromium ores of the normal type are mined in the Lamia district of Greece; but in addition to these there is a large amount of chromiferous iron ore mined at Locrida and other localities. This iron ore contains about 50 per cent. of iron, and up to 3 per cent. of chromic oxide (see p. 202).

INDIA.—In India chromite is mined chiefly in Baluchistan, but it is produced also in the Mysore, Hassan, and Shimoga districts of the State of Mysore, and in the Singhbhum district of Bihar and Orissa (Bengal). Chromite occurs also in the Chalk Hills of Salem (Madras), a locality of importance as a source of magnesite (see p. 349).

The chromite of Baluchistan is mined in the Quetta-Pishin and Zhob districts, where it is found as veins and masses in serpentinized peridotite intrusions of Upper Cretaceous age.

COBALT.

The important ore minerals of cobalt are smaltite ($CoAs_2$) and cobaltite ($CoAsS$), the former being the more important. Erythrite (Gr. *erythros*, red) or cobalt-bloom is a hydrated arsenate of cobalt, often formed as a red incrustation on smaltite and other cobalt arsenides, but is of no importance as an ore mineral. Asbolite (Gr. *asbole*, soot) or earthy cobalt is cobaltiferous wad; it is a black hydrated manganese oxide impregnated with cobalt compounds, and was formerly used in the manufacture of smalt.

Smalt is a blue glass containing about 6 per cent. of cobalt. Cobalt is used in the manufacture of various other pigments and chemicals. It also yields a number of useful alloys. Alloyed with iron, it yields a product of exceptionally high magnetic permeability, suitable for the manufacture of electromagnets. It is alloyed with chromium and tungsten to form the alloy "stellite," which is valuable not only on account of its acid-resisting properties, but also for the manufacture of special cutting-tools.

Smaltite (also called *tin-white cobalt*).

General.—Cubic, sometimes showing good cubo-octahedral crystals, but usually massive. Cleavage octahedral, but not good. Fracture, uneven. Hardness, 5. Specific gravity, about 6·2.

Optical.—Colour tin-white. Lustre, metallic. Streak, dark grey. Opaque.

Chemical and blowpipe.—Arsenide of cobalt ($CoAs_2$), but usually contains some nickel, owing to admixture with chloanthite ($NiAs_2$). Fusibility, 2½. Fuses easily on charcoal to a magnetic globule, and gives off arsenical fumes. Borax bead tests yield the characteristic blue beads; but the arsenic should be roasted off before the bead tests are made. Yields a mirror of arsenic when strongly heated in a closed tube. Decomposed by nitric acid, yielding a pale-red solution.

Cobaltite (*Cobalt-glance*).

General.—Cubic. Often crystalline and resembling pyrite in form, usually showing combination of pyritohedron and cube. Cleavage not good. Fracture, uneven. Hardness, 5½. Specific gravity about 6.

Optical.—Colour silver-white, with a pinkish tinge. Lustre, metallic. Streak, greyish black. Opaque.

Chemical and blowpipe.—Sulpharsenide of cobalt ($CoAsS$). Fusibility, 2½. Yields good cobalt beads, but should first be roasted. Fuses readily to a globule on charcoal. Decomposed by nitric acid, yielding a pale-red solution. Distinguished from smaltite by the fact that it gives off sulphur dioxide in the open tube and does not readily yield an arsenic mirror when heated in a closed tube.

Occurrence and distribution of cobalt ores.—The most important source of cobalt ore at present is that of the Cobalt district, near the north end of Lake Temiskaming, in Ontario, where smaltite and cobaltite are found abundantly in the silver ores. The production of cobalt as a by-product of silver mining in the Cobalt district has given Canada first place in the world's output of cobalt. Prior to the utilization of cobalt in the manufacture of steel and other alloys, which is a recent development, cobalt was required chiefly for pigments. For this purpose the requirements were very small, and were met by trifling outputs in various scattered localities, notably in New Caledonia, New South Wales, and Germany.

Canada.—The rocks of the Cobalt district include conglomerates, sandstones, slates, quartzites, and metamorphosed basalts, together with intrusive granites and sills of dolerite (Nipissing diabase), all of pre-Cambrian age. Cutting these pre-Cambrian rocks are later intrusions of granite, dolerite, and basalt, and veins containing the cobalt-silver ores. The veins are found chiefly in the conglomerates, sandstones, and quartzites of the " Cobalt Series " and the overlying sill of Nipissing dolerite. The junction zone of the sill and the underlying " Cobalt Series " is the most richly mineralized. The veins are thin, not more than four inches on the average, but they are very rich.

The vein-stuff consists largely of calcite and dolomite. The chief ore minerals in the veins are those of silver, notably native silver and argentite ; but these are associated with smaltite, cobaltite, niccolite, and native bismuth. In the formation of the veins it is supposed that smaltite, niccolite and dolomite were the first minerals to be deposited ; and that the calcite and silver minerals were deposited during a later re-opening of the veins. Where the veins are exposed to the action of surface agents, erythrite, annabergite, asbolite, and other alteration products have been formed.

A representative high-grade ore from these veins was found to contain 10 per cent. of silver, 9 per cent. of cobalt, 6 per cent. of nickel, and 39 per cent. of arsenic. In recent years dressed ore has been obtained averaging about 3½ per cent. of nickel, 8½ of cobalt, 25 of arsenic, and 300 to 1000 oz. of silver per ton.

Other Localities.—New Caledonia was formerly of importance as a producer of cobalt ore. The New Caledonian ore mineral is asbolite, which occurs as bluish-black nodules in a ferruginous clay arising from the decomposition of peridotites. Asbolite occurring under similar conditions has been worked near Port Macquarie in New South Wales. (Compare occurrences of nickel ores in New Caledonia and New South Wales ; see p. 228.)

At Schneeberg in Saxony and Joachimsthal in Bohemia, in the region of the Erzgebirge, smaltite and other cobalt minerals occur in the complex veins containing silver, uranium, nickel, and bismuth minerals. Large amounts of cobalt ore were formerly obtained from this region. For fuller details of the Joachimsthal deposits, see p. 431.

The copper ores of Katanga in Africa (Belgian Congo) have yielded supplies of cobalt in recent years. The crude copper obtained there contains about 3 per cent. of cobalt.

Cobaltite occurs in streaks and lenses in a black slate near Khetri in the Jaipur State, Central India, where it is associated with arsenopyrite and chalcopyrite. It was formerly mined at this locality and used by natives for colouring glass bangles. It was also used by the Jaipur jewellers as a blue enamelling material.

COPPER.

The chief ore minerals of copper are native copper (Cu), chalcopyrite ($Cu_2S \cdot Fe_2S_3$), bornite ($3Cu_2S \cdot Fe_2S_3$), chalcocite (Cu_2S), enargite ($3Cu_2S \cdot As_2S_5$), cuprite (Cu_2O), malachite $\{Cu(OH)_2 \cdot CuCO_3\}$, azurite $\{Cu(OH)_2 \cdot 2CuCO_3\}$, and brochantite $\{CuSO_4 \cdot 3Cu(OH)_2\}$.

Less important are tenorite (CuO), covellite (CuS), tetrahedrite ($3Cu_2S \cdot Sb_2S_3$), tennantite ($3Cu_2S \cdot As_2S_3$), chrysocolla ($CuSiO_3 \cdot 2H_2O$), and atacamite $\{CuCl_2 \cdot 3Cu(OH)_3\}$.

Pyrite (see p. 424) frequently has associated with it a small proportion of chalcopyrite ; and such cupriferous pyrites sometimes occurs as large deposits, serving primarily as a sulphur mineral, the copper being obtained as a by-product from the residue after roasting.

A small amount of copper is recovered in the form of copper precipitate from mine waters containing copper sulphate in solution. The copper is precipitated by means of scrap iron, the solution taking up iron in place of the copper deposited.

In addition to its extensive use for domestic utensils, and as conducting-wires for electrical purposes, copper is a constituent of many important alloys, notably *brass* (copper and zinc) and *bronze* (copper and tin). *Gun metal* and *bell metal* are alloys of copper and tin. *Monel metal* and *cupro-nickel* are alloys of copper and nickel.

Native Copper.—*General.*—Cubic. Crystals usually ill-shapen. The cube, octahedron, and rhombic dodecahedron are the common forms. Occurs in the form of scattered grains, dendritic aggregates (see fig. 130), and irregular masses ; also in wiry and platy shapes. Fracture, hackly. Malleable. Hardness, about $2\frac{1}{2}$. Specific gravity, about 8·7.

Optical.—Colour a characteristic red (copper-red). Streak, copper-red. Surface frequently tarnished and coated with malachite and other alteration products. Lustre, metallic. Opaque.

Chemical and blowpipe.—Consists as a rule of fairly pure copper, but sometimes carries a little silver. Fusibility, 3 ; small grains fuse to a malleable globule in a blowpipe flame. Soluble in nitric acid, yielding a blue solution when excess of ammonium hydrate is added.

Chalcopyrite (Gr. *chalkos*, copper; also called copper-pyrites).

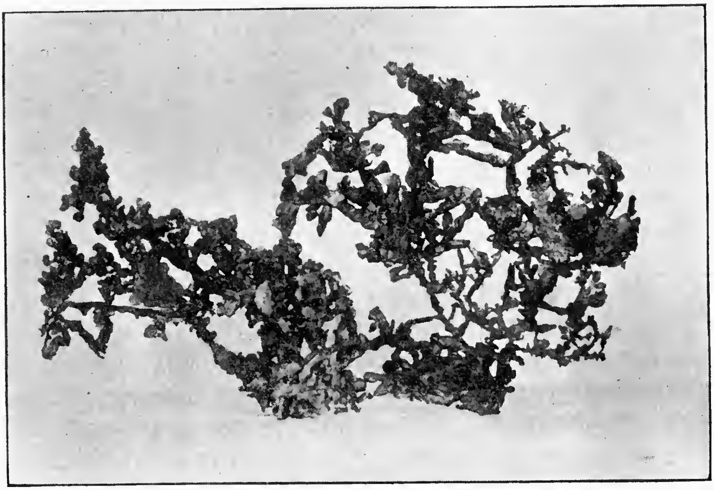

FIG. 130.—Dendritic copper, Cornwall. (× $\frac{1}{3}$). B.M.

General.—Tetragonal. The common forms are sphenoids and the crystal often closely resembles a tetrahedron (figs. 131, 132). Crystals frequently twinned. Usually found massive or in scattered grains. Fracture uneven. Hardness, about 4. (The hardness of pyrite is about 6½.) Specific gravity, about 4·2.

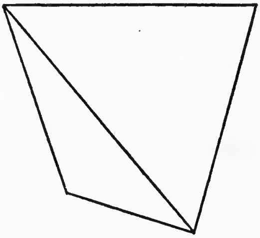

FIG. 131.—Chalcopyrite.

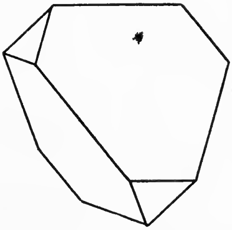

FIG. 132.—Chalcopyrite.

Optical.—Colour brassy yellow, but darker than iron pyrites; frequently tarnished and iridescent. Lustre, metallic. Streak, greenish black. Opaque.

Chemical and blowpipe.—Sulphide of copper and iron ($CuFeS_2$), containing about 34·5 per cent. of copper. Fusibility, 2; fuses readily to a black magnetic globule in a blowpipe flame. Yields an azure-blue colour to flame when moistened with hydrochloric acid. Gives a sublimate of sulphur when heated in a close tube. On fusion and reduction with soda on charcoal, crushing the reduced mass in an agate mortar, and washing away the dust, metallic copper is obtained in the form of scales. Dissolves in nitric acid; the solution becomes blue and yields a precipitate of ferric hydrate when treated with excess of ammonium hydrate; to see the colour advantageously the ferric hydrate should be allowed to settle or filter off.

Bornite (named after von Born, a mineralogist. Also called erubescite and variegated copper-ore).

General.—Cubic. Usually found massive. Fracture, uneven. Hardness, 3½. Specific gravity, 4·9—5·4.

Optical.—Colour, reddish brown, often with a purple tarnish. Lustre, metallic. Streak, greyish black. Opaque.

Chemical and blowpipe.—Sulphide of copper and iron ($3Cu_2S \cdot Fe_2S_3$); but massive specimens vary considerably in composition due to admixture with chalcopyrite and chalcocite, in consequence of which the amount of copper varies from 55 to 70 per cent. Fusibility, 2½. Chemical behaviour resembling that of chalcopyrite.

Chalcocite (also called copper-glance and redruthite).

General.—Orthorhombic, but usually found in a massive condition. Fracture, uneven. Hardness, 2½. Specific gravity, about 5·7.

Optical.—Colour, dark grey; often shows a black tarnish. Lustre, metallic. Streak, dark grey. Opaque.

Chemical and blowpipe.—Cuprous sulphide (Cu_2S), containing 79·8 per cent. of copper. Fusibility about 2½, fuses readily to a globule which is non-magnetic. Chemical behaviour resembles that of chalcopyrite, except that no sulphur sublimate is formed on heating in a closed tube, and the nitric acid solution yields little if any ferric hydrate on treatment with ammonia solution. Readily yields a globule of copper if roasted in charcoal and afterwards reduced without the aid of soda. Soluble in nitric acid and answers the wet test for copper mentioned under chalcopyrite.

It should be remarked that chalcocite occurs intimately associated with bornite, and specimens often consist of a mixture of these two minerals.

Tetrahedrite (so named from the fact that it is usually found in the form of well-developed tetrahedral crystals. Also known as "grey copper." It is the *fahlerz* of German miners).

General.—Cubic, frequently in the form of the tetrahedron (figs. 133, 134, 135), but also found massive. Fracture, uneven. Hardness, $3\frac{1}{2}$. Specific gravity, about 4·8.

Optical.—Colour, grey. Streak, black. Lustre, metallic. Opaque.

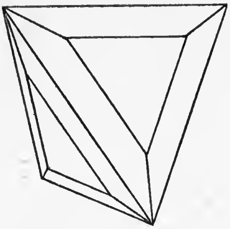

FIG. 133.—Tetrahedrite.

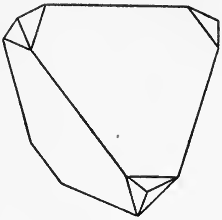

FIG. 134.—Tetrahedrite.

Chemical and blowpipe.—Sulphide of copper and antimony

$$(3Cu_2S \cdot Sb_2S_3).$$

The antimony is replaceable by arsenic, and the corresponding arsenic mineral is *tennantite* ($3Cu_2S \cdot As_2S_3$). An argentiferous variety of tetrahedrite, in which copper is partly replaced by silver, is called *freibergite*. Fusibility, $1\frac{1}{2}$. Red sublimate of antimony sulphide in closed tube. Sublimate of antimony oxide in open tube and on charcoal. Copper reactions. Decomposed by nitric acid, and yields a deep blue solution on addition of ammonia in excess after dilution.

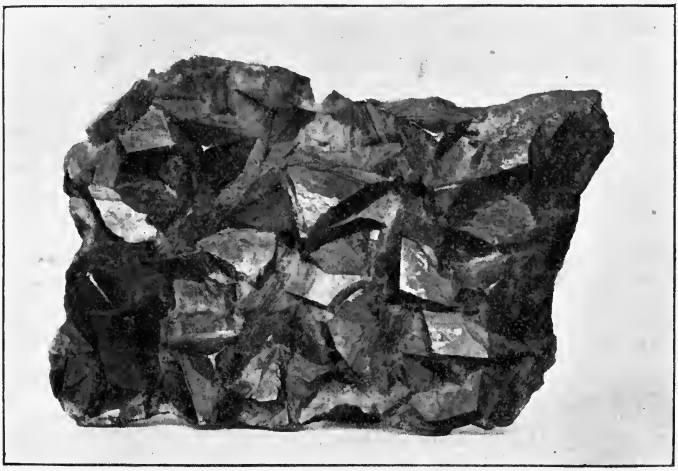

FIG. 135.—Tetrahedrite, Chile. ($\times \frac{2}{3}$). B.M.

Enargite (Gr. *enargos*, distinct; named in allusion to the perfect cleavage of the mineral).

General.—Orthorhombic; usually prismatic in habit, with striations parallel to prism edge; but sometimes tabular, with base well developed. Also in columnar or granular masses. Prism cleavage perfect, yielding angles of 82° and 98°. Hardness, 3. Specific gravity, about 4·4.

Optical.—Colour, greyish black. Streak, black. Lustre, metallic. Opaque.

Chemical and blowpipe.—Sulpharsenate of copper ($3Cu_2S \cdot As_2S_5$), containing about 48·4 per cent. of copper. Arsenic in enargite is replaceable by antimony, due doubtless to isomorphous admixture with famatinite ($3Cu_2S \cdot Sb_2S_5$), a mineral sometimes found associated with enargite, as at Famatina in the Argentine, and some other localities. Fusibility, 1. Gives a sublimate of sulphur when heated in a closed tube. In open tube yields smell of sulphur dioxide. Readily yields a globule of copper if roasted on charcoal and afterwards reduced, without the aid of soda. Soluble in nitric acid and answers the wet test for copper mentioned under chalcopyrite.

Cuprite (L. *cuprum*, copper; also called red copper-ore).

General.—Cubic, the predominant forms being the octahedron, cube, and rhombic dodecahedron. Frequently found as granular masses, and sometimes as capillary growths. Octahedral cleavage. Fracture, uneven. Hardness, about 3½. Specific gravity, about 6.

Optical.—Colour, red. Streak, brownish red. Lustre, submetallic or adamantine. Under microscope fragments are translucent, red, and isotropic. Refractive index extremely high (about 2·85).

Chemical and blowpipe.—Cuprous oxide (Cu_2O), containing 88·8 per cent. of copper. Fusibility, 3. Easily reduced to a button of copper on charcoal. Soluble in nitric acid, answering the wet test for copper mentioned under chalcopyrite; also yields the flame test when moistened with hydrochloric acid.

Malachite (Gr. *malache*, mallow, in allusion to its green colour; also called green copper carbonate).

General.—Monoclinic. Occurs in the form of fibrous masses and frequently shows a mammiform surface (fig. 136). Hardness, 3½. Specific gravity, about 3·95.

Optical.—Colour, bright green. Lustre, vitreous. Refractive index high, $\beta = 1{\cdot}88$. Birefringence extremely high ($\gamma - \alpha = 0{\cdot}2$). Optical sign, negative. Fragments of prismatic shape and show oblique extinction, the angle being about 23°. Twinning common.

Chemical and blowpipe.—Basic carbonate of copper

$$\{CuCO_3 \cdot Cu(OH)_2\},$$

containing 57·7 per cent. of copper. Fusibility, 3. Gives copper flame-reaction when moistened with hydrochloric acid. Gives off water in a closed tube, and turns black. Yields copper when reduced on charcoal. Dissolves with effervescence in hydrochloric acid.

Azurite (name given in allusion to its azure-blue colour; also called chessylite from Chessy near Lyons in France, where good specimens have been found).

General.—Monoclinic, the crystals being usually stumpy or tabular in habit. Fracture, conchoidal. Hardness, $3\frac{1}{2}$. Specific gravity, about 3·8.

Optical.—Colour, intense azure-blue. Lustre, vitreous. Refractive index very high, and greater than sulphur in methylene iodide. Birefringence extremely high ($\gamma - \alpha = 0{\cdot}20$). Optical sign positive.

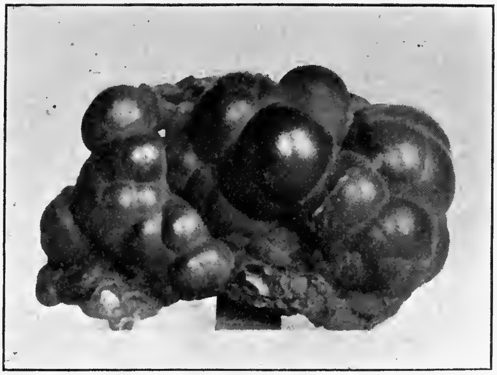

FIG. 136.—Malachite, Perm, Russia. ($\times \frac{1}{2}$). B.M.

Chemical and blowpipe.—Basic carbonate of copper

$$\{2CuCO_3 \cdot Cu(OH)_2\},$$

containing 55·3 per cent. of copper. Fusibility, 3. Chemical behaviour resembles that of malachite. Azurite tends to lose carbon dioxide and change into malachite. Hence the frequent association of blue and green colours, due to these minerals, so often seen on oxidized copper-ore.

Brochantite (named after *Brochant* de Villiers, a French mineralogist).

General.—Orthorhombic; occurring usually as encrustations and fibrous masses, and formed by the oxidation of chalcopyrite. Perfect pinakoidal cleavage. Hardness, $3\frac{1}{2}$. Specific gravity, about 3·9.

Optical.—Colour, emerald-green. Lustre, vitreous. Refractive index above and below that of methylene iodide (1·74). Microfragments prismatic and show straight extinction.

Chemical and blowpipe.—Basic sulphate of copper [$CuSO_4 \cdot 3Cu(OH)_2$], containing about 56 per cent. of copper. Fusibility, $3\frac{1}{2}$. Copper reactions as for malachite. Dissolves in hydrochloric acid, but unlike malachite does not effervesce, and gives sulphate reaction.

Origin of copper ores.—Ore minerals of copper are very sensitive to changes in their environment, and have originated in a variety of ways. Chalcopyrite, sometimes associated with enargite, is frequently found in hydrothermal veins. It is also found abundantly as a product of segregation from basic igneous magmas. At the surface, copper ores suffer oxidation, the sulphides being transformed into oxides and carbonates. Frequently the copper has been carried downward as sulphates by descending waters, to enrich the deeper-lying ore by reduction and deposition in the form of chalcocite and bornite. Some of the most important copper-ore deposits owe their value to this process of secondary enrichment which has converted many poor copper ores into very rich ones. At greater depth these enriched deposits give place to leaner primary deposits in which the chief ore mineral is chalcopyrite. A large part of the world's supply of copper for many years past has been obtained from these comparatively superficial enriched deposits; and the maintenance of the world's supply of cheap copper in the future will depend upon further discoveries of deposits of this type.

Occurrence and distribution of copper ores.—More than half the world's total output of copper ore is obtained in the United States. Most of the remainder comes from Mexico, Spain and Portugal, Japan, Australia, Chile, Peru, Russia, Canada, Germany, and Africa. Other countries contribute altogether only some 2 or 3 per cent. to the output.

UNITED STATES.—The ore is obtained chiefly from Montana, the Lake Superior region of Michigan, and Arizona. Arizona has several important mines and is now the leading State in copper production.

The most productive copper mines in the world are those of the famous Butte mining camp in Montana, an area occupied by Tertiary igneous rocks. The ore-bearing veins occur in a large intrusive mass of quartz-monzonite, a syenite with a little quartz and much plagioclase. This quartz-monzonite is cut by intrusions of granite, and also by veins of aplite. Both the monzonite and the granites are cut by still later intrusions of quartz-porphyry; and the last phase of igneous activity in the district is indicated by outpourings of rhyolite and ash. The mineralization is supposed to have taken place in the interval between the intrusion of the quartz-porphyry and the ejection of the rhyolites.

The more abundant of the vein minerals at Butte are chalcocite, enargite, bornite, and pyrite in a quartzose gangue. Chalcopyrite, covellite, tetrahedrite, tennantite, and argentite (Ag_2S) also occur.

The bornite, chalcocite, and covellite are largely products of secondary enrichment, and it is to their formation that the so-called bonanza ore-bodies of Butte owe their value. Below the zone of secondary enrichment enargite, pyrite, chalcocite and bornite occur as primary minerals, but the veins are much poorer. It is noteworthy that Butte began its history as a gold-mining camp, then became a silver producer, and now in its third phase it is the richest of the world's copper-fields.

In the Lake Superior region of Michigan, native copper occurs abundantly in the Keweenawan series, the strata of which are of pre-Cambrian age. The Keweenawan series consists of conglomerates and sandstones, with an abundance of interbedded amygdaloidal basalt. The native copper occurs partly as a metasomatic replacement of the conglomerate beds and lavas, partly as an infilling of the vesicles (*i.e.* as amygdales) in the lavas, and partly also in the form of true fissure-veins, which cut across the bedding of the rocks. The chief minerals associated with the native copper, both in the amygdales and in the veins, are calcite, zeolites (hydrous silicates), and quartz; a little native silver also occurs.

In the Bisbee district of Arizona, the ores formerly worked for many years consisted entirely of oxidized copper minerals such as cuprite, malachite, and azurite; but these have been largely worked out, and the deeper zone of unaltered sulphides, chiefly chalcopyrite with pyrite and a little zinc-blende, is now being worked. These unaltered sulphides occur as metasomatic replacements of limestone and are supposed to have been deposited by solutions arising from an intrusive mass of porphyry that penetrates the shales and limestones of the district. Between the zone of unaltered sulphides and the upper zone of oxidation, is an intermediate zone of secondary enrichment characterized by the presence of chalcocite.

The important deposits of the Ray and Miami districts in Arizona owe their value to secondary enrichment, and the chief ore mineral is chalcocite. The chalcocite is disseminated, partly in granite- or monzonite-porphyry, but mainly in schist into which the porphyry is intrusive. The ore mined contains on the average from 1½ to 2 per cent. of copper. The primary ore of these districts is chalcopyritic, and is too poor to be worked under present conditions.

Mexico.—The most important copper-ore deposits in Mexico are those of Boleo, in Lower California, on the western shore of the gulf of California, opposite Guaymas. The deposits are of Tertiary age. There are five beds of copper ore, interbedded with conglomerates and tuffs of detrital origin, which have arisen from the disintegration of a mass of igneous rocks consisting of trachytes and basalts. Chalcopyrite is rare, and the ore is largely oxidized. The dominant ore-minerals are malachite, azurite, atacamite, and chrysocolla, together with the red and black oxides of copper. The ore minerals lie in an argillaceous matrix. Oxide of manganese and gypsum are very abundant in the beds of copper ore. The other minerals present include anglesite and pyromorphite.

Other important copper deposits are those of Cananea in northern Mexico. The rocks of this area consist of Cambrian quartzites and limestones, into which granodiorites (granites with much plagioclase) and porphyries, probably of Tertiary age, are intrusive. In some places there appears to be clear evidence that the ore deposits are genetically connected with the granodiorite. At Puertecitos, for example, an epidote-garnet rock containing chalcopyrite, galena, and zinc-blende occurs along the contact of the granodiorite with metamorphosed limestone.

Spain and Portugal.—In the province of Huelva, in southern Spain, there are important copper-ore deposits that have contributed largely to the world's supply of copper in the past, and are still very productive. The rocks of the area consist largely of Palæozoic slates and sandstones, which are traversed by igneous rocks (porphyries and dolerites). The ores occur in lenticular bodies and are regarded as having been deposited at a time closely succeeding the intrusion of the igneous rocks. At Rio Tinto the pyritic ores are associated with intrusions of porphyry which traverse Carboniferous slates. The ore consists chiefly of pyrite, with small amounts of chalcopyrite, zinc-blende, and galena. The average percentage of copper in the ore has diminished in recent years. In 1895 the average amount of copper in the ore was 3 per cent.; in 1905 it had fallen to 2·3 per cent.; and in 1910 it was only 1·6 per cent. Lenticular deposits of cupriferous pyrites occur in various other parts of this region, notably at Tharsis, and San Domingo in Portugal, under conditions closely similar to those at Rio Tinto.

Japan.—In the Ashio district north of Tokio, quartz veins with chalcopyrite occur. The district is occupied by Palæozoic sediments and granite, with an abundance of later rhyolites; and associated with the chalcopyrite are pyrite, arsenopyrite, galena, and zinc-blende. Copper ores are worked at various localities in the northern part of Hondo Island, and in most cases the ores occur in intimate association with Tertiary igneous rocks.

In Shikoku Island, at Besshi, there is a large lenticular body of pyrites associated with quartz and magnetite, occurring in crystalline schists. The ore carries from 4 to 5 per cent. of copper. Copper ore of a somewhat similar character occurs at several localities in Kiushiu Island.

Australia.—In Queensland, Mt. Morgan and the Cloncurry district are the chief producers. A description of the Mt. Morgan ore-body is given on p. 190. The rocks of the Cloncurry district are metamorphosed sediments, porphyrites, and intrusive granite. The ore deposits occur in fracture-zones that lie along the line of strike of Palæozoic quartzites, slates and schists. Ores of the oxidized surface type have been worked extensively in the Cloncurry district.

In New South Wales, at the Great Cobar copper mine, copper ore has been deposited from ascending solutions along fracture zones that traverse Silurian and Devonian strata. These fracture zones were formed as the result of earth movements that took place in late Devonian times. The ore-bodies of the Great Cobar lode consist of three large lenses. The ore mineral is chalcopyrite in a matrix of pyrrhotite, magnetite, quartz, and slate, and the ore contains about 2·6 per cent. of copper. Other lodes in the Cobar district are characterized by the presence of pyrite, galena, and zinc-blende.

In South Australia, important copper ore deposits have been worked at Burra Burra about 100 miles north of Adelaide, and at Wallaroo and Moonta in the Yorke Peninsula. At Burra Burra, where large amounts of ore were produced formerly, the lodes occur in metamorphosed limestone. The ore minerals in the surface zone were chiefly carbonates, oxides, and metallic copper. These were succeeded at some depth by bornite, and at depths below 600 feet chalcopyrite was the ore mineral. For many years the ore produced at this mine averaged 22 per cent. of copper. At Wallaroo the nature and succession in depth of the ore minerals much resemble those of Burra Burra.

At Mount Lyell, in Tasmania, there is a lenticular ore-body along a junction of schist with Silurian sediments. The ore is cupriferous pyrite, which is slightly auriferous and argentiferous; small amounts of zinc-blende, galena, and barite are associated with the ore.

Chile.—Copper ores occur abundantly at various localities in Chile, notably in the Chuquicamata and Collahuasi districts, associated with syenites, porphyries, and other igneous rocks. Chalcopyrite is a common ore mineral in the Chilian deposits; associated with it are secondary copper minerals and sometimes also magnetite and tourmaline. Chilian ores were formerly rich in copper, and yielded 12 to 15 per cent. of the metal. The ores mined at present, however, include some of very low-grade quality. At Chuquicamata to the north-east of Antofagasta, for instance, a low-grade ore containing only about 2 per cent. of copper is mined. It is an oxidized ore, with brochantite as the chief ore mineral, and is not amenable to concentration by physical methods. The inferior quality of the ore is compensated for by the immense size of the ore-body, which is estimated to contain several hundred million tons of ore.

Peru.—The chief copper-ore producing districts of Peru are Cerro de Pasco, Morococha, and Casapalca. The Peruvian copper ores are argentiferous. In the Cerro de Pasco district, which was formerly an important silver producer, the rich silver ores were in the oxidation zone. The ores now being worked are argentiferous copper sulphides, which occur as veins and replacements in rhyolite tuffs and agglomerates that are associated with Mesozoic limestone, shale, and sandstone. The ore minerals include the ordinary copper sulphides, but there is also an abundance of enargite and famatinite. The ore contains about 7 per cent. of copper and about 11 oz. of silver per ton.

The ores of the Morococha district occur as veins in porphyry and limestone, and resemble those of Cerro de Pasco in composition.

The ores of the Casapalca district are poorer in copper but richer in silver, and contain an abundance of tetrahedrite.

Russia.—The chief copper-ore regions in Russia are those of the Urals and the Caucasus; but copper ore is mined also at Spassky and other localities in the Akmolinsk district of Siberia.

In the Soimonovsk valley south of Kyshtim in the Perm government, southern Urals, cupriferous pyrite is mined. The rocks of this area are Palæozoic quartzites, crystalline limestones, together with various interbedded schists (including chlorite-schist) that have been formed by the metamorphism of basic igneous rocks. The ore-bodies consist of lenticular masses of granular pyrite associated with small amounts of chalcopyrite, zinc-blende, tennantite, barite, and quartz, and are intimately associated with beds of chlorite schist. The ore consists chiefly of pyrite; it contains on the average about 3½ per cent. of copper, and 0·12 oz. of gold per ton.

In the Bogoslovsk district of the Urals, copper ores occur in Devonian grits and limestones which have been metamorphosed by intrusions of granite and diorite. In the limestone, sulphides of iron and copper are associated with zinc-blende, garnet, and pyroxene.

At the Medno-Rudiansk mine in the Nijni-Tagilsk district, chalcopyrite is found associated with magnetite and zinc-blende in veins occurring at the contact of Devonian limestones with altered igneous rocks. This mine is famous for the large amounts of malachite it formerly yielded (see p. 304).

At Kedabek in the Caucasus copper ore is found in quartz-porphyry; the ore occurs in lenticular masses of iron-pyrites containing chalcopyrite associated with magnetite, zinc-blende and galena. At Akthala, also in the Caucasus, copper occurs in dacites (quartz-andesites); chalcopyrite and bornite are the ore minerals, and associated with them are pyrite, argentiferous galena, and zinc-blende.

At Pitkäranta on Lake Ladoga in Finland, where a red granite is intrusive in schists, the granite carries inpregnations of chalcopyrite, associated with which are the minerals cassiterite, pyrite, pyrrhotite and galena.

At Spassky and Atbasar in the Akmolinsk district of Siberia, veins and sheets of copper ore are found in slates and sandstones of Permian age. The chief ore minerals are chalcocite and bornite, in a zone formed by secondary enrichment, and ore averaging over 13 per cent. of copper has been obtained. Malachite is abundant at the outcrops, and the primary ore mineral is chalcopyrite.

Canada.—The chief copper-mining areas of Canada are British Columbia and Ontario. Cupriferous pyrites is mined in Quebec (see p. 426).

The mines of the Boundary district in southern British Columbia have yielded a large output of copper. Here the ores are of low grade, but they are very uniform in character and contain from 1 to 2 per cent. of copper, with from 1 to 2 dwt. of gold per ton. The ores occur along the contact of Palæozoic limestones and other sediments with Tertiary intrusions of syenite and granodiorite. The ore mineral is chalcopyrite; it is associated with considerable amounts of garnet and pyrrhotite, and small amounts of pyrite and hæmatite. Ore deposits somewhat similar in character and mode of origin are mined in the Rossland district farther east. Low-grade chalcopyrite ores are also mined in Vancouver Island, Texada Island, and on the mainland in various parts of the coastal districts.

The only notable Ontario locality for copper ore is that of Sudbury, where chalcopyrite is found abundantly with nickeliferous pyrrhotite in deposits that have been formed by segregation from a gabbro magma. An account of the Sudbury deposits is given under nickel ore on p. 227.

Germany.—At Mansfield in Germany copper ore occurs abundantly in the Permian Kupferschiefer, a series of argillaceous beds which overlie the conglomerates known as the Rotliegendes. The cupriferous bed consists of a thin black band of bituminous marl, and forms a very persistent feature. It contains finely divided chalcopyrite, bornite, chalcocite, pyrite, and galena. Compounds of zinc, silver, nickel, cobalt, molybdenum, and manganese are also present in a finely divided state.

Africa.—Noteworthy deposits of copper ore are found at Ookiep, Nababeep, and Tweefontein in Little Namaqualand, Cape Province, South Africa. The area is occupied by granites and schists, and these are traversed by dykes of norite through which chalcopyrite and bornite are disseminated.

In some places large bodies of rich ore occur, as at the three localities mentioned above, where productive mines have been worked.

The Insizwa deposits of nickeliferous pyrrhotite with chalcopyrite are referred to on p. 229.

In the northern Transvaal, at the Messina mine, copper ore is found along a fracture zone in gneissose granite. Chalcocite is the chief ore mineral, associated with a little bornite and chalcopyrite. The ore is thus in the zone of secondary enrichment and is practically free from oxidation products, but at and near the surface, and down to a depth of 120 feet the ore was oxidized and consisted chiefly of copper carbonate (malachite). Concentrates containing up to 50 per cent. of copper are obtained from the ore now worked at this mine.

At Umvuma (Falcon mine) in Rhodesia a band of schist is impregnated with chalcopyrite, and the ore is auriferous. The fresh ore contains 2½ per cent. of copper and 5 to 6 dwt. of gold.

At Tsumeb and other localities in the Otavi district of South-West Africa, important deposits of lead-copper ore occur in the dolomite of the Otavi series (Lower Palæozoic) in a steeply-dipping fracture zone that has presumably been mineralized by ascending solutions. The predominant ore minerals of the lode are galena, chalcocite, enargite and famatinite. A notable feature of the Tsumeb deposit is the large variety of minerals found in the zone of oxidation. In addition to the usual oxidized lead and copper minerals, these include mottramite, wulfenite, vanadinite, and many others. The ore is argentiferous.

At Katanga in the Belgian Congo, large deposits of malachite with some azurite and chrysocolla occur at the surface, but pass downward into fracture zones containing unaltered sulphides. These fracture zones traverse dolomites of apparently the same age as the Otavi dolomites in South-West Africa. The Katanga copper belt is some 250 miles in length and from 30 to 60 miles wide. In a general way it follows the strike of the rocks, but in some places it cuts across the strike.

GLUCINUM.

The metal glucinum (beryllium) is of some interest on account of its low specific gravity, which is about 1·9, and therefore much below that of aluminium. In recent years there have been important developments in the uses of metals in small quantities for special purposes; and if, as seems probable, there should arise a demand for glucinum for use in small quantities for special purposes, beryl is the mineral from which it is most likely to be obtained. For an account of beryl, see p. 274. In this connection it may be mentioned that gadolinite (see p. 435), which has been worked as an yttrium mineral, contains glucinum also. Euclase (see p. 292) contains more glucinum than either beryl or gadolinite, but is too rare and valuable as a gemstone to be available as an ore of glucinum, so far as is known at present.

GOLD.

The chief ore mineral of gold is native gold. Pyrite often contains sufficient gold in a state of intimate admixture to make its extraction profitable. Gold is also frequently present in copper, silver, and lead ores, from which it is often recovered, sometimes as the most valuable constituent, sometimes as a by-product. Other ore minerals of gold of some importance are the tellurides, notably calaverite and sylvanite.

Native gold.—*General.*—Cubic; but seldom shows crystalline form. Occurs as grains of various size and shape in stream deposits, and sometimes large nuggets are found. Also occurs irregularly scattered through masses of quartz in quartz veins. Sometimes found as a very fine powder (mustard gold), the particles of which may be so small and disseminated that the gold is not visible, though the ore may be very rich. Gold is extremely malleable and ductile. Hardness, $2\frac{1}{2}$. The specific gravity of native gold ranges from 15 to 19 according to the amount of silver present; the specific gravity of pure gold is 19·37.

Optical.—Colour when pure is a characteristic yellow; the colour becomes paler when silver is present. Lustre, metallic. Opaque.

Chemical and blowpipe.—Consists of metallic gold with varying amounts of silver alloyed with it, and sometimes also small amounts of other metals, notably copper. When the amount of silver exceeds 20 per cent. the colour is very pale, and the alloy is called electrum. Fusibility, about 3. Insoluble in hydrochloric or nitric acid alone, but soluble in a mixture of these acids (aqua regia).

Calaverite (name derived from Calaveras Co., in California, where the mineral was first discovered).

General.—Monoclinic. Fracture, uneven. Usually occurs in a massive condition. Hardness, 2½. Specific gravity, about 9.

Optical.—Colour white, or a pale, brassy yellow, somewhat resembling that of pyrite. Lustre, metallic. Opaque.

Chemical and blowpipe.—A telluride of gold ($AuTe_2$), containing about 44 per cent. of gold. Two or three per cent. of silver is usually present. Fusibility, 1. Flame-coloration, bluish green. Fuses with extreme readiness on charcoal in a blowpipe flame, yielding white fumes and a globule of gold. When heated in concentrated sulphuric acid it yields a reddish violet solution.

Sylvanite (named from Transylvania, where the mineral occurs. Sometimes called graphic tellurium, in allusion to the manner in which its crystal aggregates often imitate written characters).

General.—Monoclinic. Pinakoidal cleavage perfect. Hardness, 2. Specific gravity about 8.

Optical.—Colour, silver-white. Lustre, metallic. Streak, grey. Opaque.

Chemical and blowpipe.—A telluride of gold and silver ($AuAgTe_4$), containing about 24 per cent. of gold and about 13 per cent. of silver. Fusibility, 1. Flame-coloration, bluish green. Yields a pale-yellow alloy of gold and silver when reduced with soda on charcoal. Behaviour towards hot, strong sulphuric acid resembles that of calaverite.

Origin of gold ore.—Native gold is originally formed for the most part as a hydrothermal product in quartz veins. It is also found sparingly disseminated in granites and other igneous rocks, in which it has arisen as a direct product of crystallization of igneous magmas.

In regions where gold-bearing rocks have been exposed for long ages to atmospheric weathering and denudation, the gold becomes concentrated in various ways. The free gold is washed into the streams, where, on account of its high specific gravity, it is less readily transported than is the lighter material such as quartz. Hence it tends to accumulate in the stream bed, and the alluvial deposits thus formed may become rich in gold, especially in certain places where the nature of the bed favours the concentration of the heavy minerals. A similar concentration can take place in the sand and gravel deposits of sea-beaches. Such sand and gravel deposits containing gold or other valuable heavy minerals are called "placer" deposits, and they constitute an important source of gold, though they are relatively less important now than they were formerly. The "banket" gold-ores, such as those of the Witwatersrand in South Africa and the Gold Coast in West Africa, are geologically ancient detrital deposits which have been consolidated by pressure and cementation to form hard conglomerates, and have been somewhat metamorphosed.

Where pyritic gold ores occur, the solutions of sulphate of iron arising from their decomposition dissolve the gold and carry it downwards into the underlying rocks where reduction takes place, pyrite and gold being re-deposited. As a result of this action, long continued in a region where gold is sparsely disseminated, the rocks may become enriched in gold for some distance beneath the surface, and in this way workable gold ores arise through secondary changes in rocks which would otherwise be of no value as a source of gold.

Occurrence and distribution of gold ores.—The chief producers of gold, in order of their importance, are Africa (especially the Transvaal), United States, Australasia, Mexico, Russia and Finland, India, China, Canada, and South America.

AFRICA.—The goldfields of the Transvaal are the most productive in the world. The chief ore in the Transvaal is the "banket," a coarse conglomerate of quartz-pebbles, with a metamorphosed matrix, which contains pyrite and gold. The origin of the gold in the banket has been a matter of controversy for some time. The prevalent view is that the gold is of detrital origin, and that the banket as a whole is an ancient conglomerate derived from the destruction of gold-bearing quartz veins. Some authorities believe, however, that the gold was not present when the conglomerate was originally formed, and that it has been introduced by infiltration at a later date. The most productive of the gold-bearing conglomerates are those of the Rand goldfield; they occur at various horizons in the Witwatersrand system, the age of which is probably pre-Cambrian.

"Banket" deposits also occur in the Gold Coast Colony of West Africa, and are worked to a considerable extent, though they are not so important as those of the Rand. The Gold Coast banket is metamorphosed, and the hæmatite and magnetite disseminated through its matrix have probably arisen from the metamorphism of limonitic cement. The gold of the Gold Coast "banket" is indubitably of detrital origin. In various rivers of the Gold Coast, a considerable amount of gold is obtained by dredging.

In Rhodesia, native gold is found in the metamorphic rocks of various formations, partly in a disseminated condition, and partly in the quartz veins which traverse these rocks in the neighbourhood of granitic intrusions; the gold is also found disseminated in the intrusive rocks themselves, and occurrences in granite, syenite, and serpentine are worked for gold. At the Globe and Phœnix mine, gold occurs associated with jamesonite in a quartz vein.

In Tanganyika Territory, and in Mozambique Territory, gold occurs in the quartz veins associated with granitic and dioritic intrusions, under conditions closely resembling those of Rhodesia. The good ore occurs near the surface, where there has been enrichment by weathering, and becomes poor at depths of 50 feet or so.

United States.—In the United States gold ores occur extensively in the Cordilleran region, and to a lesser extent in the Appalachian region. The chief gold-producing States are Colorado, California, Nevada, and Alaska. Less important is the production in South Dakota, Utah, Montana, Arizona, Idaho, Washington, Oregon, and New Mexico.

In the Cripple Creek district of Colorado, the gold ores are genetically connected with phonolitic, andesitic, and other volcanic rocks which were extruded on a large scale during Tertiary times. The ores occur partly in fissure veins, and partly as irregular deposits formed by replacement of granite. The chief ore minerals are tellurides, notably calaverite and sylvanite. The associated minerals are tetrahedrite, stibnite, molybdenite, fluorite, pyrite, dolomite and quartz. When native gold occurs it is of secondary origin, and is the result of the oxidation of telluride ore.

In the Mother-Lode Belt of California, the gold occurs native or as auriferous pyrite, in quartz veins which traverse slates and altered volcanic rocks of Carboniferous and Jurassic age.

In Nevada, as at Comstock and Tonapah, gold is found partly native, and partly associated with sulphides, in quartz veins that traverse Tertiary diorites, andesites and rhyolites.

In the Mercur district of Utah, gold ores occur at the base of a sheet-like mass of quartz-porphyry which is intrusive in Carboniferous limestone. The gold is native and is associated with quartz, limonite, barite, and arsenical sulphides.

The alluvial deposits of California have yielded large supplies of gold, much of which has been obtained in recent years by dredging. By the use of dredges a vast bulk of alluvium can be treated, and gold can be obtained profitably from gravels containing not more than threepennyworth of gold per cubic yard, a value which is much too low to permit of profitable treatment by placer mining on a small scale.

Alluvial gold deposits are worked in Alaska. The gold is sparsely disseminated through the various metamorphic and other rocks of the region, and has been left behind in the surface weathering residues. The latter have been sorted by glacial streams, and especially rich pay-streaks of gold occur in the alluvial deposits laid down by these streams arising from the snow- and ice-fields of Alaska.

Australasia.—The chief gold-producing areas of Australasia are as follows, in order of importance: Western Australia, Victoria, New Zealand, Queensland, and New South Wales.

In the Kalgoorlie district of Western Australia, gold occurs abundantly in the form of tellurides, impregnating schists (chiefly hornblende-schists) which are associated with granites and gneisses. The schists are traversed by dykes of porphyry, porphyrite, and peridotite. The minerals associated with the tellurides include auriferous pyrite, calcite, galena, zinc-blende, bismuthinite, chalcopyrite, and scheelite. In other parts of the State gold is widely distributed, but often in rather poor ore-bodies associated with greenstone and other intrusives that traverse the metamorphic rocks which cover such a large area in the interior of the country. Very often the gold occurs disseminated in the condition of a yellowish powder known as " mustard gold," in surface ironstone.

In Victoria, gold occurs in quartz veins which traverse the Ordovician and Silurian sedimentary rocks, and the various igneous rocks (largely granodiorites) that have metamorphosed them. A large amount of gold has however been obtained in Victoria from alluvial deposits, including those known as " deep leads " (fig. 119). " Deep leads " are alluvial deposits that have been covered by flows of basalt. A notable feature in Victorian gold mining has been the large number of nuggets obtained from the alluvial deposits. These nuggets have been found almost entirely within what is known as " the indicator belt," an area characterized by the presence of a thin bed of black shale which is called the " indicator," because the auriferous quartz veins are very rich in gold where they cross it. Another notable feature in Victorian gold deposits is the abundance of " saddle reefs," as in the Bendigo goldfield, where they occur as deposits of auriferous quartz in the anticlines of the folded Ordovician slates and sandstones. The " saddle reefs " are thickest at the crest of the anticlines, and thin out along the flanks. Occasionally the saddles are inverted, having formed in the synclinal depressions (fig. 121).

In New Zealand, gold is obtained chiefly from quartz veins occurring in the Ohinemuri and Thames counties; but large amounts have also been obtained by dredging and placer-mining generally.

In Queensland, a notable deposit of gold ore is that at the Mount Morgan mine. The ore-body occurs in beds of Carboniferous age which have been metamorphosed by intrusions of hornblende-granite. The highly-weathered surface zone consisted of very rich ore, and some of the surface masses of limonitic ore yielded as much as 800 oz. of gold per ton. Beneath this was a zone of porous quartz, which passed at greater depths into a pyrite-chalcopyrite zone. It was formerly supposed that the Mount Morgan ore-body was of geyser origin, and that it was a siliceous sinter; this view has now been abandoned and the ore is regarded as due to partial replacement of sandstone by pyrites. The porosity of the cellular quartz is explained by the fact that the pyrites has been dissolved out in the zone of oxidation, leaving a cellular mass of quartz. The pyrite-chalcopyrite ore carries from 2½ to 3½ per cent. of copper, and from 1½ to 8 pennyweights of gold per ton.

In New South Wales, gold occurs in a variety of ways, viz., in alluvial deposits; in quartz veins; as impregnations of numerous sedimentary and igneous rocks; and as deposits of auriferous ironstone.

Mexico.—In Mexico, as at the Esperanza and El Oro mines, on the Michoacan border, gold is associated with Tertiary igneous rocks (andesites, etc.), which have been intruded into, and poured out over, a series of black calcareous shales of Cretaceous age. The gold is free but finely divided, and is associated with pyrite, magnetite and argentite. The ore-bodies are siliceous replacements of the shales and andesites, and appear to have been produced in the interval between two periods of igneous activity during which the eruption of andesites took place.

Russia.—Gold is abundant in the Ural Mountains, both as quartz veins and disseminations in the rocks, and as alluvial gold in the detrital deposits, though the gold is obtained chiefly from the latter. In the Berezovsk district, mica-schists are penetrated by granite intrusions which send off dykes of microgranite into the schists; and these microgranites are traversed by auriferous quartz veins. The gold is associated with pyrite, galena, chalcopyrite, magnetite, tennantite, tetrahedrite, and aikinite (a sulphide of copper and bismuth). Schists with intrusions of granite also occur at Kotchkar near Zlatoust; here the auriferous quartz veins occur only in the granite, and carry arsenopyrite in addition to the other sulphides referred to as occurring in the Berezovsk district.

The placer deposits of the Ural district, particularly those of the Miask and its tributaries, are richly auriferous. So also are those of various localities in central and eastern Siberia, notably those of Transbaikal and those associated with certain parts of the river systems of the Yenissei, the Lena, and the Amur, where there are extensive auriferous districts characterized by a marked development of various igneous and metamorphic rocks.

INDIA.—The most important locality for gold in India is that of the Kolar goldfield in Mysore. The gold occurs in quartz veins that traverse the hornblende-schists of the Dharwar system (pre-Cambrian). These hornblende-schists appear to have been formed by the metamorphism of basic igneous rocks of the basalt and dolerite types. The gold is associated with pyrite, pyrrhotite, chalcopyrite, arsenopyrite, galena, and zinc-blende.

CHINA.—In China, gold has long been mined in the province of Shantung, where it occurs in quartz veins that traverse granite or gneiss, and is associated with pyrite, chalcopyrite, and galena; but the gold has been chiefly obtained from the alluvial deposits.

SOUTH AMERICA.—In the State of Minas Geraes, Brazil, auriferous bands occur in the pre-Cambrian quartz-hæmatite schists (itabirites). Auriferous quartz veins also occur in the schistose rocks of this region, and at Passagem the gold is associated with tourmaline, arsenopyrite, pyrite, pyrrhotite, monazite, and zircon. Gold is also disseminated in the gneissic complex that underlies the pre-Cambrian itabirites and other schists. Here and elsewhere in South America, as in the Guianas, the gold-bearing rocks have been extensively decomposed, and have yielded a great thickness of surface weathering products (laterites, etc.), some of which are gold-bearing. Where these gold-bearing weathering products have been sorted by stream action, the gold has been still further concentrated in the stream deposits.

CANADA.—The chief gold-producing areas of Canada are those of British Columbia and the Yukon. In both areas the gold has been obtained chiefly from placer deposits, and this is still the case in the Yukon territory, where the rich deposits of Klondike have yielded large amounts of gold. In British Columbia, however, placer mining is now unimportant compared with lode mining. At Hedley the gold occurs along the contact of igneous dykes with limestones and other sediments which are probably of Carboniferous age. The igneous dykes are stated to have the nature of diorites. Garnet and epidote occur as secondary minerals in the limestone, and the ore contains arsenopyrite together with copper sulphides, pyrrhotite, and hæmatite. In the Boundary district the gold occurs in low-grade quartz veins; the associated minerals are calcite, chalybite, chalcopyrite, pyrite, galena, tetrahedrite, silver, and argentite (see p. 183).

IRIDIUM.

Iridium occurs in nature usually alloyed with osmium or platinum. The natural alloy of osmium and iridium is very variable in composition. The type in which iridium preponderates is conveniently named *osmiridium* to distinguish it from *iridosmium* in which osmium preponderates. An alloy of iridium and platinum, consisting chiefly of iridium, also occurs naturally, but is very scarce.

Iridium is a scarce and very valuable metal, more so even than platinum. Platinum usually contains some iridium, and an alloy of these two metals is used for tipping the points of gold pen-nibs. It is also used in making standard weights and certain parts of physical instruments. Iridium has been used to make a black pigment for porcelain ware. Platinum-iridium alloy containing over 30 per cent. of iridium, like iridium and osmiridium, resists attack by aqua regia.

Osmiridium (known also as *Iridosmine*).

General.—Trigonal. Usually found in the form of irregular but somewhat flattened grains. Basal cleavage, perfect. Hardness, about 6½. Specific gravity, about 20.

Optical.—Colour tin-white to yellowish grey. Streak, grey. Lustre, metallic. Opaque.

Chemical and blowpipe.—Alloy of osmium and iridium. Characteristic smell of osmium when heated with potassium nitrate in closed tube, due to osmium oxide (OsO_4), a poisonous vapour the odour of which resembles somewhat that of bromine. Insoluble in single acids and in aqua regia.

Occurrence and distribution.—Iridium alloyed with platinum and osmium is usually found with platinum, and the entire supplies were formerly obtained from the platinum-bearing gravels, notably those of the Urals, and the Choco district of Colombia. Iridium is still obtained to some extent from the iridium residues yielded by the processes for refining platinum. A little osmiridium is also frequently found in association with gold.

In recent years, however, Tasmania has proved an important source of iridium ore. The ore mineral here is iridosmium, and the locality of its occurrence is Bald Hill, Heazlewood district, in the north-western portion of the Island. The rock of this locality is serpentine, and the iridosmium has been found in the serpentine.

It is noteworthy that osmiridium has also been found in peridotite at Nijni-Tagilsk in the Urals.

The Tasmanian mineral is obtained by sluicing from the sands of the Savage River and those of Nineteen Mile Creek and its tributaries. The grains are usually small, but nuggets weighing 2 oz. have been obtained.

For occurrence and distribution of platinum, see p. 230.

IRON.

Metallic iron occurs as a mineral in certain dolerites and basalts, but is rare. Minerals containing iron in a combined form are very abundant, especially the oxides magnetite and hæmatite, the hydrated oxides limonite and goethite, the carbonate chalybite, and the sulphides pyrite and marcasite. Of these magnetite, hæmatite, limonite, goethite, and chalybite are the chief ore minerals.

Oolitic brown iron-ores often contain the mineral chamosite, a hydrated silicate of iron and aluminium. The so-called "purple ore," obtained by roasting pyrites in the manufacture of sulphuric acid, may be regarded as artificial hæmatite.

The chief impurities in iron ore are silica, alumina, titanium, sulphur, and phosphorus. Silica is frequently present in the form of quartz, but is also often present as silicates. Alumina is usually present in combination with silica. The titaniferous impurity is usually in the form of ilmenite or rutile or both. The sulphur occurs generally as pyrites; and the phosphatic impurity is frequently in the form of apatite.

Iron ores of the best quality contain 50 per cent. or more of metallic iron. They should contain little or no titanium and not much more than traces of sulphur and phosphorus. Such ores can be smelted to yield the high-grade pig-iron required for the manufacture of steel by the ordinary ("acid") process. Phosphatic iron ores containing up to two or three per cent. of phosphoric oxide are, however, of very common occurrence; these when smelted yield a phosphatic pig-iron which can be used for the manufacture of steel by the basic process, a phosphatic slag which is of use as a fertilizer being obtained as a by-product. In England, France, and Germany, a vast amount of low-grade iron ore occurs and can be successfully mined owing to its occurrence in easily workable beds, its ready accessibility, and its proximity to coalfields. This low-grade ore usually contains an appreciable amount of phosphorus, and not more than 30 or 35 per cent. of metallic iron.

Magnetite (named from Magnesia in Asia Minor, where the occurrence of the mineral was known to the ancients. Often called *magnetic* *iron-ore.* Also frequently known by the name *lodestone* from the fact that it exhibits magnetic polarity).

General.—Cubic; frequently shows well-developed octahedral crystals; sometimes also the rhombic dodecahedron (fig. 137). More frequently, however, it occurs in a massive granular condition. Parting planes sometimes present parallel to octahedral face, due to twinning. Fracture, uneven. Hardness, about 5½. Specific gravity, about 5. Highly magnetic, fragments being readily attracted by a small horse-shoe magnet.

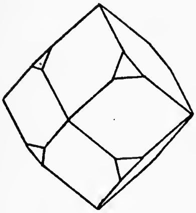

FIG. 137.—Magnetite.

Optical.—Colour and streak, black. Lustre, metallic. Opaque even in the smallest splinters.

Chemical and blowpipe.—An oxide of iron (Fe_3O_4), containing 72·4 per cent. of metallic iron. Fusibility, 5½, and can be fused only with difficulty in a blowpipe flame. Good iron reactions with beads of borax and microcosmic salt. When powdered, dissolves readily in a strong solution of hydrochloric acid, yielding a solution of deep-yellow colour which reacts copiously for iron when treated with ammonium hydrate. Distinguished from ilmenite by the fact that it is very highly magnetic; also when pure it yields no violet titanium reaction on reduction with metallic tin after dissolving in hydrochloric acid.

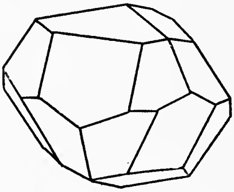

FIG. 138.—Hæmatite.

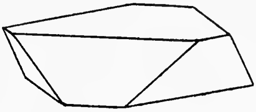

FIG. 139.—Hæmatite.

A variety intermediate between magnetite and ilmenite occurs, and is not uncommon in basic igneous rocks. It consists of an intergrowth of the two minerals, and is distinguished by the fact that it is highly magnetic, but gives titanium reactions. This variety is variously called *titaniferous magnetite*, *ilmenitic magnetite*, or *magnetitic ilmenite*.

Hæmatite (from Gr. *haima*, blood, in allusion to its blood-red colour when powdered. Often called red iron-ore, and specular iron-ore).

General.—Trigonal; often crystalline, showing a combination of rhombohedra and basal pinakoid (fig. 139). Sometimes as very thin small plates or scales and then called *micaceous* or *scaly hæmatite*. Frequently occurs massive, with mammiform surfaces, and then called *kidney iron-ore* (fig. 140). No true cleavage, but often shows partings parallel to rhombohedral and basal planes. Fracture, uneven. Hardness, about 6. Specific gravity, about 5.

Optical.—Colour black or reddish black in the mass. Earthy varieties are red. Lustre, submetallic and splendent when crystalline. Freshly fractured surfaces are often dull when the mineral is compact or fibrous. Streak, reddish brown. Microfragments are translucent, and show a blood-red colour. Refractive index extremely high, $\epsilon = 2{\cdot}94$. Birefringence extremely high, $\omega - \epsilon = 0{\cdot}28$. Scales show emergence of optic axis with negative sign.

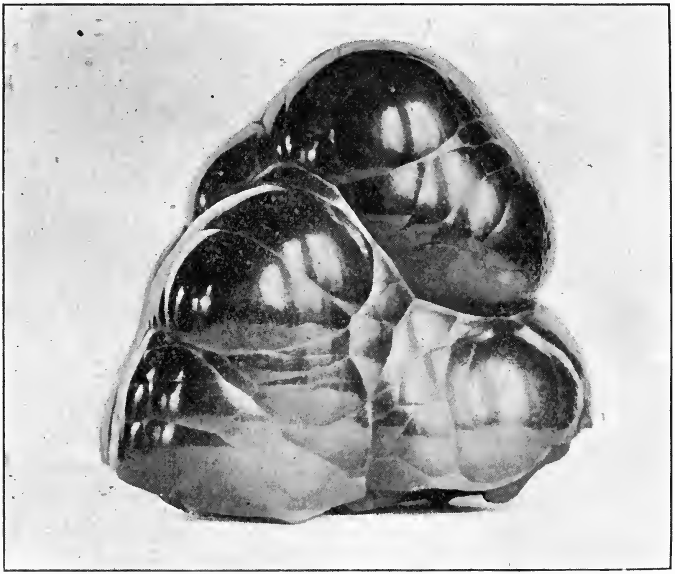

FIG. 140—Hæmatite, Cleator Moor, Cumberland. ($\times \frac{1}{2}$). B.M.

Chemical and blowpipe.—Ferric oxide (Fe_2O_3) containing about 70 per cent. of metallic iron when pure, but often contains titaniferous impurity probably as intergrowths of ilmenite. Fusible with difficulty in the reducing flame and changed to magnetite (fusibility, $5\frac{1}{2}$). Yields little or no water when heated in a closed tube. Gives good iron reactions with fluxes on charcoal and in bead tests.

Limonite (from Gr. *leimon*, a meadow ; also called *brown iron-ore*).

General.—Amorphous. Usually occurs in massive forms, sometimes with a mammiform, fibrous, or concretionary structure ; stalactitic, oolitic, and pisolitic forms are not uncommon. Hardness, about $5\frac{1}{2}$.

Specific gravity variable, but commonly about 3·8 when free from earthy impurities.

Optical.—Colour usually yellow or brown. Streak, yellowish brown. Lustre, usually dull. Translucent in small splinters under the microscope, and acts irregularly though often isotropically between crossed nicols. Refractive index very high, and greater than sulphur in methylene iodide.

Chemical and blowpipe.—A hydrated ferric oxide, containing a variable amount of water, and about 60 per cent. of metallic iron when pure. The composition corresponds approximately to the formula $2Fe_2O_3 \cdot 3H_2O$. Fusibility, about $5\frac{1}{2}$. Becomes highly magnetic when fused in the reducing flame. Gives off water copiously when heated in a closed tube and turns red. Charcoal and bead reactions indicate an abundance of iron. Dissolves fairly readily when powdered and heated in strong hydrochloric acid, yielding a strongly coloured yellowish-brown solution which gives a copious precipitate of ferric hydrate with ammonia.

Goethite (after *Goethe*, the German poet. Like limonite, which it frequently resembles, it is often called *brown iron-ore*).

General.—Orthorhombic, but seldom shows good crystals. Usually in massive forms, in mammiform, and fibrous or platy aggregates. One cleavage present, parallel to the length of the crystals. Hardness, about $5\frac{1}{2}$. Specific gravity, about 4·2, but rather variable.

Optical.—Colour, yellowish to dark brown. Lustre, streak, and appearance under microscope much like those of limonite; but goethite acts anisotropically between crossed nicols and shows straight extinction. Refractive index very high, and greater than sulphur in methylene iodide.

Chemical and blowpipe.—A hydrated ferric oxide, containing about 10 per cent. of water and about 63 per cent. of metallic iron. The composition corresponds to the formula $Fe_2O_3 \cdot H_2O$. Fusibility, closed-tube and other reactions like those of limonite (see above).

Chalybite (Gr. *chalybos*, steel, from the Chalybes, an ancient tribe of Asiatic iron-workers; also often called spathic iron-ore, and siderite, from Gr. *sideros*, iron).

General.—Trigonal. Commonly shows crystalline development, usually in the form of the rhombohedron, the faces of which are often curved. Also in massive-granular or coarsely crystalline masses. Good rhombohedral cleavage. Hardness, about 4. Specific gravity, about 3·8.

Optical.—Colour usually a pale yellowish brown. Lustre, vitreous or pearly. Streak, white. When crushed and examined under the microscope it yields rhomboidal plates which are anisotropic and show symmetrical extinction. Refractive index high ($\omega = 1{\cdot}87$). Birefringence extremely high ($\omega - \epsilon = 0{\cdot}24$). The birefringence is not seen at its maximum in the rhomboidal plates, though it is very high in these, as may be well seen by mounting the fragments in monobromnaphthalene and rotating between crossed nicols, when a great difference in relief will be noticed for the two rays. The refractive index of the extraordinary ray in a cleavage microfragment exceeds that of methylene iodide. The rhomboidal plates show the excentric emergence of an optic axis (uniaxial) of negative sign, when examined between crossed nicols in convergent light.

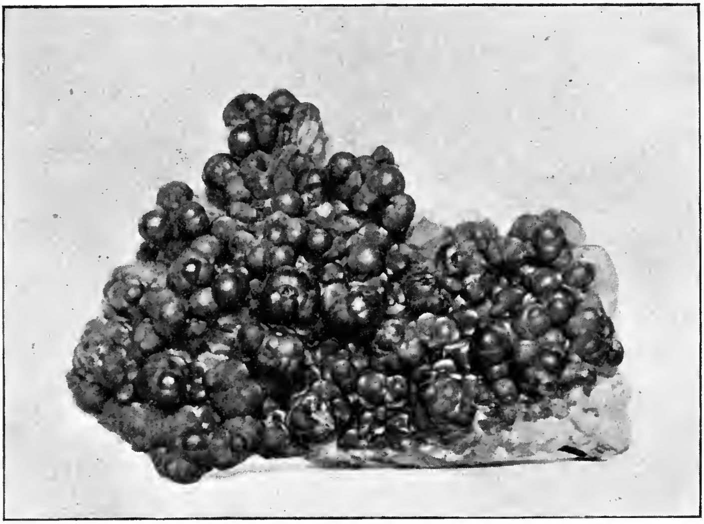

FIG. 141.—Botryoidal chalybite, Kapnik, Hungary. ($\times \frac{1}{2}$). B.M.

Chemical and blowpipe.—Carbonate of iron ($FeCO_3$), containing 48·3 per cent. of metallic iron; but a little lime, magnesium, and manganese are usually present as isomorphous replacements. Fusibility, about $5\frac{1}{2}$; fuses with difficulty, turning black and yielding a highly magnetic oxide (magnetite) in reducing flame. Yields good iron reactions on charcoal, and in beads. Dissolves in dilute hydrochloric acid with effervescence on warming, the solution containing ferrous chloride, and remaining feebly coloured until a few drops of nitric acid are added, after which a copious precipitate of ferric hydrate is given with a solution of ammonia. The precipitate obtained is the green ferrous hydrate unless the solution is oxidized.

Clay-ironstone is a nodular argillaceous variety of chalybite. It is usually very compact and contains a large amount of earthy impurity. These nodules occur abundantly in the coal-measures, and are also found in other formations. " Blackband ironstone " is a carbonaceous variety of clay-ironstone.

Chamosite (from Chamoson in the Valais, Switzerland, where it was first found as a constituent of an iron ore) is a green or greenish black chloritic mineral consisting of hydrated silicate of iron and aluminium, and containing about 40 per cent. of ferrous oxide. It occurs in a microcrystalline condition, often showing an oolitic structure. It is moderately magnetic, or strongly so when in admixture with granular magnetite. Cleavage basal; and cleavage flakes show an almost uniaxial figure. Birefringence low. Fuses readily to a black magnetic glass. Easily decomposed and gelatinized by hydrochloric acid. It occurs frequently in oolitic iron ores, as in those of Wabana in Newfoundland, and Meurthe-et-Moselle and many other localities in Europe. The mineral "thuringite" is closely similar to, if not identical with, chamosite.

Occurrence and distribution of iron ores.—The chief iron-ore producing countries are the United States, France, the United Kingdom, Spain, Sweden, Russia, Austria, Cuba, Germany, and Newfoundland. Less significant is the output of Algeria, Italy, Greece, Tunis, Canada, China, Japan, Korea, Belgium, Australia, and India.

United States.—The most important iron-ore region in the world is that around Lake Superior, especially in the States of Michigan, Wisconsin, and Minnesota. About half the world's total output of iron ore is contributed by the United States, and of this over 80 per cent. is obtained in the Lake Superior region, where there are immense reserves of ore.

The Lake Superior iron ore is chiefly hæmatite, and occurs almost entirely in the Huronian (pre-Cambrian) strata, in the form of lenticles and irregular masses, some of which are of enormous size. The predominant rocks are cherty iron carbonates, slates, schists, and quartzites, with doleritic intrusions. The strata are much folded, and the ore-bodies often occur in the synclines of the folds.

The ore-bodies are supposed to have arisen by a process of enrichment due to the solution of iron compounds in percolating waters and their re-deposition at greater depths on impermeable floors of rock. A good example of this is provided by the Penokee-Gogebic deposits, where the ore-body is found in jasper-like rocks (ferruginous cherts) and lies on a floor of basic igneous rock which has cut across the highly inclined beds of ferruginous chert.

In the Mesabi Range of Minnesota the original sedimentary source of the iron oxide is supposed to have been greenalite (a ferrous silicate), a variety of glauconite which occurs in the rocks of the district, and which by alteration is capable of giving rise to carbonate and oxide of iron.

Another important source of hæmatite in the United States is the Clinton ore, which is mined extensively in the eastern and central States, viz. New York, Pennsylvania, Wisconsin, Virginia, Kentucky, Ohio, Tennessee, Georgia, and Alabama. This ore is interbedded with the Clinton limestone and shale, and is of Silurian age. It contains numerous crinoidal and other fossil remains, and is for this reason known as *fossil ore.* Some of the Clinton fossil ore is rich in calcium carbonate and consists of imperfectly replaced limestone.

Elsewhere in the United States, notably in New York, New Jersey, and Pennsylvania, large ore-bodies of magnetite are found among the gneisses and other rocks of the Laurentian series. These, however, and the hydrated iron ores that occur extensively among the Palæozoic rocks, as well as the chalybite ores, are of smaller importance at present than the hæmatite ores of the Lake Superior region.

Titaniferous magnetite masses, which have arisen by segregation from basic magmas, also occur extensively in the United States, as in the Adirondack region; the presence of titanium has prevented the use of these as iron ore on any large scale, but they are worthy of note as possible sources of ferro-titanium (see p. 250).

GERMANY and LUXEMBURG.—The iron ores used in Germany are obtained in part from the State of Luxemburg, from strata of Jurassic age. The ores are of an earthy type rich in silica, and some of them are sufficiently calcareous to be self-fluxing. The iron is present partly as carbonate and partly as oxides. The beds of iron ore extend into Lorraine. They are four or five in number, and cover a large area. The ore is of low grade, the best averaging only about 36 per cent. of metallic iron, and containing as much as 1·7 per cent. of phosphoric acid.

Of numerous German iron-ore deposits, those of the Siegerland area, where the ore mineral is chalybite occurring in veins that traverse Devonian strata, are of special interest.

FRANCE.—The chief iron-ore producing districts in France are those of Lorraine and Meurthe-et-Moselle in the north-east. The deposit is one of concretionary limonite, and is an extension of the iron-ore deposits of Luxemburg (see above). Less important deposits of hæmatite ore are worked in Normandy, where they occur in folded strata of Ordovician age. The most important of the French iron ores are thus closely similar in character and age to the Cleveland and Northamptonshire iron-ores of England (see below).

United Kingdom.—The most productive districts are those of Cleveland (in north Yorkshire), Lincolnshire, Leicestershire, Northamptonshire, and Oxfordshire, though the ores obtained in these districts are of low grade; they contain on an average only about 30 per cent. of metallic iron and are phosphatic. In the Cleveland district the ore occurs in a bed which is from 7 to 17 feet thick, and of Middle Lias age. The strata are almost horizontal, and the iron ore outcrops on the hill and valley slopes. The ore is in the form of oolitic iron carbonate; it contains 10 per cent. or more of siliceous impurity, but there is also sufficient lime and alumina present to give the ore self-fluxing properties. The Cleveland ore is worked by underground mining.

In Oxfordshire, Northamptonshire, Leicestershire, and Lincolnshire, the ore beds consist of a low grade carbonate and have been formed by the partial replacement of oolitic limestone. In Northamptonshire the ore is worked at a somewhat higher horizon than the Cleveland ore and forms part of the Inferior Oolite. Where it has been exposed to weathering, near the outcrops, the ore is hydrated, and exists in the form of an impure limonite which is of better grade that the unweathered ore. The ore in these countries is chiefly obtained by open working. The Northampton ore is siliceous and averages about 32 per cent. of iron. The ore obtained in the Frodingham district of Lincolnshire contains only about 26 per cent. of iron; but it is got from an easily-worked bed the thickness of which reaches 25 feet. It is a calcareous ore, and is therefore useful for admixture with siliceous ores from other localities.

In Cumberland, near the Whitehaven coalfield, and in the Furness district of north Lancashire, there are important deposits of hæmatite ore. Though the total output of this ore is less significant than the outputs of the low grade ores referred to above, it is a much richer ore, containing 50 per cent. or more of metallic iron and little or no phosphorus. It occurs as large masses of irregular shape in the Carboniferous limestone, and appears to have been formed by metasomatic replacement of the limestone, notably along the junction where these limestones lie unconformably on the older Palæozoic rocks. In addition to the foregoing, iron-ore deposits of less importance are found at various localities in the United Kingdom. Of these the most notable are the clay-ironstones of the coal measures. The so-called "blackband ironstone" of various British localities is a coal-measure clay-ironstone containing sufficient coaly matter to enable it to be smelted without the use of additional fuel. There is a bedded iron-ore deposit of Lower Jurassic (Lias) age in the Isle of Raasay on the north-west coast of Scotland.

SWEDEN.—Notable deposits of high-grade magnetite ores occur in the province of Norbotten, in northern Sweden, at Kirunavaara, Luossavaara and Gellivare. Here the ore is found in huge bodies associated with syenites, and appears to have arisen by a process of segregation from an igneous magma. The ore is magnetite ; it contains little or no titanium and thus differs from the magnetite ore-bodies which have segregated from basic magmas, and which are as a rule characterized by a considerable percentage of titanium. In some instances however, the Swedish ore contains an appreciable quantity of phosphatic impurity in the form of apatite, and this impairs its quality. These Swedish ores contain on the average over 65 per cent. of iron, and they constitute the largest known source of supply of iron ore of this high grade. The ore-bodies of the Kirunavaara, Luossavaara and Gellivare are estimated to contain reserves of about 1000 million tons of ore.

At various localities in central Sweden to the west of Stockholm, and also in many parts of Norway, there are low-grade magnetite deposits which repay magnetic concentration.

SPAIN.—Important iron-ore districts are those of Bilbao, Santander, Oviedo, and Lugo in northern Spain. The Bilbao ores occur as replacement deposits in Cretaceous limestones and are worked largely in open quarries. They consist chiefly of hæmatite and limonite ; they contain over 50 per cent. of metallic iron, and are low in phosphorus. They are consequently suitable for the production of the high-grade pig-iron required for making steel by the “ acid ” process, and are exported largely to England and elsewhere for that purpose.

RUSSIA.—There are rich deposits of iron ore in the Krivoj Rog district of southern Russia. The ore-bodies form huge lenticles of magnetite and hæmatite in a steeply-dipping series of ferruginous quartzites. The quartzites themselves contain a considerable percentage of iron, but the ore-lenticles contain as much as 60 to 65 per cent. of metallic iron, and are thus of high-grade character. Good iron ores also occur in the Nijni-Tagilsk district of the Ural Mountains. Here the origin of the iron ore resembles that of the north Swedish ores. The ore is largely magnetite, which is regarded as having arisen by segregations from a syenitic magma. The ore-bodies are in part hydrated and consist of brown iron ore.

AUSTRIA.—Here the chief iron-ore producing district is that of Leoben in the province of Styria, and the ore is chiefly spathic iron carbonate (chalybite), occurring as a replacement of Triassic limestone. The deposit of chalybite at Erzberg near Eisenerz in Styria is the largest of its kind in the world.

Cuba.—Large deposits of high-class iron ore occur in the province of Oriente, where it is largely obtained by surface quarrying. The ore consists of hæmatite and brown iron-ore; it contains on the average about 58 per cent. of metallic iron. It is shipped to the United States. With reference to the nickel- and chromium-bearing iron ores of Mayari, in Cuba, see p. 229.

Newfoundland.—An important deposit of oolitic hæmatite iron ore is that of Wabana on Bell Island in Conception Bay. The ore is found in a series of beds, twelve in number, varying in thickness from one to ten feet, and interstratified with Cambrian shales and sandstones. The beds are nearly horizontal, and the two largest beds were so near the surface that they could be worked by the open-cast method, only some 5 feet of overburden having to be removed. The ore is now being mined below the sea, where there are immense reserves available. The beds dip seaward at a few degrees. Analyses of the ore show a variation from 54 to 59 per cent. of metallic iron, 7 to 14 per cent. of silica, 0·9 per cent. of phosphorus, and 1 per cent. of moisture. The Wabana ores are thus suitable only for the production of phosphatic pig-iron, and for steel production by the basic process.

The Newfoundland iron ore is smelted at Sydney in Cape Breton, Nova Scotia, where there is a large coalfield from which the necessary fuel is obtained.

Canada.—The most productive iron-ore district in Canada is the Michipicoten range near Lake Superior. The ore formerly worked at the Helen mine in this district varied from hæmatite with 60 per cent. of iron to limonite with 53 per cent. Chalybite ore deposits have been developed recently in this district.

Other Localities.—Of the remaining and less important deposits, mention may be made of the hæmatite ores of the island of Elba, and the manganiferous iron ores of Monte Argentario, in Italy. The Elba ores have for long been worked for export as high-grade ores.

At Locrida in the Atalanti district in Greece, and in the island of Skyros, hæmatite iron ores containing 50 per cent. of iron and up to 3 per cent. of chromic oxide, and some nickel, have been worked for export. These ores are associated with serpentines and recall the chromiferous and nickeliferous iron ores of lateritic origin found at Mayari in Cuba.

Important deposits of iron ore occurring as metasomatic replacements of Mesozoic limestones are worked largely by surface quarrying in Algeria, in Africa; and deposits of brown iron-ore (limonite) of moderately good quality, but phosphatic, occur at Mount Patti, near Lokoja, in Nigeria.

Immense reserves of hæmatite iron ore await exploitation among the itabirites (hæmatite-quartz schists) of Minas Geraes and other parts of Brazil; and important deposits of high-grade iron ore occur also in Chile.

Deposits of iron ore containing immense reserves are worked near Hankow in China.

Large deposits of hæmatite iron ore low in phosphorus and of high grade quality are worked at Iron Knob in South Australia and shipped to Newcastle in New South Wales to be smelted.

Extensive deposits of hæmatite form the summits of parallel ranges of hills at Kolhan and other localities in the southern parts of Singbhum, India. The Kolhan hæmatites contain as a rule about 65 per cent. of iron, 0·03 to 0·08 of phosphorus, and less than 0·03 per cent. of sulphur.

LEAD.

The chief ore minerals of lead are galena (lead sulphide) and cerussite (lead carbonate). Anglesite (lead sulphate) and pyromorphite (lead chlorophosphate) are less important, but occur frequently.

The most important of these lead-ore minerals is galena, which is often argentiferous. It is invariably as galena that lead ore occurs in deep-seated veins which have not suffered oxidation. Where the veins have been oxidized and weathered, cerussite and anglesite arise as alteration products, cerussite being more common. Anglesite is unstable compared with cerussite, and changes into the latter when acted upon by carbonated waters. Where the solutions in the oxidation zone traverse phosphatic rocks, pyromorphite develops. Where the galena is argentiferous, silver minerals arise as the result of oxidation, and some of the most important silver ores in the world have been formed in this way.

Numerous minerals occur in association with galena in veins of lead ore, one of the commonest of these being zinc-blende. The more important of the other associated minerals are calcite, dolomite, chalybite, pyrite, chalcopyrite, barite, and fluorite.

Lead is used largely in the form of sheets and pipes in building construction. It is used in making alloys, notably *soft solder*, *antifriction metal*, *pewter*, and *type metal*. It is also used in the manufacture of shot, for which purpose it is alloyed with about 0·3 per cent. of arsenic.

Galena (from Gr. *galene* meaning tranquillity, in reference to its supposed soothing effect in certain diseases).

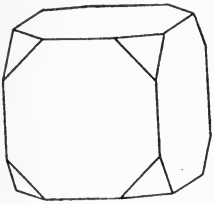

FIG. 142.—Galena.

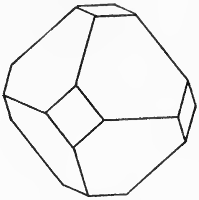

FIG. 143.—Galena.

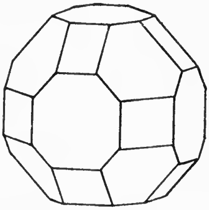

FIG. 144.—Galena.

General.—Cubic, commonly showing the simple cube or combination of cube and octahedron (figs. 142 to 145). Usually massive and coarse-grained, but sometimes fine-grained. The perfect cubic cleavage of crystals is a marked characteristic (fig. 146). Hardness, 2½. Specific gravity, about 7½.

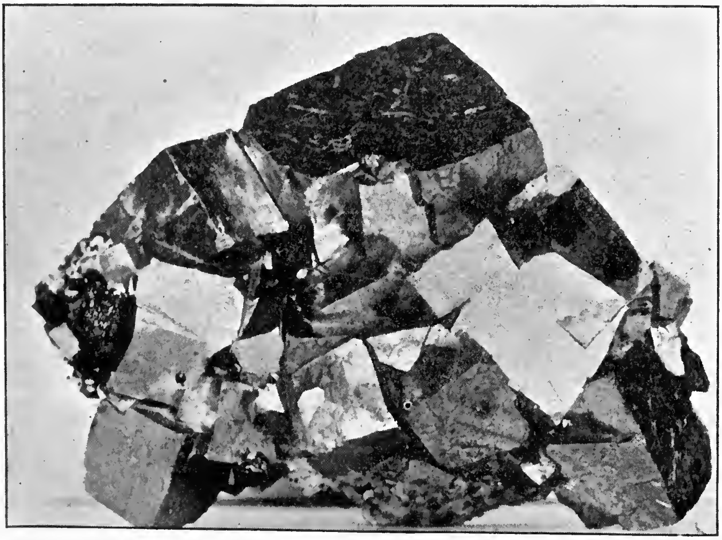

FIG. 145.—Galena, Joplin, Missouri. (× ½). B.M

Optical.—Colour and streak, lead-grey. Lustre, metallic. Opaque.

Chemical and blowpipe.—Lead sulphide (PbS) containing 86·6 per cent. of metallic lead. Fusibility, 2. Yields sulphur dioxide when heated in open tube. Fuses readily on charcoal in blowpipe flame to a malleable bead, yielding a yellow sublimate of lead oxide near the assay and a white sublimate of lead sulphate more remote. On adding a mixture of potassium iodide and sulphur to the assay, and re-heating, a bright yellow sublimate of lead iodide is obtained. Dissolves in hot hydrochloric acid, giving off sulphuretted hydrogen, and needles of lead chloride separate on cooling.

To test for the presence of silver in galena obtain first of all a fairly large bead of lead. Place this on a bone-ash cupel, and heat strongly in the oxidizing flame of the blowpipe. By this means the lead is oxidized and the lead oxide is absorbed by the bone ash. If silver is present it remains behind as a bright bead which resists oxidation, and its identity can be confirmed by dissolving in dilute nitric acid and precipitation with hydrochloric acid; it yields a white curdled precipitate which is insoluble in hot hydrochloric acid.

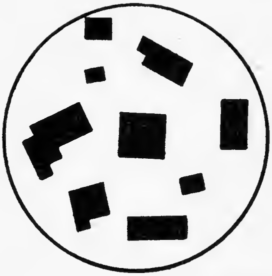

FIG. 146.—Cleavage fragments of galena.

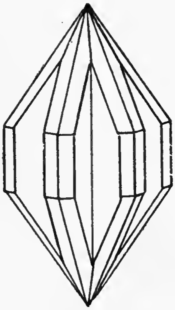

FIG. 147.—Cerussite.

Cerussite (L. *cerussa*, white lead, from *cera*, wax. Also known as white lead-ore).

General.—Orthorhombic, sometimes pseudo-hexagonal in form due to twinning on prism face (fig. 147). These twins frequently show re-entrant angles, but the re-entrant angles in some cases become infilled, and a pseudo-hexagonal bipyramid like that of witherite (fig. 215) is then produced. Usually massive and granular, or fibrous; and sometimes reticulated (fig. 148). Fracture, uneven or conchoidal. Hardness, about 3½. Specific gravity, about 6·5.

Optical.—Colourless, white or greyish. Lustre, adamantine. Streak colourless. Splinters under the microscope are transparent. Refractive index very high, $\alpha = 1{\cdot}80$. Double refraction extremely high, $\gamma - \alpha = 0{\cdot}270$. Optical sign, negative.

Chemical and blowpipe.—Lead carbonate ($PbCO_3$), containing 77·5 per cent. of lead. Fusibility, 1½. Decrepitates to some extent in blowpipe flame, but fuses with extreme ease. Charcoal and other chemical reactions much the same as for galena, but yields no smell of sulphur dioxide when heated in open tube. Effervesces with nitric acid.

Anglesite (named from its occurrence in Anglesea, where it was first found. Also known as lead vitriol, and sulphate of lead).

General.—Orthorhombic. Rhombic prism usually predominant. Often massive, and sometimes granular. Very brittle. Fracture, conchoidal. Hardness, about 3. Specific gravity, about 6·3.

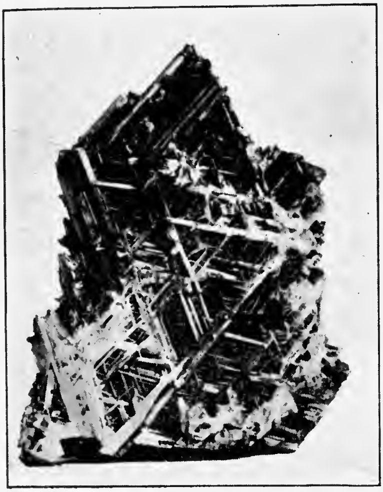

FIG. 148.—Cerussite, Broken Hill, N.S.W. (× ½). B.M.

Optical.—Colourless or white. Streak, colourless. Lustre, adamantine. Refractive index very high ($\alpha = 1{\cdot}877$). Birefringence very low as compared with cerussite ($\gamma - \alpha = 0{\cdot}016$). Optical sign, positive.

Chemical and blowpipe.—Sulphate of lead ($PbSO_4$), containing 68·3 per cent. of lead. Fusibility, 1½ ; fuses in a candle flame.

On charcoal in oxidizing flame of blowpipe fuses to a clear globule which becomes white on cooling. In reducing flame yields metallic lead. With sodium carbonate on charcoal in reducing flame, metallic lead obtained, and sodium sulphide formed. When the fused mass is placed on a silver coin with a few drops of water, a black stain of silver sulphide is produced. Anglesite is soluble with difficulty in nitric acid, and the solution yields a precipitate of barium sulphate when barium chloride is added.

Pyromorphite (Gr. *pyr*, fire, and *morphe*, form ; this name was given to the mineral on account of the faceted shapes assumed by fused globules on cooling).

General.—Hexagonal. Occurs commonly in the form of small hexagonal prisms (fig. 149). Fracture, uneven. Hardness, about $3\frac{1}{2}$. Specific gravity, about 7.

Optical.—Colour variable, but usually green or brown. Streak white. Lustre, resinous and adamantine. Microfragments irregular and transparent, and colourless or nearly so. Refractive index, above 2. Birefringence low; $\omega - \epsilon =$ about 0·010. Optical sign negative.

Chemical and blowpipe.—Chloro-phosphate of lead

$$\{3Pb_3(PO_4)_2 \cdot PbCl_2\},$$

containing 76·3 per cent. of lead.

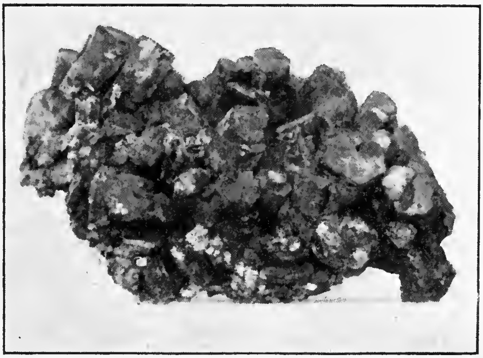

FIG. 149.—Pyromorphite, Huelgoat, Brittany. (× ⅓). B.M.

Fusibility, about 2; and gives a bluish-green colour to the flame. The fused globules develop facets on cooling. Yields metallic lead when reduced on charcoal with sodium carbonate. When fused in a microcosmic bead with a little copper oxide, it gives an azure blue colour to the flame due to the presence of copper chloride. Dissolves in nitric acid, and the solution yields a yellow precipitate of ammonium phospho-molybdate on the addition of ammonium molybdate.

Occurrence and distribution of lead ores.—About 90 per cent. of the world's output of lead ore is produced by the United States of America, Spain, Australia, Germany and Silesia, and Mexico. The remaining 10 per cent. is produced chiefly by Great Britain, France, Canada, Greece, Italy, and Austria.

UNITED STATES.—In the U.S.A., lead ore is obtained almost entirely from the States of Missouri, Idaho, Utah, and Colorado.

In the south-eastern district of Missouri, galena occurs in the form of extensive impregnations in limestones of Ordovician age. Sandstones occur in the formation, but these contain no ore. The ore is remarkable for the fact that it contains practically no zinc minerals. It contains on the average about 7 per cent. of galena, and can be dressed by jigs to yield a product containing from 60 to 70 per cent. of the mineral. In south-west Missouri, Joplin is the most important locality. Here the ore-bodies are sometimes several hundred feet thick, and the ore is found as veins or as breccia-cement in limestones of Lower Carboniferous age. The chief ore mineral is zinc-blende, which is cadmium-bearing (see p. 166), but galena also is found in abundance. The lead-zinc ores of northern Arkansas may be referred to along with those of Missouri. They occur in limestones of Ordovician and Carboniferous age, partly in veins, and partly in breccias or in a disseminated condition; the chief ore minerals are galena and zinc-blende, embedded in a gangue of calcite, dolomite, barite, and chert.

The lead and zinc ores of the Missouri region are supposed to have arisen by a process of slow concentration of lead and zinc sulphides from the limestones, through which they are disseminated in small amounts. The operation was probably effected by the oxidation of disseminated sulphides to sulphates, their transportation in solution, and their re-precipitation as sulphides under the reducing influence of the organic matter in the limestones. Shale beds are supposed to have played an important part in the deposition of the ores, by arresting the circulation of the solutions prior to precipitation.

Important deposits of argentiferous lead ore are mined at Cœur d'Alene, Idaho, where the geological formations consist of folded sandstones, slates, and quartzites. The ore occurs in veins. The chief ore mineral is argentiferous galena, and this is associated with chalybite, quartz, and zinc-blende. The workable ore-bodies contain from 5 to 25 per cent. of lead, and from 7 to 10 ounces of silver per ton.

Large deposits of argentiferous lead ore are found in the Tintic district of Utah, in the folded Palæozoic limestones and associated Tertiary igneous rocks of that area. The chief ore mineral is argentiferous galena, associated with zinc-blende, pyrite, enargite, barite, and quartz.

Other important deposits of argentiferous lead ore in the U.S.A. are those of the Leadville district of south-central Colorado. The sedimentary rocks of the region are of Palæozoic age and include thick beds of Carboniferous limestone. These sediments are traversed by dykes of porphyry and are extensively interbedded with igneous rocks of the same type. These porphyries are connected with the plutonic masses of granite that underlie the region. The rocks are extensively folded and faulted as a consequence of the late-Cretaceous earth-movements which produced the Rocky Mountains, and these earth-movements are supposed to have had some influence in stimulating the deposition of the ores. The ore-bodies occur frequently beneath the sills of porphyry where these are in contact with the Carboniferous limestone. The chief ore mineral is argentiferous galena, associated with calcite, barite, chert, and native gold; but in the weathering zone, cerussite and anglesite are abundant, associated with limonite and silver chloride.

SPAIN.—Lead ores occur abundantly in southern Spain. Argentiferous lead-ore is mined in the provinces of Murcia, Ciudad Real, and Almeria; and ordinary lead ore in the provinces of Jaen, Cordova, and Badajos.

In the Cartagena district of Murcia, there are veins of argentiferous galena of Tertiary age in Triassic limestones and shales. The argentiferous galena in the unaltered veins is associated with zinc-blende, pyrite, and chalcopyrite. Another type of deposit met with in Cartagena and also in the Mazarron district, has the appearance of a bedded deposit, and is interstratified with Triassic shales. In this type the ore minerals are argentiferous galena and zinc-blende, associated with pyrite, chalcopyrite, quartz, barite, and siderite, and the deposits have arisen by replacement (metasomatism).

Farther north, in the Linares district of the province of Jaen, and on the south of the Sierra Morena, veins of rich lead ore traverse the Lower Palæozoic slates and quartzites, as well as the granites that are intrusive in these strata. The Linares veins are characterized by the abundance of galena and the scarcity of zinc-blende. The galena is associated with dolomite, chalybite, barite, and plenty of quartz. In the weathering zone cerussite is abundant, associated with iron and copper carbonates, lead phosphate, barite, and calcite. The veins are confined to the Palæozoic beds, and are not found in the overlying Triassic and younger rocks.

GERMANY and SILESIA.—Lead ore is mined in Silesia and the Harz, and less extensively in the provinces of Rhenish Prussia, Nassau, and Westphalia.

In Upper Silesia lead ores are found in the folded Muschelkalk (Triassic) dolomitic limestones. Where fresh, the ore minerals consist of zinc-blende and galena associated with pyrite. In the weathered zone the ore minerals are calamine and cerussite, and the pyrite is oxidized. The galena of Tarnowitz contains 0·03 to 0·04 per cent. of silver.

In the Clausthal district of the Harz, there are veins of lead ore in strata of Devonian and Carboniferous age; they are particularly well developed in the Culm beds, which consist of shales and sandstones and are of Lower Carboniferous age. The chief ore mineral is galena, which is in part argentiferous. The galena is associated with zinc-blende, pyrite, chalcopyrite, quartz, calcite, dolomite, chalybite, and barite.

Important deposits of lead ore occur in the Aix-la-Chapelle (Aachen) district of Rhenish Prussia. Here the ore-bodies consist partly of veins and partly of irregular replacements in Devonian and Carboniferous limestones. Galena and zinc-blende are the ore minerals of the unaltered deposits, but cerussite and smithsonite are abundant in the upper levels.

The rocks of the Freiberg mining-field of Saxony consist chiefly of biotite-gneiss with some mica-schist, and in these granite and porphyry occur as intrusives. A complex series of veins traverse these rocks. Some of the veins carry argentiferous galena and zinc-blende associated with pyrite, arsenopyrite, chalcopyrite, quartz, calcite, chalybite, and barite. The weathered zone of these deposits is rich in secondary silver minerals and native silver, and has yielded an abundance of this metal.

At Ems and Holzappel in Nassau, veins of lead-zinc ore occur in Devonian slates and sandstones. The ore minerals are argentiferous galena and zinc-blende, associated with pyrite, chalcopyrite, calcite, dolomite, chalybite, and abundant quartz. The crude ore contains about 2½ per cent. of zinc, 4 of lead, and 2 oz. of silver per ton.

Australia.—In Australia the chief occurrence is that of the silver-lead-zinc ore deposit of Broken Hill in the Barrier district of New South Wales, which is one of the largest and most important deposits in the world. Broken Hill is an anticlinal ridge, the rocks of which are highly metamorphosed and consist of gneiss, schist, and quartzite of supposed pre-Cambrian age traversed by intrusions of granite and diorite. The lode extends along the summit of the anticline, and is regarded by some authorities as a saddle-reef formation, but other authorities do not accept this view. The unaltered ore now being worked consists of argentiferous galena and ferriferous zinc-blende associated with pyrite, chalcopyrite, rhodonite, quartz, garnet, and felspar, together with small amounts of fluorite, arsenopyrite, and wulfenite. The ore contains from 5 to 50 per cent. of lead, 14 to 30 per cent. of zinc, 6 to 36 oz. of silver per ton, and 2 to 3 dwts. of gold per ton. In the oxidized zone cerussite and halogen compounds of silver were abundant, and the outcrop consisted chiefly of manganiferous limonite. The cerussite ore originally worked carried as much as 60 per cent. of lead, and 300 oz. of silver per ton. The ore has been removed at the outcrop by an open cut 20 to 100 ft. wide, for a distance of about a mile and a half along the ridge.

With reference to occurrence of galena in Tasmania, see p. 264.

MEXICO.—The chief lead-producing districts of Mexico are those of Mapimi, Santa Eulalia, and Sierra Mojada. These Mexican occurrences are remarkable as furnishing instances of pipe-like deposits in Cretaceous limestone. A deposit of this type occurs at the Ojuela mine in the Mapimi district, where the pipe extends downwards for several hundred feet, and has a thickness of about 130 ft. The ore minerals are galena and zinc-blende, associated with pyrite, chalcopyrite, arsenopyrite, stibnite, magnetite, quartz, calcite, chalybite, dialogite, fluorite, and barite.

BRITISH ISLES.—Argentiferous lead ore is mined at numerous localities in the British Isles. The most productive mines are in Derbyshire, Flintshire, Durham, Lanarkshire, Dumfriesshire, Westmorland, and the Isle of Man. In Derbyshire, Durham, Westmorland, Flintshire, and Dumfriesshire the veins occur chiefly in Carboniferous strata. Limestone seems to provide specially favourable conditions for the precipitation of lead ores, as is well seen in Derbyshire, where the limestones are interbedded with " toadstones " (basic igneous rocks), and are overlain by Millstone grit. The veins are productive where they traverse the limestone, and become unproductive where they traverse the " toadstone " and the Millstone grit. Calcite, fluorite, zinc-blende, and chalybite are associated with the galena in these veins, and the fluorite is sufficiently abundant in some cases to form an important by-product in mining.

At Foxdale in the Isle of Man the lead ore occurs as veins in granite, associated with quartz, pyrite, and pseudomorphs of iron carbonate after fluorite. At Laxey, also in the Isle of Man, galena occurs in Ordovician slates associated with zinc-blende and copper sulphides, and the galena is richly argentiferous.

At many localities in Wales, Shropshire, Devonshire, and Cornwall, galena occurs in veins which traverse Lower Palæozoic rocks (shales, slates, and flagstones) and is frequently associated with zinc-blende, pyrite, quartz, barite, fluorite, and copper sulphides.

With reference to the amount of silver in British lead ores, see p. 239.

OTHER LOCALITIES.—See notes on zinc-lead ore in Canada (p. 266), Burma (p. 267), Rhodesia (p. 267), Russia (p. 266), Sweden (p. 266), and Japan (p. 267).

MAGNESIUM.

Metallic magnesium has come into use for many purposes in recent years. The metallurgical processes involved in its production are costly to operate, and the metal is as yet too expensive to be used as largely as it might otherwise be used.

It can be obtained by the reduction of magnesia with potassium or carbon at high temperatures; but it seems to have been made chiefly by electrolysing fused magnesium chloride in admixture with alkali chlorides.

Magnesium is a very light metal (specific gravity 1·75) and alloys readily with aluminium and many other metals. Magnalium is an alloy of aluminium and magnesium. When fairly pure, magnesium compares with aluminium as regards conductivity, and its lightness compared with aluminium, the specific gravity of which is 2·7, makes this metal of considerable prospective interest in connection with the possibility of using it for building aircraft.

Magnesium combines eagerly with oxygen and nitrogen and on that account is useful for drossing off various deleterious oxides in the manufacture of brass and other alloys. As an illuminant, magnesium is used for military and other purposes in making flare lights, shrapnel trailers, etc.

MANGANESE.

The chief ore minerals of manganese are pyrolusite (MnO_2), psilomelane (impure hydrated dioxide), and braunite ($Mn_2O_3 + MnSiO_3$). Less important are manganite ($Mn_2O_3 \cdot H_2O$), rhodonite ($MnSiO_3$), rhodochrosite ($MnCO_3$), hausmannite (Mn_3O_4), wad (an earthy variety of psilomelane), and franklinite (see p. 262). In some of the unoxidized Indian deposits the mineral spessartite (manganese garnet) is very abundant.

One of the most important uses of manganese is as an alloy of iron. Alloys containing from 5 to 20 per cent. of manganese are called *spiegeleisen*. *Ferro-manganese* contains over 20 per cent. of manganese and may contain as much as 80 per cent. Manganese steel containing from 10 to 15 per cent. of manganese is permanently hard and very serviceable in many ways. A considerable amount of manganese steel of this hard type is used in the manufacture of those parts of rails, crushing and other machinery that require specially durable steel.

Most of the manganese used in iron metallurgy, however, is used in much smaller quantities (one per cent. or less), for the purpose of improving and controlling the quality of pig-iron and steel, through its action as a deoxidizer and desulphurizer.

Manganese ore is used in the chemical trades in various ways. It has been used in the manufacture of chlorine. Pyrolusite of high grade containing not more than one per cent. or so of iron oxide, is used as an oxidizing agent in decolorizing green glass, and as a depolarizing agent in dry batteries. Pyrolusite for this purpose should contain from 85 to 90 per cent. of manganese dioxide (MnO_2), and is much more valuable than ordinary manganese ore.

Manganese ore is also used as a colouring agent in the manufacture of glass and porcelain. Among other minor utilities is its employment in the manufacture of permanganates for use as disinfectants.

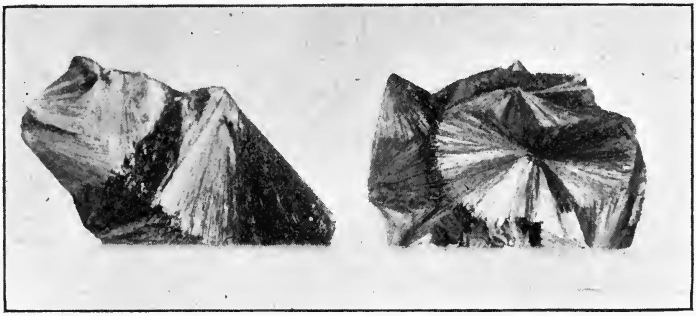

FIG. 150.—Pyrolusite, Elgersburg, Gotha. (× ½). B.M.

Pyrolusite (Gr. *pyr*, fire, and *luo*, to wash ; named from its decolorizing property in glass manufacture).

General.—Amorphous. Occurs in massive fibrous forms (fig. 150). Hardness, about 2. Specific gravity, about 4·8.

Optical.—Colour, black. Streak, black. Lustre, dull to submetallic. Opaque.

Chemical and blowpipe.—Manganese dioxide (MnO_2), containing 63·2 per cent. of manganese. Infusible. Yields a purple-coloured borax bead in oxidizing flame ; and if not too much of the mineral has been added, the bead becomes colourless in the reducing flame. Dissolves in hydrochloric acid with evolution of chlorine.

Psilomelane (Gr. *psilos*, smooth, and *melas*, black).

General.—Amorphous. Occurs in massive forms, often showing reniform, botryoidal, and stalactitic shapes (fig. 151). Hardness, about 6. Specific gravity, about 4·3, but variable.

Optical.—Colour, black. Streak, brownish black. Lustre, dull to submetallic. Opaque.

Chemical and blowpipe.—Hydrated oxide of manganese, containing a variable amount of water and baryta. Infusible. Borax bead same as pyrolusite. Yields water when heated in a closed tube. Dissolves in hydrochloric acid with evolution of chlorine.

Braunite (named after Mr. Braun of Gotha).

General.—Tetragonal, but usually found in massive granular form. Fracture, uneven. Hardness, about 6½. Specific gravity, about 4·8.

FIG. 151.—Stalactitic psilomelane. (× ¼). B.M.

Optical.—Colour and streak, brownish black. Lustre, submetallic.

Chemical and blowpipe.—Sesquioxide of manganese, usually with an appreciable percentage of manganese silicate ($Mn_2O_3 + MnSiO_3$). Infusible. Borax bead same as pyrolusite. Dissolves in hydrochloric acid with evolution of chlorine; usually gelatinizes with hydrochloric acid, owing to the presence of manganese silicate.

Manganite.—*General.*—Orthorhombic; usually in forms showing a well-developed prism, with longitudinal striations. Also massive and fibrous. Perfect pinakoidal cleavage. Hardness, about 4½. Specific gravity, about 4·3.

Optical.—Colour, black. Streak, dark brown. Lustre, submetallic.

Chemical and blowpipe.—Hydrated sesquioxide of manganese ($Mn_2O_3 \cdot H_2O$), with 62½ per cent. of manganese and 10·2 per cent. of water. Infusible. Borax bead same as pyrolusite. Yields water when heated in a closed tube. Dissolves in hydrochloric acid with evolution of chlorine.

Rhodonite (Gr. *rhodon*, a rose).

General.—Triclinic (fig. 152). Usually found massive, with a compact structure. Cleavage, perfect, yielding prismatic fragments. Hardness, about 6. Specific gravity, about 3·5.

Optical.—Usually pinkish in colour, but often blackened on surface and along cracks owing to oxidation. Streak, white. Lustre, dull or vitreous. Microfragments transparent and colourless. If obtained from a well-crystallized specimen the fragments are prismatic in shape, owing to the presence of two good cleavages. These prismatic fragments show oblique extinction; and the angle of extinction is about 22°. Refractive index high; $\gamma = 1{\cdot}74$. Birefringence, moderately high; $\gamma - \alpha = 0{\cdot}020$.

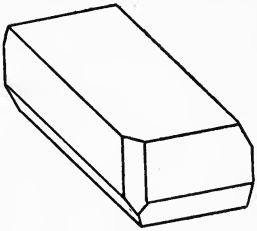

FIG. 152.—Rhodonite.

Chemical and blowpipe.—Silicate of manganese ($MnSiO_3$) with about 42 per cent. of manganese. Usually, however, the mineral is impure. Fusibility about 3; fuses readily to a black glass. Borax bead same as pyrolusite. Attacked by hydrochloric acid, and may show some effervescence owing to admixture with manganese carbonate.

Rhodochrosite (Gr. *rhodon*, a rose, and *chrosis*, colour. Also called dialogite from Gr. *dialoge*, doubt, presumably on account of its confusion with rhodonite).

General.—Trigonal. Crystallizes in rhombohedra, but usually found in a massive granular condition. Cleavage, rhombohedral. Hardness, about 4. Specific gravity, about 3·5.

Optical.—Colour usually pink; sometimes red or brownish. Streak, white. Lustre, vitreous. Microfragments highly transparent. Refractive index high ($\omega = 1{\cdot}82$). Birefringence extremely high ($\omega - \epsilon = 0{\cdot}220$); the full effect of this maximum value is not seen in cleavage fragments, but these show a very strong birefringence effect. Optical sign, negative.

Chemical and blowpipe.—Manganous carbonate ($MnCO_3$), with 47·8 per cent. of manganese. Infusible, but darkens, and decrepitates when heated in a blowpipe flame. Borax bead same as with pyrolusite. Dissolves with effervescence in hot hydrochloric acid.

Occurrence and distribution of manganese ores.—Of the world's total output of manganese ore, about 90 per cent. is contributed by India, Russia, and Brazil; the remainder is produced mainly by Germany, Austria and Rumania, the United States, Japan, Spain, France, Sweden, Great Britain, and Italy.

INDIA.—The chief districts in India where manganese ore is mined are the Nagpur, Balaghat, Bhandara and Chhindwara districts of the Central Provinces. Considerable amounts are also mined in the Vizagapatam district of the Madras Presidency, as well as in the provinces of Bengal, Mysore, Bombay, and Central India.

In the Central Provinces the ore occurs as beds and lenticles in a group of metamorphic rocks of Dharwar (pre-Cambrian) age. These rocks include gneisses, quartzites, schists, and crystalline limestones. The ore minerals are chiefly braunite and psilomelane, and these two minerals are usually found mixed, forming compact masses of ore. Rhodonite and various other manganese silicates also occur. The ores are regarded as having been laid down in the first place contemporaneously with the sediments in which they occur, *i.e.* as true bedded deposits; but they have suffered intense metamorphism, and the metamorphic agents which transformed the original sands and clays into quartzites and schists have also metamorphosed the manganese ores, and have produced a great variety of manganese minerals in these deposits. The ores of the Central Provinces contain on the average about 50 per cent. of manganese, 6 of iron, 6 of silica, 0·1 of phosphorus and about 1 per cent. of moisture.

The manganese ores of the Vizagapatam district have arisen from the alteration of manganiferous rocks of igneous origin. These rocks also are of pre-Cambrian age, and are rich in rhodonite and manganese garnet. The ore minerals are associated with lithomarge, ochres, wad, and chert, which, like the ore minerals themselves, have arisen from the alteration of the igneous rocks. The chief ore mineral is psilomelane, associated with pyrolusite, braunite, and various other manganese minerals. The Vizagapatam ores are on the whole inferior in quality to those of the Central Provinces. They contain from 32 to 50 per cent. of manganese, 2 to 20 per cent. of iron, 1 to 10 per cent. of silica, and 0·1 to 0·5 per cent. of phosphorus.

In some parts of Bengal, Madras, Mysore and the Central Provinces, the outcrops of the Dharwar metamorphic rocks have been extensively weathered and altered; and the resulting weathering products are rich in iron and manganese ores. The ore minerals in these deposits are psilomelane, wad, pyrolusite and manganite; and associated with these are earthy iron ores. Such deposits are comparatively poor in manganese and rich in iron, but they contain very little silica and phosphorus, and their mode of occurrence often permits them to be easily and economically mined.

Russia.—Important deposits of manganese ore occur in the Caucasus, and in the Nikopol district of Ekaterinoslav in South Russia.

At Chiaturi on the southern slopes of the Caucasus, the deposits occur in the form of very extensive beds, totalling 5 or 6 feet in thickness, between Cretaceous and Tertiary strata. The beds are almost horizontal, and are separated by layers of sandy marl; they are overlain by Eocene sandstone and underlain by Cretaceous chalk. The ore consists chiefly of pyrolusite, and is oolitic in texture; it contains about 54 per cent. of manganese, 5 per cent. of silica, 1½ per cent. of barite, and usually not more than 0·05 per cent. of phosphorus.

Near Nikopol on the Dnieper River, in Ekaterinoslav, manganese ore is interbedded with clays and glauconitic loams of Oligocene (Tertiary) age. The ore forms a bed from 5 to 7 feet thick, and consists chiefly of concretionary pyrolusite and psilomelane. It contains on the average about 45 per cent. of manganese, 1 of iron, 12 of silica, and 0·2 to 0·3 per cent. of phosphorus.

It is clear from their mode of occurrence that the Chiaturi and Nikopol deposits are true bedded deposits and that they were precipitated from the waters of the shallow sea in which their associated sediments were formed. In this connection it is worthy of note that manganese compounds are being deposited on the floors of modern seas in some places, as for instance in the Black Sea.

Brazil.—In Brazil, there are important deposits of manganese ore in the State of Minas Geraes, where the largest mine is the Morro da Mina, near Lafayette, in the Quelez district. Here the ore occurs in schists and contains 50 per cent. of manganese, 2 of silica, and about 0·07 of phosphorus.

Important deposits are found also at Miguel Burnier and Ouro Preto in Minas Geraes, in a formation consisting of mica-schists, limestone and itabirites (magnetite-hæmatite schists). The ore minerals are pyrolusite and manganite, and occur in beds which reach a thickness of 6 feet. These ores contain from 53 to 55 per cent. of manganese, and not more than about 0·3 per cent. of phosphorus.

Manganese ores occur also in the States of Matto Grosso and Bahia.

Germany.—In Germany, manganese ores have been mined chiefly in Nassau and Hesse, where they are found abundantly in surface residues produced by the weathering of Middle Devonian limestone. The limestone is partly dolomitized at the surface, and has a covering of clay, sand, and gravel in which the ore forms crusts and spongy masses of irregular shape, and sometimes compact lumps. The ore minerals consist of pyrolusite, psilomelane, manganite, wad, and limonite, associated with barite. The manganese in these ores does not exceed 20 per cent.; but in addition to this the ores contain from 30 to 35 per cent. of iron. Like certain deposits in India referred to above, and certain of the United States deposits (see below), these German ores have been formed by concentration due to weathering. The residue of clay and sand was rich in iron and manganese compounds, and these segregated to form crusts and concretions of manganiferous iron ore.

The iron ore obtained from the chalybite veins of Siegerland, referred to on p. 199, is in part manganiferous. The manganiferous chalybite of Siegerland averages about 12 per cent. of manganese.

Austria and Rumania.—Manganese ores occur as lenticular deposits in the mica-hornblende schists of Eisenthal, near Jakobeny, in the Bukovina. Where unaltered, the ore consists of rhodonite with rhodochrosite and quartz. In the oxidized zone it consists chiefly of pyrolusite with hæmatite. Rhodochrosite occurs abundantly in various parts of the Eastern Alps, as in Styria, where it was formerly mined.

Japan.—Manganese ore is mined at numerous localities in Japan, notably in Shiribeshi, Hokkaidō; and in Mutsu and Tamba, Honshū. The Japanese ores occur partly in the Lower Palæozoic and partly in the Tertiary strata, or in surface weathering residues derived from these. At Fuku-ura in Mutsu the ore occurs as a bed 2 to 4 feet thick interstratified with Tertiary shale.

The predominant ore minerals in the Japanese ores are pyrolusite, psilomelane, and wad, usually occurring in a mixed condition. The ores contain on the average about 50 per cent. of manganese and about 3 per cent. of iron. The amount of silica in most of the ores ranges from 1 to 8 per cent., phosphorus 0·1 to 0·4 per cent., and moisture 3 to 8 per cent. Sulphur is absent or present only in traces.

United States.—In the United States high-grade manganese ore is mined at Crimora in Virginia. The ore mineral, which is psilomelane, occurs as large masses in beds of residual clay. Masses of limonitic iron ore also occur. The ores appear to be of concretionary origin, and the clay in which they occur has been formed by the weathering of the underlying Cambrian rocks. Deposits closely resembling those of Crimora in mode of origin occur at Cartersville in northern Georgia; they consist of psilomelane associated with limonitic iron ore, bauxite and barite, and have arisen from the weathering of Lower Palæozoic rocks. These should be compared with the German and certain of the Indian deposits mentioned above.

More important in respect of the total yield of manganese is the franklinite ore of New Jersey. This contains only about 12 per cent. of manganese, but it contains zinc as well (see p. 262).

Occurrences of manganese ore are numerous in California and other western States, and in recent years there has been a considerable output in California.

The iron ores of the Lake Superior region (Michigan and Wisconsin) are to a slight extent manganiferous; but the amount of manganese is stated not to exceed 1 per cent. as a rule, and it is misleading to regard these as manganese ores, since this gives a false impression regarding the significance of the contribution by the United States to the world's total production.

CANADA.—High-grade manganese ores occur in Nova Scotia and New Brunswick. At New Ross in Lunenburg Co., Nova Scotia, veins of manganese ore rich in pyrolusite and associated with psilomelane and manganite, occur in granite. Another noteworthy Nova Scotian deposit of pyrolusite is that in the Carboniferous limestone of Hants Co., in which it occurs largely in the form of nodules. These pyrolusite deposits of Nova Scotia and New Brunswick contain from 85 to 90 per cent. of manganese dioxide, and contain a sufficiently low percentage of iron oxide to make them valuable as oxidizers for dry batteries.

FRANCE.—The most important deposits of manganese ore in France are those of Romanèche, in Saône-et-Loire. They occur partly as veins and partly as infillings of cavities in Liassic limestone. The ore mineral is psilomelane, rich in barium. The ore contains 60 to 70 per cent. of manganese dioxide and 13 per cent. of baryta.

Other deposits occur at Las Cabesses near St. Girons in Ariège, where the ore consists of manganese carbonate, changed into black oxide at the outcrops. The carbonate ore contains from 40 to 45 per cent. of manganese, 6 per cent. of silica, and not more than 0·4 per cent. of phosphorus. By calcination at the mines the percentage of manganese is raised to 55.

GOLD COAST.—An important deposit of psilomelane has been worked recently at Dagwin in the Wassaw district, on the eastern side of the Taquah Banket Range, West Africa. Much of the ore contains over

50 per cent. of manganese. It contains only about 4 per cent. of silica and 0·1 per cent. of phosphorus.

British Isles.—Small deposits of manganese ores have been worked in various parts of the British Isles, notably in North Wales, Cornwall, and Devon; but in recent years only those of North Wales (Carnarvon and Merionethshire) have produced any considerable amount of ore.

In the Lleyn peninsula of Carnarvonshire, deposits have been worked near Rhiw, and at Nant near Aberdaron; and it is from these mines that the output in recent years has been chiefly obtained. At the mines near Rhiw, the ore occurs as a bed of mixed carbonate and silicate from 10 to 20 feet thick, in strata consisting of shales and sandstones of Ordovician age. It is blackened by oxidation near the surface, and contains from 30 to 33 per cent. of manganese.

In Merionethshire, at Llanbedr and Barmouth the ore occurs in the form of a bed at two horizons in the Lower Cambrian (Harlech) grits. The beds are not more than a foot or a foot and a half in thickness, and have a foot-wall of pyritic slate or grit. The ore is massive and fine grained, and when fresh is of a greyish or pinkish colour. It consists of an impure mixture of carbonate and silicate of manganese and contains only about 27 per cent. of the metal. Where exposed, as along the outcrop and in the joints, it is altered to black oxide.

Chile.—Chile was formerly an important producer of manganese ore, and still has many rich deposits in the provinces of Atacama and Coquimbo. The ore has been obtained chiefly in the Carrizal district of the Atacama province, where it occurs as beds of psilomelane in cherty limestone of Mesozoic age.

MERCURY (See Quicksilver).

MOLYBDENUM.

The chief ore mineral of molybdenum is molybdenite (MoS_2), which is frequently found associated with pyrite and chalcopyrite. Wulfenite ($PbMoO_4$) and molybdite ($Fe_2O_3 \cdot 3MoO_3 \cdot 7H_2O$) arise from molybdenite by oxidation and occur as alteration products. Ilsemannite is a rare bluish molybdate, soluble in water, found as an oxidation product in sandstones and associated with decomposing pyrites.

Uses.—Molybdenum ores are utilized for the manufacture of ferro-molybdenum, a steel-hardening alloy, which is used as a rule in conjunction with chromium, nickel, or tungsten. Molybdenum is added to certain of the cobalt-chromium or cobalt-chromium-tungsten alloys known as stellite, in which it acts as a hardener. The metal is used to a small extent in the form of wire for electric lamps. Among other uses of molybdenum ores should be mentioned their application in the chemical trades for the manufacture of ammonium molybdate, and also for the manufacture of certain blue pigments and dyes.

Molybdenite.—*General.*—Hexagonal (fig. 153). Sometimes massive, but usually found in platy or scaly forms resembling those of graphite, with which mineral it is liable to be confused. Perfect basal cleavage. Hardness, 1. Specific gravity, about 4·7. Graphite has a specific gravity about 2·2 and floats lightly on bromoform (2·85), whereas molybdenite sinks heavily in this liquid. When graphite and molybdenite occur mixed with one another, as they sometimes do, they can be separated in this way.

FIG. 153.—Molybdenite, Aldfield, Quebec. (× $\frac{1}{2}$). B.M.

Optical.—Colour, bluish black. The streak has a greenish tinge. Lustre, metallic. Microfragments, opaque.

Chemical and blowpipe.—Molybdenum sulphide (MoS_2) with 60 per cent. of molybdenum. Infusible. Flame coloration, yellowish green. Microcosmic bead green in reducing flame and colourless in oxidizing flame. Heated in open tube yields smell of burning sulphur. On charcoal alone yields a white sublimate with oxidizing flame; the sublimate turns deep blue when touched with the reducing flame—an important distinctive test. When only small flakes are available, too light to withstand the blowpipe treatment, they should be treated on a microscope slide with strong nitric acid. A white oxide is left after evaporating to dryness, and this turns blue when held in the reducing flame.

Molybdite ($Fe_2O_3 \cdot 3MoO_3 \cdot 7H_2O$).—A yellow earthy powder sometimes found as an alteration (oxidation) product associated with molybdenite, especially in the presence of decomposing iron sulphide (marcasite). Contains about 60 per cent. of MoO_3. Yields water copiously when heated in a closed tube, and reacts chemically for iron and molybdenum.

Wulfenite (named after Wulfen, an Austrian metallurgist).

General.—Tetragonal. Crystals usually platy (fig. 154), but occasionally showing pyramidal forms (figs. 155, 156). Fracture, uneven. Hardness, about 3. Specific gravity, about 6·7.

FIG. 154.—Wulfenite.

Optical.—Colour usually yellow, brown, or red. Streak, white. Lustre, adamantine. Microfragments transparent. Refractive index extremely high ($\omega = 2{\cdot}40$). Birefringence very high ($\omega - \epsilon = 0{\cdot}100$). Optical sign, negative. Crystalline plates show a good uniaxial figure with a negative optical sign.

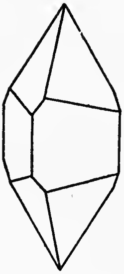

FIG. 155.—Wulfenite.

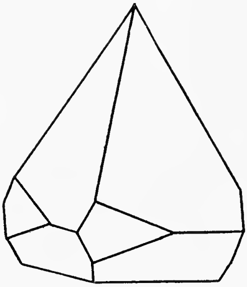

FIG. 156.—Wulfenite.

Chemical and blowpipe.—Lead molybdate ($PbMoO_4$), with about 26 per cent. of molybdenum. Fusibility, 2. Yields metallic lead when reduced with carbonate of soda on charcoal. Decomposed by hot hydrochloric acid, and on adding a little metallic tin to effect reduction the colour of the solution becomes deep blue.

Occurrence and distribution of molybdenum ores.—Molybdenum ores are not mined extensively and the output has been rather irregular. Molybdenite is widely distributed in small amounts associated with pyrites and other sulphides in quartz masses or veins, and granites.

The chief producers are the United States, Australia, Canada, Norway and Sweden, Spain, and Japan.

United States.—A rich deposit of molybdenite has been found and worked near Climax near the Summit County border, Colorado, where it occurs in a matrix of quartz associated with pyrite.

At Catherine Hill, in the State of Maine, molybdenite is found in granite and constitutes about 1·5 per cent. of the rock in certain places. At Cooper, Washington Co., in the same State, molybdenite occurs in veins of pegmatite traversing granites.

An interesting occurrence of molybdenum ore in the United States is that of the Mammoth Mine, in Arizona, where wulfenite occurs in association with auriferous copper ore and constitutes from 1 to 3 per cent. of the crude ore.

Australia.—Important deposits of molybdenite are mined at Wolfram Camp in the Chillagoe district of Queensland. The deposits consist partly of quartz veins in granite and partly of contact deposits along the margin of an intrusion of granite in slate. The molybdenite is associated with wolframite and bismuth.

In New South Wales the ore-bodies assume the shape of quartz pipes traversing granite, and here again bismuth and wolframite are frequently associated with the molybdenite. The ore has been mined chiefly at Whipstick mine near Pambula, Kingsgate mine near Glen Innes, and near Deepwater. The pipes vary from ten to fifty feet in diameter and contain large masses of ore. In some parts of New South Wales molybdenite is associated with cassiterite.

Canada.—Molybdenite occurrences have been actively investigated and developed in various parts of Canada, chiefly at Quyon in Quebec, Lost Creek in British Columbia, and various localities in Ontario, notably near Aldfield and near Renfrew. The molybdenite is found in quartz veins and pegmatites connected with granite intrusions; it is frequently associated with pyrites, pyrrhotite and sometimes biotite.

Norway and Sweden.—At Knaben near Flekkefjord and various other localities in southern Norway, molybdenite occurs in veins of massive quartz and also in hornblende-granites, commonly associated with chalcopyrite and mica. In nearly all these occurrences granite or gneiss is the country rock, but in some localities the molybdenite is found in quartz veins traversing slates.

In Sweden, molybdenite is found associated with chalcopyrite in pegmatite veins that cut across gneisses and schists. Veins of this type having a thickness of several feet have been worked on the island of Ekholmen to the north of Westervik in south-east Sweden.

Japan.—Molybdenite is found at various localities in the provinces of Hida, Bizen, Idzumo, and Yechigo, usually in quartz veins, and invariably associated with granitic intrusions. In some places, as at Shirakawa in Hida, large masses of molybdenite are found in decomposed rock and can be easily extracted.

Spain.—Molybdenite is known to occur at many localities in Spain, but of Spanish deposits of molybdenum ore perhaps the most interesting are those of wulfenite in the province of Granada. The best known deposits are those of the Sierra Nevada about 12 miles from Granada, where wulfenite occurs associated with galena in Triassic limestone.

NICKEL.

The chief ore minerals of nickel are nickeliferous pyrrhotite, in which nickel is usually if not always present as pentlandite {(Fe,Ni)S}, garnierite (a silicate), and niccolite (NiAs). The garnierite deposits of New Caledonia formerly furnished almost the whole of the nickel of commerce; but the discovery of nickeliferous pyrrhotite in great abundance at Sudbury in Ontario was followed by rapid development at that locality, and the Sudbury deposits now yield most of the world's supply of nickel.

Other nickel minerals of some note are millerite (NiS), chloanthite ($NiAs_2$), gersdorffite (NiAsS), zaratite (hydrated carbonate of nickel) and annabergite (hydrated arsenate of nickel). None of these minerals is of much importance as an ore mineral, but annabergite occurs frequently as a green incrustation arising from the decomposition of nickel arsenides, and is on that account of some importance to prospectors as an indicator of the presence of such nickel minerals as niccolite, chloanthite, and gersdorffite.

In connection with the fact that the chief ore mineral of nickel is nickeliferous pyrrhotite, it is worthy of note that there is a nickeliferous variety of pyrite (see remarks below on nickeliferous vanadium ore at Minasragra in Peru and a nickeliferous deposit in the Urals).

Nickel is used chiefly in the form of alloys. Of these the most important are the nickel steels and nickel-chromium steels which are used extensively in bridge building, in the motor-building industry, as well as in the manufacture of armour plate, big guns, and armour-piercing projectiles.

An alloy of iron and nickel containing 36 per cent. of nickel and 0·2 per cent. of carbon, and known by the name of *invar*, has a very low coefficient of expansion. Rods made of it suffer very little change in length for large ranges of temperature, and on that account it is useful for making surveyor's tapes and clock pendulums.

Alloys of nickel, copper, and zinc are used largely under the names of *nickel silver*, *German silver*, *Nevada silver*, and *argentan.*

Monel metal and *cupro-nickel* are alloys of copper and nickel, useful on account of their acid-resisting power.

Pentlandite (named after Mr. Pentland).

General.—Cubic. Usually massive and granular, and found as inclusions in pyrrhotite. Octahedral parting. Hardness, about 4. Specific gravity, about 5. Weakly magnetic when free from pyrrhotite.

Optical.—Colour, pale bronze-yellow. Streak, brownish black. Lustre, metallic. Opaque.

Chemical and blowpipe.—Sulphide of nickel and iron {(Fe,Ni)S}; the amount of nickel is variable, but averages about 20 per cent. Fusibility, 2 ; fuses to a highly magnetic globule. Bead reactions those of nickel and iron. Smell of sulphur dioxide in open tube. Decomposed by nitric acid ; and the solution gives a precipitate of ferric hydrate on adding ammonia.

Pyrrhotite (Gr. *purrhotes*, reddish ; also known as magnetic pyrites).

General.—Probably hexagonal. Occurs in the form of hexagonal plates, but usually found massive. Fracture uneven. Hardness, about 4½. Specific gravity, about 4½. Highly magnetic.

Optical.—Colour usually a bronze-yellow, but sometimes much paler. Lustre, metallic. Streak, greyish black. Opaque.

Chemical and blowpipe.—Sulphide of iron, with a variable but usually small amount of nickel. Pyrrhotite has a composition approximating to that represented by the formula FeS ; there is usually an excess of sulphur over the amount required by this formula, and the formula is frequently written Fe_6S_7. The excess is variable, however, and may be in all cases due to admixture with pyrite, from which pyrrhotite is frequently formed by thermal metamorphism. Fusibility, about 3; readily fused to a black and highly magnetic globule in the reducing flame. Iron bead reactions. Little or no sulphur in closed tube. Smell of sulphur dioxide in open tube. Decomposed by hydrochloric acid, and gives off sulphuretted hydrogen.

Garnierite (named after Jules Garnier, who discovered the New Caledonian nickel ore. Also named genthite and noumeaite).

General.—Amorphous or compact. Occurs in the form of soft earthy masses. Fracture, uneven. Hardness, about 3. Specific gravity, about 2·5, but variable, ranging from about 2·3 to 3.

Optical.—Colour, pale green to dark green. Microfragments transparent and cryptocrystalline in texture. Refractive index about 1·59. Birefringence low.

Chemical and blowpipe.—Composition variable, but essentially a hydrated silicate of magnesium and nickel, containing up to 30 per cent. of nickel. Infusible. Blackens and gives off much water in closed tube. Nickel bead reactions. Becomes magnetic after heating in blowpipe flame on charcoal. Decomposed by hydrochloric acid, but does not yield gelatinous silica.

Niccolite (also named *nickeline, nickelite,* and *copper nickel.* The German name is *Kupfernickel,* meaning false or worthless copper, and was given to the mineral on account of its fancied resemblance to copper. It was from the opprobrious German epithet *nickel* used in this connection that the metal nickel derived its name. It was in the mineral niccolite that Cronstedt first found the metal).

General.—Hexagonal, but usually found in a massive condition. Fracture, uneven. Hardness, 5½. Specific gravity, about 7·5.

Optical.—Colour, pale copper-red. Streak, brownish black. Lustre, metallic. Opaque.

Chemical and blowpipe.—Arsenide of nickel (NiAs), with about 44 per cent. of nickel when pure. It is frequently found mixed with smaltite, cobaltite, and breithauptite (NiSb), and on that account may contain appreciable quantities of cobalt, sulphur, and antimony. Fusibility, 2. Yields a sublimate of arsenic and odour of arsenic in open tube or on charcoal. Decomposed by nitric acid, and yields an apple-green solution.

Millerite (NiS) is rhombohedral, and is usually found as hair-like growths. It is opaque, brassy yellow in colour, and metallic in lustre. It has a hardness of about 3½, and a specific gravity 5·65.

Gersdorffite (NiAsS) is cubic. It is opaque and of metallic lustre, with a white colour, often with a grey tarnish. Hardness, about 5½. Specific gravity, about 6.

Chloanthite ($NiAs_2$) is cubic. It frequently contains cobalt and iron replacing the nickel. Opaque. Tin-white. Lustre, metallic. Hardness, about 6. Specific gravity, about 6·6.

Annabergite ($Ni_3As_2O_8 \cdot 8H_2O$) is an apple-green, earthy alteration product found on weathered specimens of niccolite and other nickel arsenide minerals.

Occurrences and distribution of nickel ores.—Of the world's supply of nickel, 70 per cent. is obtained in Ontario, Canada; the remainder is produced chiefly by New Caledonia, and a little is mined in Norway.

Canada.—The production of nickel ore in Canada is limited to the province of Ontario, and nearly the whole of it is obtained at Sudbury, where nickeliferous pyrrhotite associated with chalcopyrite occurs in a matrix of norite (hypersthene gabbro). This norite forms the lower portion of a huge laccolitic intrusion, the upper portion of which consists of micropegmatite (a fine-grained mixture of quartz and felspar).

The laccolite is enclosed by pre-Cambrian rocks. It has a roof of altered conglomerate. The floor of the laccolite consists of granite and other igneous rocks, as well as various metamorphic rocks. The granite floor is in part intrusive, and the ore-bodies doubtless owe some of their peculiarities to readjustments effected as the result of these later granitic intrusions.

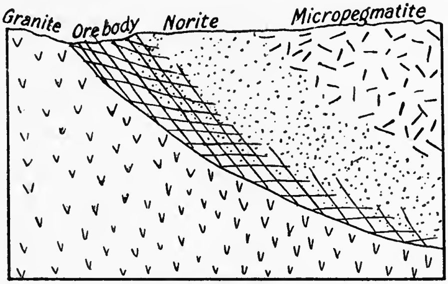

FIG. 157.—Section showing Sudbury nickel deposit (after Coleman).

The Sudbury laccolite is a huge one. It covers an area of over 500 square miles, and its present volume is estimated to be not less than 600 cubic miles. The intrusion is probably of late pre-Cambrian age. It is supposed that the igneous magma became differentiated after injection, forming (1) a lower layer of norite containing nickeliferous pyrrhotite and the other basic minerals which crystallized out first and sank towards the floor of the laccolite, (2) an upper layer of micropegmatite (fig. 157). After intrusion the floor of the laccolite sank somewhat and formed a basin-shaped depression.

The ore-bodies occur partly as irregular masses along the floor of the norite, and partly as pipe-like or sheet-like masses at and near the basic edge of the norite. Some of the Sudbury ore-bodies are of very large size. One at Creighton covered an area of 30,000 sq. ft. and had a depth of over 400 ft. The pipe-like ore-bodies are characterized by a larger percentage of copper and precious metals than are the ordinary masses found along the floor of the norite. The pipes extend to considerable depths, and one has been proved to a depth of over 2000 ft.

The chief sulphide mineral in the Sudbury ore is pyrrhotite, which encloses irregular grains of pentlandite. There is also a considerable amount of chalcopyrite present in the ore. Other minerals that have been observed include millerite, gersdorffite, niccolite, and sperrylite. The sperrylite (platinum arsenide) is scattered in small grains through the chalcopyrite.

The ore as mined contain on the average about 45 per cent. of iron, 3 per cent. of nickel, and 2 per cent. of copper. The percentage of the latter metals is increased by smelting it to a matte which contains about 80 per cent. of copper and nickel, together with 0·02 to 0·3 oz. of gold, 2½ to 7 oz. of silver, and 0·17 to 0·5 oz. of platinum per ton. The matte is partly exported in this condition for further metallurgical treatment.

Nickel is found also in the silver-cobalt ores of the Cobalt district, already described on p. 171. The nickel vein-minerals at this locality are chiefly niccolite and chloanthite, in a matrix of carbonates (calcite and dolomite). Millerite also occurs in the ore, and the weathered portions of the veins frequently contain annabergite. The nickel in the ore of the Cobalt district is not paid for by the smelters.

A third locality in Ontario where nickel ore is found is at the Alexo mine near Matheson, in northern Ontario. The origin of the ore in this case is closely similar to that at Sudbury, but the matrix is serpentine and not norite. The ore-body is situated at the margin of a mass of serpentine intrusive into andesite. The ore minerals consist of pyrrhotite, chalcopyrite, and pentlandite, as at Sudbury.

New Caledonia.—In New Caledonia, notably in the Thio district on the east side of the island, nickel ore occurs abundantly in serpentine which has been formed by the alteration of intrusive peridotites. The ore mineral is garnierite, occurring as veins and concretionary masses in the serpentine. The unaltered olivine rock contains nickel, usually in small amounts, though specimens have been found containing as much as 2½ per cent. of nickel.

The richer garnierite of the veins contains from 20 to 45 per cent. of nickel oxide (NiO), but the ore for the most part is much poorer than this. The ore is obtained in surface quarries, and as produced contains on the average not more than six or seven per cent. of nickel. It is in part smelted locally to obtain a rich matte.

The ultimate product of weathering of the serpentine in New Caledonia is a red lateritic clay and much of this is associated with the nickel ore.

Other Occurrences.—Garnierite deposits closely resembling those of New Caledonia are found at Port Macquarie in New South Wales, and at various localities in Madagascar.

Deposits of nickeliferous pyrrhotite of a promising character and closely resembling those of Sudbury in Ontario, are found in the norite sills of the Insizwa Range in Cape Province, South Africa. These sills are intrusive in Karroo shales. The ore minerals are pyrrhotite, chalcopyrite and pentlandite, and are found chiefly along the floor of the sill, where the rock (picrite) is rich in olivine and poor in felspar as compared with the overlying norite.

A noteworthy occurrence of nickeliferous ore is the rather peculiar type of iron ore at Mayari and other localities on the northern side of Cuba. These nickeliferous iron ores appear to have been formed by the laterization of masses of serpentine containing nickel and chromium. The ore is highly hydrated when freshly quarried, and contains up to 45 per cent. of water. It contains about 1 per cent. of nickel, and between 1 and 2 per cent. of chromium. The dried ore as shipped contains 55·5 per cent. of iron, 4·4 of silica, 14·2 of alumina, 2·1 of chromium, 1 of nickel and only 0·022 of phosphorus. These Cuban ores are smelted in the U.S.A. to obtain a nickel-chromium iron, which, when converted into steel, retains part of the chromium and nearly the whole of the nickel.

At the Flood mine near Evje, and other localities in Norway, deposits similar in character to those of Sudbury and Insizwa are found. The ore obtained near Evje contains on the average 2·3 per cent. of nickel and 1·2 per cent. of copper.

A somewhat unusual type of ore containing nickeliferous pyrites occurs in the Verkhne-Ufalei district south-east of Revdinsk in the Ural region of Russia. It is a carbonaceous deposit containing 14·85 per cent. of fixed carbon, 26·55 of volatile matter, 35·65 of moisture, and 1·69 of nickel and cobalt. The ash obtained by burning this coaly material constitutes over 20 per cent. of the mass, and contains 7·2 per cent. of nickel. The nickel is present in the form of nickeliferous pyrites, presumably similar or closely related to the nickeliferous pyrites (bravoite) found in the vanadium ore (patronite) of Minasragra in Peru (see p. 257).

PALLADIUM.

Palladium is invariably alloyed with native platinum. It occurs also in nickeliferous pyrrhotite. The palladium of commerce is obtained chiefly from the copper-nickel mattes got by smelting the pyrrhotite ore of Sudbury, Ontario (see p. 227). A little is obtained from ordinary copper ore, as in the case of the chalcocite-bornite concentrates of the Saltchuck mine, Ketchikan district, south-east Alaska. Palladium salts are used for photographic purposes. Metallic palladium is used in making surgical and mathematical instruments, and in jewellery.

PLATINUM.

Native platinum is the chief ore mineral of this rare and valuable metal. An appreciable amount of platinum is obtained from nickeliferous pyrrhotite, in which it exists in the form of sperrylite, an arsenide of platinum; but the metal could not be obtained economically from this source except as a by-product. The increased demand for platinum, and the failure to discover new sources of supply, has resulted in a large increase in its value. The supply of platinum has been almost a Russian monopoly, and as there is no prospect of important new sources of supply being discovered, it is not likely that there will be any reduction in value unless some substitute can be found. The substitutes hitherto introduced, such as gold-palladium alloy, stellite, and fused silica, have not so wide a range of usefulness as platinum for chemical ware, and cannot replace it entirely.

Platinum is used extensively in chemical laboratories and in chemical trades on account of its highly acid-resistant character. As a catalyser it is used in the contact process of sulphuric acid manufacture, and in other chemical industries, notably in the manufacture of nitric acid from ammonia. It is used for making roof-plates in dentistry. It is also used in jewellery, and a considerable demand for platinum and platinum-iridium has grown in recent years in the automobile industry for the manufacture of sparking points. Platinum-iridium alloys are used in the electrical industries, chiefly for contact points.

Native Platinum. *General.*—Cubic, but crystals rare, the mineral being found mostly in the form of rounded or irregular grains. The grains are usually small, but a nugget weighing 21 pounds troy has been found in Russia. Hardness, about 4½. Specific gravity, 16 to 19. (The sp. gr. of pure platinum is 21).

Optical.—Colour and streak, light steel-grey. Lustre, metallic. Opaque.

Chemical and blowpipe.—Chiefly platinum, alloyed with variable amounts of iridium, osmium, rhodium, palladium, and iron. Infusible. Insoluble in hydrochloric, sulphuric, and nitric acid, but soluble in aqua regia, from which solution a yellow crystalline precipitate of potassium chloroplatinate is obtained by adding potassium chloride.

Sperrylite (named after Mr. Sperry of Sudbury, Ontario).

General.—Cubic; occurs in the form of small pyritohedral crystals disseminated through nickeliferous pyrrhotite ores. Fracture, conchoidal. Hardness, about 6½. Specific gravity, 10·6.

Optical.—Colour, tin-white. Streak, black. Lustre, metallic. Opaque.

Chemical and blowpipe.—Arsenide of platinum ($PtAs_2$) containing 56·5 per cent. of platinum. Fusibility, 2. Heated in open tube yields a spongy residue of platinum which is insoluble in any single acid. Fuses with ease to a globule on charcoal in blowpipe flame. Soluble in aqua regia.

Occurrence and distribution of platinum.—Most of the world's output of platinum has been obtained in the Ural district of Russia. The amounts contributed by Colombia, New South Wales, the United States, and Canada have been comparatively small.

In the alluvial deposits of the Urals, platinum is sometimes found associated with gold, and sometimes without gold. It is noteworthy that platinum is an original mineral in some peridotites; and in the Urals, where no gold occurs in the platinum-bearing gravels, these gravels can be seen to have been derived from peridotite or serpentine and the associated basic rocks. Where gold occurs this has been derived from quartz veins. The platinum is associated also with chromite, another mineral which occurs frequently in peridotites and serpentines. Other minerals found associated with platinum in alluvial deposits are iridium and osmiridium. The Ural placer deposits contain on the average about 5 dwt. of platinum per ton, but occasionally much richer deposits are found.

The most productive of the Ural placers are those occurring along the Iss and Pura rivers, and these are said to yield about 80 per cent. of the Russian output.

In western Colombia, South America, platinum-bearing gravels occur chiefly in the Choco district; and platinum is also found to a small extent in the gold-bearing gravels of the Barbacoas district farther south.

Platinum is found in gravels at Fifield, in New South Wales; in the gold-bearing gravels and beach-sands of California and Oregon in the United States; in the placers of Seward peninsula, Alaska; and in those of the Tulameen and Similkameen rivers in British Columbia.

In Canada, platinum is obtained from the mattes obtained by smelting the nickel-copper ore of Sudbury, in Ontario. The high-grade mattes contain from 0·2 to 0·5 oz. of platinum metals per ton. (For the geological conditions of this occurrence, see p. 227).

The platinum occurs in the Sudbury copper-nickel ore as sperrylite, embedded in chalcopyrite. Platinum-bearing nickeliferous pyrrhotites are known to occur elsewhere, as in the Insizwa Range of Cape Province in South Africa. Considerable amounts of platinum are obtained from the Sudbury mattes, but the Insizwa deposits have not been worked hitherto as a source of nickel.

Platinum is reported to occur in the highlands of Ronda, Malaga province, Spain, where there is an abundant development of serpentinized peridotites. The platinum is associated with chromite, and is concentrated in the basal layer of the surface gravels.

Platinum is associated with gold and osmiridium in the island of Borneo.

QUICKSILVER (MERCURY).

The only ore mineral of quicksilver of importance is cinnabar (HgS). The black cubic variety of sulphide of mercury (metacinnabarite) is sometimes found associated with cinnabar. Also associated with cinnabar, and arising from it by alteration, native quicksilver is occasionally found.

Cinnabar (a word of ancient origin; used also of a red resinous juice, otherwise called Dragon's blood, obtained from certain trees in the East Indies).

General.—Trigonal, but usually found disseminated through rocks in a massive granular form. Cleavage, perfect, parallel to faces of hexagonal prism. Fracture, uneven. Hardness, about 2½. Specific gravity about 8·1.

Optical.—Colour usually cochineal-red, but sometimes brownish and occasionally black. Streak, scarlet. The lustre of crystals is adamantine, but massive varieties have often a dull appearance. Microfragments transparent. Refractive index exceptionally high ($\epsilon = 3{\cdot}2$). Birefringence exceptionally high ($\epsilon - \omega = 0{\cdot}347$). Optical sign, positive.

Chemical and blowpipe.—Sulphide of mercury (HgS), with 86·2 per cent. of mercury. Fusibility, about 1½. Volatile. In a closed tube yields a black sublimate of sulphide of mercury, and when mixed with a little dry sodium carbonate a deposit of metallic mercury. In open tube yields sulphur dioxide, and globules of mercury. Decomposed by nitric acid.

Uses.—Mercury amalgamates with gold, silver, and some other metals, and is used extensively in the gold-mining industry to extract gold from its ores. Quicksilver finds another important use in making thermometers, barometers, and other scientific instruments. The red sulphide is the pigment known commercially as vermilion. The chlorides calomel and corrosive sublimate are useful chemicals, and fulminating mercury is a useful explosive.

Occurrence and distribution.—Spain is the chief producer of quicksilver ore. Italy, the United States, Austria, and Mexico also produce considerable amounts. The amounts produced in Russia, China, Turkey, Peru, and Algeria are comparatively small.

SPAIN.—The most productive quicksilver mines in the world are those of Almaden in the province of Ciudad Real, southern Spain. The predominant rocks of the district are highly inclined slates and quartzites, into which dolerites are intrusive. The ore mineral is cinnabar, occurring as an impregnation of the quartzite beds. There are three of these quartzites beds, each about 25 feet thick, separated from one another by beds of slate. Ore containing over 80 per cent. of quicksilver has been obtained from these quartzites. At the present time it is stated that the ore carries on the average about 8 per cent. of quicksilver; and though this is poor in comparison with much of the ore that has been obtained at Almaden it is rich in comparison with ore that is mined elsewhere. The cinnabar at Almaden is associated with native mercury, pyrite, and chalcopyrite, together with small amounts of barite and bituminous matter.

At La Pena, in the province of Asturias, various Carboniferous sediments carry impregnations of cinnabar, associated with small amounts of metacinnabarite, amalgam, realgar, and orpiment. These ores are poor in comparison with those of Almaden, and usually contain only about 0·7 per cent. of quicksilver.

ITALY.—Quicksilver ores are mined in the district of Monte Amiata in southern Tuscany, where they occur as an impregnation of clays of Upper Lias age. The cinnabar is associated with pyrites and gypsum. The rock was originally a clayey limestone, and the cinnabar is supposed to have been deposited in the rock by acid solutions which converted the limestone into gypsum. Cinnabar also occurs among Eocene limestones near the contact of these with trachytic intrusions. In the Monte Amiata district, ores yielding only from 0·2 to 0·3 per cent. of quicksilver are worked at a profit.

UNITED STATES.—Most of the United States quicksilver ore is produced in California; the amounts mined in Texas, Nevada, and Oregon are comparatively small.

At New Idria in San Benito Co., California, the ores occur in folded Cretaceous slates and sandstones. There are numerous igneous intrusions in these, and the ores, which occur as veins and impregnations, appear to be frequently associated with andesites and basalts.

At New Almaden, in Santa Clara Co., there is an ore-body carrying cinnabar at the contact of sediments with serpentine and other intrusions;

the cinnabar is associated with quicksilver, pyrite, chalcopyrite, quartz, calcite, dolomite, and magnesite. The Santa Clara Co. ores contain on the average about 0·4 per cent. of quicksilver as smelted.

Elsewhere in California cinnabar is associated with antimonite, arsenopyrite, bitumen, and sulphur.

In the Terlingua district of Brewster Co., Texas, cinnabar occurs associated with native mercury, calcite, and haematite in Cretaceous limestones and shales that are traversed by Tertiary igneous intrusions. The Texas ores yield about 1·7 per cent. of mercury as smelted. In Nevada a richer ore is obtained, yielding 7½ per cent. of mercury as smelted, but the deposits are small.

AUSTRIA.—There are important quicksilver mines at Idria in Carniola. The ore is found chiefly as impregnations and pockets in dolomitic limestones, shales, and slates of Triassic age. The cinnabar occurs in a matrix of quartz, calcite, and dolomite, associated with native mercury, pyrite, barite, fluorite, and bituminous matter.

MEXICO.—Rich deposits of mercury ore are found in the State of San Luis Potosi, in folded limestones which are traversed by granite and porphyry intrusions. At the Guadalupana mine the cinnabar is associated with calcite, gypsum, barite, and fluorite, and the ore contains about 10 per cent. of quicksilver.

Elsewhere in Mexico, as in the State of Guerrero at Huitzuco, cinnabar is associated with metacinnabarite, sulphur, and bituminous matter.

RUSSIA.—Mercury ores are mined at Nikitovka in the Ekaterinoslav district of southern Russia, where they are found in sandstones of Carboniferous age. The cinnabar is associated with sulphur and antimonite, and the ore contains from 0·4 to 1·1 per cent. of mercury.

SERBIA.—Noteworthy deposits of quicksilver ore have been mined at Mont Avala, some miles to the south of Belgrade in Serbia, where a peridotite that is intrusive in Cretaceous limestone has been altered to serpentine. The serpentine is cut by quartz veins, and associated with these quartz veins are impregnations of cinnabar and galena. The ore contains on the average from one to two per cent. of quicksilver.

SILVER.

The chief ore minerals of silver are argentiferous galena, native silver, argentite, pyrargyrite, proustite, stephanite, tetrahedrite, and kerargyrite. The minerals embolite $Ag(Cl, Br)$ and polybasite $9(Ag, Cu)_2S . Sb_2S_3$ are comparatively unimportant, whilst bromyrite ($AgBr$) and iodyrite (AgI) are rare. For a description of argentiferous galena, see p. 203 and tetrahedrite, p. 174.

Native Silver. *General.*—Cubic, but generally found in massive, wiry, and arborescent forms (fig. 158). Hardness, 3. Specific gravity, about 10·5. Malleable.

Optical.—Colour, white when fresh, but readily tarnished. Streak, white. Lustre, metallic. Opaque.

Blowpipe and chemical.—Consists of silver, alloyed as a rule with a little gold and copper. Fusibility, 2. Dissolves in nitric acid, and the solution gives a white precipitate on adding hydrochloric acid.

Argentite (L. *argentum*, silver. Also named silver-glance).

General.—Cubic, crystallizing in cubes, but usually found massive or in the form of arborescent growths. Fracture, uneven. Hardness, about 2½. Specific gravity, about 7·2.

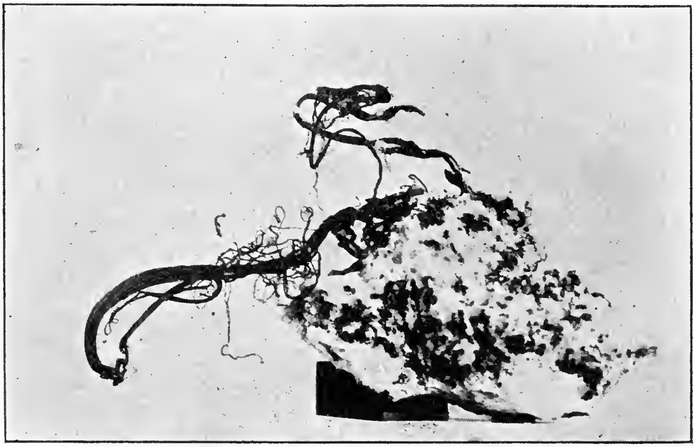

FIG. 158.—Wiry silver, Guanajuato, Mexico. (× ½). B.M.

Optical.—Colour and streak, a very dark lead-grey, nearly black. Lustre, metallic. Opaque.

Chemical and blowpipe.—Sulphide of silver (Ag_2S) with 87·1 per cent. of silver. Fusibility, 1½. Smell of sulphur dioxide in open tube. Fuses with extreme readiness in blowpipe flame on charcoal and yields a malleable residue of silver in oxidizing flame.

Pyrargyrite (Gr. *pyr*, fire and *argyros*, silver. Also named ruby-silver or dark-red silver-ore).

General.—Trigonal, frequently showing form of a hexagonal prism capped by rhombohedral planes. Also massive. Fracture, conchoidal. Hardness, about 2½. Specific gravity, about 5·8.

Optical.—Colour, cochineal-red to reddish black. Streak, cochineal-red. Lustre, metallic-adamantine. Microfragments red and transparent, with an extremely high refractive index ($\omega = 3{\cdot}08$). Birefringence extremely high ($\omega - \epsilon = 0{\cdot}20$). Optical sign, negative.

Chemical and blowpipe.—Sulphide of silver and antimony ($3Ag_2S \cdot Sb_2S_3$) with 59·8 per cent. of silver. Fusibility, 1. Smell of sulphur dioxide in open tube, and a sublimate of antimony oxide. In blowpipe flame on charcoal fuses with extreme readiness to a globule of silver sulphide, which yields a bead of silver in oxidizing flame. Decomposed by nitric acid, with separation of sulphur and antimony oxide.

Proustite (named after Proust, a French chemist. Also named ruby-silver or light-red silver-ore).

General.—Trigonal, and isomorphous with pyrargyrite, which it resembles. Also found in massive granular forms. Fracture, uneven to conchoidal. Hardness, about 2½. Specific gravity, about 5·6.

Optical.—Colour, scarlet-vermilion. Streak, scarlet. Lustre, adamantine. Microfragments transparent, with an extremely high refractive index ($\omega = 2{\cdot}98$). Birefringence extremely high ($\omega - \epsilon = 0{\cdot}27$). Optical sign, negative.

Blowpipe and chemical.—Sulphide of silver and arsenic ($3Ag_2S \cdot As_2S_3$) with 65·95 per cent. of silver. Fusibility, 1. In closed tube yields a sublimate of arsenic sulphide. Smell of sulphur dioxide in open tube and a sublimate of arsenic, which is more volatile than that of the antimony oxide yielded by pyrargyrite. On charcoal yields a button of metallic silver. Decomposed by nitric acid, with separation of sulphur.

Stephanite (named after Archduke Stephen of Austria. Also called brittle silver-ore).

General.—Orthorhombic; in flat or elongated six-sided prisms, terminated by basal plane; but usually massive, and compact, or in a disseminated form. Fracture, conchoidal or uneven. Hardness, 2½. Specific gravity, about 6·2.

Optical.—Colour, greyish black. Streak, greyish black. Lustre, metallic. Opaque.

Chemical and blowpipe.—Sulphide of silver and antimony ($5Ag_2S \cdot Sb_2S_3$), with 68·5 per cent. of silver. Fusibility, 1. Charcoal reactions, and chemical behaviour generally, like those for pyrargyrite.

Polybasite (Gr. *polys*, many, and *basis*, base, signifying the presence of many metallic bases).

General.—Monoclinic, with tabular crystals simulating hexagonal form. Also massive and disseminated. Fracture, uneven. Hardness, 2½. Specific gravity, about 6·2.

Optical.—Colour and streak, iron-black. Lustre, metallic. Microfragments translucent and reddish, with a very high refractive index, exceeding 1·9.

Chemical and blowpipe.—Sulphide of silver, copper and antimony $\{9(Ag, Cu)_2S \cdot Sb_2S_3\}$, with about 70 per cent. of silver. The corresponding and isomorphous arsenic mineral is pearceite, with which polybasite is usually isomorphously mixed. Fusibility, 1. Charcoal reactions much like those of pyrargyrite, but yields also copper reactions.

Kerargyrite (Gr. *keras*, horn, and *argyros*, silver. Also called horn-silver, from its horny appearance).

General.—Cubic, but usually massive and often encrusting. Hardness, about 2. Specific gravity, about 5·5.

Optical.—Colourless, pale grey, greenish or bluish. Darkens on exposure to light. Lustre, resinous to adamantine. Microfragments translucent and show a very high refractive index, exceeding 2. Isotropic.

Chemical and blowpipe.—Silver chloride ($AgCl$) containing 75 per cent. of silver. Fusibility, about 1. In a bead of microcosmic salt it yields a fine azure-blue flame on adding copper oxide, indicating the presence of chlorine. Fuses with extreme readiness on charcoal, yielding a button of silver. Insoluble in acids, but soluble in ammonium hydrate.

Occurrence and distribution of silver ores.—Of the world's total output of silver, about 75 per cent. is contributed by Mexico, the United States, and Canada. About 20 per cent. is produced by Australia, Germany, Peru, Chile, Japan, Spain, and Bolivia. The remaining 5 per cent. is produced chiefly in Central America, France, Austria, Africa, Colombia, Greece, Italy, and the British Isles.

MEXICO.—In silver production, Mexico leads easily. Perhaps the most notable of the Mexican occurrences is that of the Veta Madre, in the Guanajuato district, which has a length of about 3 miles and reaches a width of 150 feet in places. This quartz lode lies at the junction of Palæozoic slates with younger conglomerates and rhyolitic tuffs, and its origin is probably bound up with that of the rhyolitic and andesitic eruptive masses which form an important feature in the geology of the district. The mineralization appears to have taken place during the closing phase of a mid-Tertiary period of eruptive activity. The silver ore minerals in the Veta Madre are native silver, argentite, pyrargyrite, and stephanite, and associated with these are native gold, galena, zinc-blende, and fluorite.

North-west of Guanajuato are the important silver mines of the

Zacatecas district, where the ores occur under geological conditions much like those of the Guanajuato district. In the Zacatecas district there is a rich development of oxidized ore, containing kerargyrite and embolite. In some places the veins contain an abundance of pyrargyrite and proustite.

In the Real del Monte district the silver ores are found in rhyolitic and andesitic rocks, which are cut by later basalts; but the mineralization appears to have been effected by the acid intrusives. The veinstuff is largely quartz; the ore minerals are native silver, stephanite, and pyrargyrite, associated with chalcopyrite and zinc-blende.

Other important silver-mining districts in Mexico include Mapimi, Rosario, and Carmen.

United States.—The silver output of the United States is chiefly limited to the western States, in the Rocky Mountain region. The States of Utah, Montana, Nevada, Idaho, and Colorado together produce about 86 per cent. of the total for the United States, and the remainder is contributed chiefly by California, Arizona, and New Mexico.

A large part of the silver output of the United States is derived from the silver-lead ores which occur abundantly in Utah, Colorado, and Idaho, and which have already been dealt with under lead ores (see p. 208).

At other localities in Utah, Montana, and Colorado, silver is obtained from auriferous copper ores which occur as replacement deposits in granite and other igneous rocks, and these also have contributed largely to the output. The silver ores of the Butte district in Montana are of this type and have yielded large amounts of silver. (For an account of the Butte ores, see p. 178).

In various parts of Nevada, Montana, Colorado, and California, quartz veins carrying silver minerals traverse basic granites and various Tertiary lavas. The silver ore minerals in these veins include stephanite, pyrargyrite, proustite, polybasite, and tetrahedrite. They are associated with galena, zinc-blende, pyrite, and chalcopyrite, and the veins are sometimes auriferous. One of the most famous lodes of this type is the Comstock lode of Nevada, which has yielded enormous amounts of gold and silver, and in which the chief ore minerals are argentite stephanite, polybasite, and native gold.

At Mercur in Utah, there are two sill-like intrusions of quartz-porphyry in Carboniferous limestone. The upper of these sills carries gold ore on its under surface, and has been referred to on p. 188. On the under side of the lower sill there is a body of silver ore carrying the minerals kerargyrite and argentiferous antimonite, and the limestone where they occur is silicified.

Canada.—Although much silver is obtained from the argentiferous lead ores of British Columbia (see p. 266), and from the copper ores of the same province, Ontario is responsible for the chief part of the Canadian output of silver ore, and most of this is obtained from the mines of the Cobalt district. For some years this has been the most productive silver-mining district in the world, and has contributed a considerable percentage of the world's recent output. At Cobalt the veins lie chiefly at and near the contact of a series of conglomerates, sandstones, and slates, with a sill of dolerite. The chief minerals of these silver-nickel-arsenic-cobalt ore deposits are native silver and argentite, associated with smaltite, niccolite, cobaltite, and native bismuth in a matrix of calcite and dolomite. Much of the ore mined has contained on the average about 4 per cent. of silver, together with about 3½ per cent. of nickel, 5½ of cobalt, and 25½ of arsenic. This percentage of silver corresponds to about 1000 oz. per ton of ore. Some consignments have been much richer than this, and ore containing as much as 7402 oz. per ton has been obtained. The amount of silver in the dressed ore is less now than it was a few years ago, and is stated to contain from 300 to 1000 oz. per ton. For a fuller account of the conditions of occurrence of the Cobalt ores, see p. 227.

Other Localities.—In Peru, Bolivia, and Chile, silver minerals occur in association with argentiferous galena, zinc-blende, and copper sulphides. Silver is recovered from copper mattes obtained by smelting argentiferous copper ores in the departments of Lima and Junin in Peru. The association of silver ore minerals with cassiterite in the Bolivian tin ores is referred to on p. 245. The occurrence of zinc-lead ore rich in silver in the Laurium district of Greece is referred to on p. 266; Tasmania on p.264; Burma on p. 267; and Japan on p. 267. Numerous occurrences of argentiferous galena are dealt with under lead ores (pp. 208-211), notably those of Broken Hill in New South Wales, and those of Spain, Germany, and the British Isles. The amount of silver in argentiferous lead ores is very variable in amount. In the British Isles, the amount of silver in dressed lead ore averages on the year's output about 5 oz. of silver per ton of ore. The richest are those of the Great Laxey mine, in the Isle of Man, which have recently contained over 40 oz. of silver per ton of dressed lead ore.

TANTALUM.

The only ore mineral of tantalum is tantalite (Fe, Mn)(Ta, Cb)$_2$O$_6$. Many other minerals contain tantalum, but they are either too rare or contain amounts too small to make them of any value in competition with tantalite. By increase in the amount of columbium, tantalite grades into columbite, in typical specimens of which columbium (niobium) is greatly in excess of tantalum; such columbite is of no value as tantalum ore, which requires to contain at least 60 per cent. of Ta_2O_5, not more than 3 per cent. of Cb_2O_5, and no chromium.

Metallic tantalum has been used in the manufacture of filaments of electric lamps. Very little is required for this purpose. One pound (avoirdupois) of the metal suffices for the manufacture of over 20,000 lamps, and it is easy to understand that the requirements for this purpose alone are not sufficient to create a steady demand for the ore. Experiments have been made to test the utility of tantalum as a steel-hardener, but hitherto there appears not to have been any considerable demand for this purpose.

Tantalite.—*General.*—Orthorhombic, and occurs frequently in the form of prismatic crystals. Fracture, uneven. Hardness, about 6½. Specific gravity variable; varieties rich in tantalum range from 7 to 8. (Columbite rich in columbium ranges in sp. gr. from 5·3 to about 6).

Optical.—Colour and streak black. Lustre, submetallic. Microfragments usually opaque.

Chemical and blowpipe.—Tantalate of iron and manganese with some columbium $\{(Fe, Mn)(Ta, Cb)_2O_6\}$, containing from 60 to 80 per cent. of Ta_2O_5. Infusible. Gives iron reaction in borax bead, and the bead becomes greyish or cloudy if saturated. Gives a greenish blue sodium carbonate bead due to manganese. When fused in potassium bisulphate and dissolved in hydrochloric acid with addition of tin or zinc, it may yield a pale blue colour due to columbium; but this reaction is not so pronounced for tantalite as for columbite, and yields no coloration when the percentage of niobium is very low. Insoluble in acids.

Occurrence and distribution.—Tantalite and columbite are not uncommon as constituents of cassiterite-bearing pegmatite veins, but the chief localities are the Black Hills of South Dakota, U.S.A., and Greenbushes and Wodgina in Western Australia, from both of which regions tantalite for economic use has been obtained.

South Dakota.—In the Black Hills of South Dakota, pegmatites carrying tantalite, columbite, cassiterite, and wolframite traverse pre-Cambrian schists. The pegmatites are offshoots from the pre-Cambrian intrusions of granite which form the central mass of the Black Hills. The tantalite occurs abundantly near Keystone, where it has been mined.

Western Australia.—Tantalite has been mined at Greenbushes and Wodgina in Western Australia. Here also the tantalite (chiefly mangano-tantalite containing little or no iron) occurs in pegmatites associated with granites that are intrusive in pre-Cambrian schists. The output is small and irregular, as there is little demand. The total output during a period of about 15 years has amounted to only about 150 tons, and most of this has been obtained from the surface residual and alluvial deposits that occur in the neighbourhood of the pegmatites.

TIN.

The chief and almost the only ore mineral of tin is cassiterite, the dioxide of tin (SnO_2). The mineral stannite (L. *stannum*, tin), a sulphide of copper, iron, and tin (Cu_2FeSnS_4), is of little significance as an ore mineral. Native tin has been reported to occur in various localities, but none of these has been proved to be a genuine natural occurrence. In all cases where metallic tin has been found it has probably arisen from smelting operations.

Tin is used in the manufacture of tin-plate. It is an essential constituent of many useful alloys, notably type metal, soft solder, pewter, Britannia metal, gun metal, bell metal, bronze, and various fusible alloys.

Cassiterite (Gr. *cassiteros*, tin. Also called tinstone).

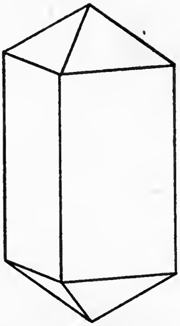

Fig. 159.—Cassiterite.

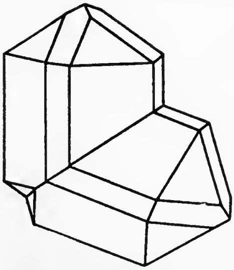

Fig. 160.—Cassiterite.

General.—Tetragonal, frequently in the form of prisms terminated by pyramids (fig. 159). Crystals frequently twinned on pyramid face (fig. 160). Also in granular masses, and sometimes finely disseminated. Occasionally fibrous with a texture resembling that of wood, and then known as "wood-tin." Fracture, uneven. Hardness, 6½. Specific gravity, about 7.

Optical.—Sometimes white or colourless; but more often black or brown. A red variety is known as "ruby-tin." "Rosin-tin" is a yellow variety. Colour when powdered, usually pale brown. Lustre, adamantine. Microfragments transparent, and have a very high refractive index ($\epsilon = 2{\cdot}09$). Birefringence very high ($\epsilon - \omega$ about 0·10). Optical sign, positive. Usually pleochroic, and sometimes very strongly so (reddish brown to nearly colourless), the extraordinary ray being the one more absorbed.

Chemical and blowpipe.—Dioxide of tin (SnO_2), and when pure contains 78·6 per cent. of tin. A little iron oxide is usually present, and it is to this that the dark colour and pleochroism are due. Infusible. On charcoal, powdered cassiterite is readily reduced to metallic tin if mixed with sodium carbonate and powdered charcoal. After a little practice a small grain of cassiterite can readily be reduced to one of metallic tin in the tip of a good reducing blowpipe flame on charcoal. This can be done without the addition of fluxes, but the grain is made more secure by placing it on a thin layer of fused sodium carbonate. A transparent grain of cassiterite becomes opaque and metallic-looking when treated with a few drops of hydrochloric acid on a zinc plate, owing to the formation of a layer of metallic tin on the surface of the grain. This is a very useful test for cassiterite; the metallic layer is easily dissolved off by hydrochloric acid and in the case of microfragments the transparency is restored. Cassiterite is insoluble in acids.

Stannite or **Tin-Pyrites** is a sulphide of copper, tin, and iron

$$(Cu_2S \cdot FeS \cdot SnS_2);$$

it contains about 29½ per cent. of copper and 27½ of tin when pure. Found usually in granular and massive form. Lustre, metallic. Colour steel-grey. Streak, black. Hardness, 4. Specific gravity, about 4·4. Reacts for tin and copper. Fuses very readily to a magnetic globule (Fus. 1½).

Occurrence and distribution of tin ore.—Of the total world's production of tin ore, about 80 per cent. is contributed by the Federated and other Malay States, Bolivia, and the Dutch East Indies. The remainder is produced chiefly in England, Australia, China, Siam, Burma, and Africa.

FEDERATED MALAY STATES.—Tin ore is abundantly distributed in the Malay Peninsula. It occurs to some extent in the native states; and it is mined to a considerable extent in Malacca, one of the Straits Settlements. It is, however, the Federated Malay States that make the chief contribution, notably the States of Perak and Selangor; the output of the States of Pahang and Negri Sembilan is comparatively small. The ore is obtained chiefly from alluvial deposits that have been derived from the disintegration of the older rocks of the Peninsula. These rocks consist of slates, schists and crystalline limestones, into which granites are intrusive.

The tin ores were introduced with the granite intrusion and were deposited for the most part in the surrounding sedimentary rocks. The region is notable as furnishing an example of the deposition of tin ore in crystalline limestone, this feature being well exemplified in the crystalline limestone of the Kinta district in Perak (fig. 161). The primary veins in the limestone have a matrix of calcite. The veins are in some places very rich in cassiterite, with little or no other associated minerals; but as a rule pyrite, chalcopyrite, arsenopyrite, and fluorite are found in the veins. An interesting feature is provided by the occurrence of primary pipes of tin ore in the limestone. The ore of these pipes, like that of the veins, consists of cassiterite and sulphides in a matrix of calcite. Another interesting feature of the limestone deposits is the occurrence of secondary pipes infilled by the weathering residues of the limestone. The presence of cassiterite makes these pipe infillings valuable as tin ore.

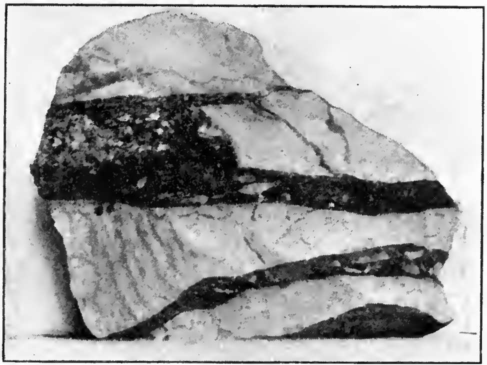

FIG. 161.—Veins of tin ore in limestone, F.M.S. ($\times \frac{1}{6}$). B.M.

Tin ore also occurs in the form of disseminations, veins, and pockets in the granite, associated with quartz, tourmaline, and topaz. At one locality a pipe of tin ore in granite has been worked. This pipe resembles those occurring in the Waterberg tinfield of the Transvaal (see below).

Most of the Malay tin-ore has, however, been obtained from the alluvial or detrital deposits that have been derived from the disintegration of the vein formations by weathering and denudation. These deposits occur superficially for the most part and are easily worked. The minerals commonly found associated with cassiterite in the alluvial deposits include ilmenite, arsenopyrite, wolframite, monazite, topaz, and tourmaline.

Dutch East Indies, Siam, Burma, and China.—The granitic ridge which forms the backbone of the Federated Malay States stretches southwards into the islands of Banka and Billiton in the Dutch Indies, and northward into Burma, Siam and the province of Yunnan in China; and in all these areas the granitic intrusions are associated with deposits of tin ore.

Banka and Billiton have contributed large supplies of tin ore. Here the origin and mode of occurrence of the alluvial deposits are much the same as in the Federated Malay States. The tinstone alluvium forms a bed about 3 feet thick lying on the granites and slates, and is surmounted by a layer of clayey and sandy overburden, the thickness of which averages about 30 feet.

In Siam and Burma also the mining has been largely alluvial. In Burma, the chief districts are those of Mergui and Tavoy, where granites are intrusive in slates and quartzites. The tin ore (cassiterite) is found as a constituent of stringers, veins, and pegmatites, associated with granitic intrusions; but it occurs also in the surface alluvium derived from these. The cassiterite is associated with wolframite.

In China, tin ore is found abundantly in the province of Yunnan, notably in the Mengtze district, where cassiterite is associated with pyrite and chalcopyrite in limestones that are supposed to be of Permo-Triassic age. Granite intrusions have penetrated these limestones, which contain veins and pipes of tin ore. In the weathering zone the limestone is traversed by fissures, and the red clay filling these fissures and other cavities contains cassiterite. The conditions of occurrence in Yunnan thus recall those met with in various parts of the Kinta limestone deposits of Perak (see above).

Bolivia.—The Bolivian tin-ore deposits are confined to the Eastern Cordillera of the Andes, with the chief mining centres at Potosi, Oruro, Quimza Cruz, and La Paz. A peculiar feature of the Bolivian ores is their association with ores of silver, as for example, at Potosi and Oruro. It used to be thought that the Bolivian ores had a mode of origin different from that of ores elsewhere, but it is now known that they are impregnation deposits of the usual type, and that the tin ore has been introduced by a granitic magma which has invaded, metamorphosed, and mineralized the surrounding rocks.

In the Quimza Cruz tin-field, the prevailing rocks are Devonian quartzites and quartz-schists with intrusions of granite and quartz-porphyry. The veins of tin ore occur in the quartzites and quartz-schists, and the cassiterite is associated with quartz, tourmaline, zincblende, pyrite, and chalybite.

In the Oruro district, andesitic volcanic rocks are abundant, in addition to the quartz-schists and quartz-porphyries; but here again the cassiterite occurs in the quartz-schists and appears to have no connection with the andesites. In this district, as at Potosi, the cassiterite is associated with bismuthinite, wolframite, and silver ores.

Many of the Bolivian vein-deposits are very rich; they commonly carry an average of 20 per cent. or more of tin oxide, and some of the veins consist of almost solid cassiterite. These rich occurrences are, however, in Bolivia as elsewhere, apt to be in the nature of local patches or thin veins, and cannot as a rule be depended upon so much as the disseminated types of occurrence, which, though usually poor in value and yielding perhaps not more than one or two per cent. of cassiterite, are more persistent and constant in their yield.

AUSTRALIA.—Australian tin-ores are mined chiefly in Tasmania, Queensland, and New South Wales, and to a smaller extent in Western Australia.

In Tasmania, one of the most productive mines is that of Mt. Bischoff, where the rocks consist of slates and quartzites into which granite and quartz-porphyry are intrusive. The cassiterite occurs both as veins in the slate and as impregnations in the quartz-porphyry. The associated minerals are quartz, topaz, tourmaline, fluorite, pyrite, arsenopyrite and wolframite. The ore is of low grade; it contains on the average only about 1¼ per cent. of cassiterite and is mined by open quarries. At the Anchor tin mines the ore is still poorer and consists of cassiterite disseminated in granite; the ore at this mine does not contain on the average more than one per cent. of cassiterite. Near Middlesex, in Tasmania, cassiterite is associated with bismuthinite and wolframite in quartz-topaz veins that traverse a metamorphosed limestone; and these veins are being worked as a source of bismuth, tin, and tungsten. In some of the vein deposits of the Zeehan district both cassiterite and stannite occur, associated with numerous other minerals, including pyrite, chalcopyrite, galena, wolframite, bismuthinite, and tetrahedrite.

In Queensland, the chief tin-mining localities are those of Herberton and Stanthorpe. In the Herberton tin-field, granite and quartz-porphyries occur intrusive in sedimentary rocks (slates, etc.). The cassiterite occurs in veins associated with wolframite, scheelite, bismuth, bismuthinite, antimonite, arsenopyrite, chalcopyrite, galena, fluorite, topaz, tourmaline, and monazite. The veins in the Herberton district are fairly rich and carry on the average about 12 per cent. of tin. In the Stanthorpe district the mining is alluvial.

In New South Wales, notable deposits of tin ore occur at Tingha and Emmaville in the New England district. Here, cassiterite occurs in numerous veins that traverse the granite, but it is the alluvial deposits derived from these that have been mined. A peculiar feature of the New South Wales alluvial deposits is that the gravels containing the cassiterite occur in the form of deep leads and are covered by flows of basalt. At Emmaville, alluvial deposits that were thought to have been exhausted are worked profitably by dredging.

In Western Australia, tin ore is mined at Pilbara and Greenbushes. Cassiterite occurs in granite, pegmatite dykes, and surface weathering residues at these localities, but almost the whole of the tin ore so far obtained has been won from alluvial deposits. At Greenbushes the minerals associated with the cassiterite include tourmaline, topaz, tantalite, and gold.

AFRICA.—There are notable deposits of tin ore in Nigeria, Transvaal, Swaziland, and South-West Africa.

In the province of Bauchi, Northern Nigeria, tin ore is abundant, and has been derived by disintegration from the cassiterite-bearing pegmatites that traverse the underlying granite and metamorphic rocks. In the alluvium the cassiterite is associated with ilmenite, topaz, columbite, and monazite. Somewhat similar alluvial deposits, in which cassiterite is associated with ilmenite, columbite, and monazite, occur in the Oban Hills of Southern Nigeria, where, as usual, intrusive granites and quartz-porphyries occur.

In the Transvaal, tin ores are mined in the Waterberg, Rooiberg, and Potgietersrust districts. In the Waterberg and Rooiberg districts tin ore occurs in the red granite, and also in the Lower Waterberg shales, quartzites, and felsites, into which the granite is intrusive. The Transvaal deposits are remarkable for the abundance of primary pipe-deposits in the granite; but stockworks, quartz veins, and disseminations are also represented. Among these Transvaal deposits the minerals associated with the cassiterite include quartz, tourmaline, fluorite, arsenopyrite, pyrite, chalcopyrite, zinc-blende, galena, and molybdenite.

In northern Swaziland, granites are intrusive in schists, and the schists are traversed by stanniferous pegmatites. In the alluvial deposits of the Mbabane and other rivers, which have been the chief source of the tin ore, the cassiterite is associated with corundum and monazite.

Stanniferous pegmatites are found traversing schists in the Erongo mountain district of South-West Africa, and tin ore is obtained from the surface gravels of this district. Somewhat similar stanniferous pegmatites occur at Katanga in the Congo Territory.

England.—In Cornwall and Devonshire, tin-ore deposits are found in an area occupied by Palæozoic sediments (Ordovician, Devonian and Carboniferous) that have been invaded and metamorphosed on an extensive scale by intrusions of granite and quartz-porphyry. The tin ore occurs to some extent disseminated in the granites, but occurs chiefly in the altered sediments (killas), and is particularly abundant in the contact-metamorphosed zone around the granite intrusion. The cassiterite is associated with wolframite, pyrite, chalcopyrite, arsenopyrite, tourmaline, fluorite, and various other minerals. The cassiterite of the Cornish ore is mostly in a very finely divided condition in the impregnated rock, and the ore has to be crushed very fine and elaborately dressed before the cassiterite can be obtained in a sufficiently concentrated condition.

TITANIUM.

The ore minerals of titanium are rutile (TiO_2) and ilmenite ($FeTiO_3$). These two minerals are abundantly distributed in many different varieties of rocks, but are usually present in small quantities.

Titanium is used in making titanium carbide electrodes for arc-lamps, and a little is used in the pottery trade. In the form of a titanium oxalate it is used as a mordant in dyeing leather and wool. The alloy ferro-titanium is used in steel manufacture to slag off the nitrogen and thus improve the quality of the steel. In the manufacture of brass, cupro-titanium is used. Titanium tetrachloride has been used to produce smoke-clouds for war purposes. Amorphous titanic acid has come into use in recent years as a white pigment, for which purpose it is claimed to be superior to zinc-white in covering power. The product is manufactured at Fredrikstad, on the south coast of Norway, from ilmenite occurring in the district. The ilmenite is decomposed with sulphuric acid, and the titanium-white is afterwards separated.

Rutile (L. *rutilus*, red inclining to yellow).

General.—Tetragonal. Often shows good tetragonal crystals in which prisms are combined with pyramids, as in cassiterite (fig. 159). These crystals are often twinned on a pyramid face to yield geniculate (knee-shaped) forms, somewhat similar to those of cassiterite. Also occurs massive and as rounded grains or pebbles in sands and gravels. Good prismatic cleavage. Fracture, uneven. Hardness, 6½. Specific gravity, about 4·2.

Optical.—Colour, black, red, or yellow. Streak, brownish to almost colourless. Lustre, metallic-adamantine. Refractive index extremely high ($\epsilon=2{\cdot}90$). Birefringence extremely high ($\epsilon-\omega=0{\cdot}28$). Optical sign, positive. Under the microscope, grains and fragments are usually red, but sometimes also yellow or dark grey in colour; they show the metallic type of lustre when examined in reflected light, and are slightly pleochroic, prisms showing the darker colour when the short diagonal of the nicol is parallel to the prism edge.

Chemical and blowpipe.—Titanium dioxide (TiO_2) containing about 60 per cent. of titanium. One or two per cent. of iron oxide usually present, and sometimes also a little vanadium. Infusible. Yields a violet bead with microcosmic salt in reducing flame. When the powder is fused with sodium carbonate on charcoal, or with hydrogen potassium sulphate on platinum foil, and afterwards dissolved in hydrochloric acid, the solution usually shows only a faint ferric chloride coloration; and on reduction with metallic tin the violet colour due to titanous chloride is obtained. Colourless titanium solutions in sulphuric acid turn brown on adding hydrogen peroxide.

Rutile is insoluble in acids, and under natural conditions is one of the most stable minerals known; hence, like zircon, it is almost universally distributed among sands.

Occurrence and distribution of rutile.—Rutile is a notable constituent of stream deposits, especially those derived from metamorphic rocks. It is, however, obtained on a large scale chiefly from vein and dyke rocks. The mineral has been mined at intervals during some years at Roseland, in Nelson Co., Virginia, U.S.A., where there are syenite-pegmatites containing about 4½ per cent. of the mineral associated with ilmenite. By crushing and concentration, this rock readily yields a product containing 95 per cent. of titanium dioxide. Ilmenite is obtained as a by-product.

Another mode of occurrence in Nelson Country is as a constituent of "nelsonite," a peculiar dyke-rock which consists of a mixture of rutile and apatite with a little ilmenite; but the expense of crushing and dressing "nelsonite" seems to be so great that the rutile cannot be obtained profitably from this source, and mining appears to be confined chiefly to the syenite-pegmatites.

Rutile has been mined for many years at Kragerö, Risör, and other localities on the south-east coast of Norway, where it is found associated with ilmenite in felspathic veins consisting largely of albite with some quartz. The rock mined contains about 25 per cent. of rutile, which is slightly vanadiferous. One specimen of the rutile was found to contain 0·55 per cent. of vanadic oxide.

Rutile has also been mined to a small extent at Talunga near Blumberg, South Australia, where it occurs in a vein of kaolinized rock about 10 feet wide.

The loose surface deposits which have arisen by the weathering and disintegration of the rutile-bearing rocks also contain rutile, and a considerable amount has been obtained by washing the surface gravels, soils, and clays that have arisen in this way.

Ilmenite (named from its occurrence in the Ilmen Mts., Urals).

General.—Trigonal. Often occurs massive, and is then not unlike magnetite in appearance. When it shows its crystal form, it is readily distinguished from magnetite by its tabular trigonal shape (fig. 162). Small grains such as are found in sands are usually scaly and lustrous. Basal and rhombohedral partings, as in corundum. Fracture, conchoidal. Hardness, about 5½. Specific gravity, about 4·7.

Optical.—Colour, black; parting surfaces often coated with whitish alteration products. Streak, black. Lustre, metallic. Microfragments usually opaque.

Chemical and blowpipe.—Titanate of iron ($FeTiO_3$), with about 31½ per cent. of titanium. Sometimes contains ferric oxide as haematite, and magnesia as magnesium titanate. [A variety named picroilmenite $(Mg, Fe)TiO_3$ has a dark, reddish brown streak, a lower specific gravity (about 4·25), and shows a deep purplish red colour in fine splinters under the microscope.] Infusible. Yields deep purplish red microcosmic beads. When powder is fused thoroughly with sodium carbonate or hydrogen potassium sulphate, and the fused mass dissolved in hydrochloric acid a deeply coloured ferric chloride solution is obtained. On reduction with metallic tin the colour due to the iron disappears and the violet colour of titanous chloride is obtained. Colourless solutions of titanium in sulphuric acid turn brown on adding hydrogen peroxide. Soluble with difficulty in hydrochloric acid.

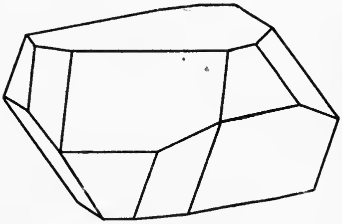

FIG. 162.—Ilmenite.

Occurrence and distribution of ilmenite.—Ilmenite is a common constituent of igneous rocks, and of the sandy detritus derived from them. It is sometimes pure, but sometimes intergrown with magnetite to form titaniferous magnetite. It is particularly abundant in basic igneous rocks such as gabbros and basalts, and is almost invariably present in them in the form of scattered granules. In some instances, however, it has segregated in large masses from basic igneous magmas and forms immense bodies of ore. The large masses of titaniferous iron ore of the Adirondack region of the United States are of this character. Similar masses occur in many other parts of the world, as in Scandinavia. The refractory character of these ores has rendered them unsuitable as a source of iron, but they are now being used as a source of ferro-titanium, which finds an application in the manufacture of rails.

Ilmenite is an important constituent of the black sands that are abundant as natural concentrates along certain beaches and rivers. The titaniferous black sands of the River St. Lawrence are derived from the anorthosites and other gabbros that occur abundantly in Quebec. These rocks consist chiefly of basic felspar, and contain scattered grains and masses of ilmenite and titaniferous magnetite which have crystallized out from a basic magma. A noteworthy deposit of this type is that at St. Urbain, near Baîe St. Paul, where there is a bed of ilmenite 90 feet thick exposed over a distance of 300 feet and traceable for over a mile. This ilmenite rock contains some rutile, and material containing 45 to 50 per cent. of titanium dioxide has been mined for use partly in making arc-light electrodes and partly for the manufacture of ferro-titanium.

The black concentrate so often obtained by panning ordinary sands consists, as a rule, largely of ilmenite ; it seldom consists of magnetite to the exclusion of ilmenite, though magnetite is often present ; but very frequently it consists of ilmenite with little or no magnetite. Many cassiterite and monazite concentrates contain a large percentage of ilmenite. The Travancore beach concentrates may contain over 50 per cent. of ilmenite, which can be obtained as a by-product in the magnetic concentration of the monazite.

TUNGSTEN.

The ore minerals of tungsten are wolframite (including ferberite) hübnerite, and scheelite. Wolframite and hübnerite constitute an isomorphous series. At one end of the series there is iron tungstate ($FeWO_4$) to which the name ferberite has been given ; at the other end is hübnerite ($MnWO_4$). These two occur mixed in all proportions. Some writers use the names ferberite and hübnerite for the extreme types and wolframite for the intermediate types. Others recognise only two species in this series, one in which the iron tungstate predominates over the manganese tungstate (wolframite including ferberite) whilst in the other species (hübnerite) manganese tungstate is predominant. As in other isomorphous series of this kind, there is a gradation in physical properties, and in this particular case the colour deepens and the mineral becomes more opaque as the percentage of iron increases.

Tungsten is one of the most valuable of the steel-hardening metals. Tungsten steel is very tough. It possesses the valuable property of retaining its temper when very hot, and on that account is used in the manufacture of high-speed tools. Tungsten is one of the best metals to use in making the filaments of electric glow-lamps, and is useful as a substitute for platinum in the manufacture of contact points. Sodium tungstate is used to impregnate wood to render it fireproof, and as a mordant in the dyeing trades.

Wolframite and hübnerite are by far the more important ore minerals of tungsten, scheelite being much less important.

Wolframite (Ger. *Wolf*, and *Rahm*, froth).

General.—Monoclinic; crystals tabular. Also found massive. Perfect pinakoidal cleavage. Hardness, about 5½. Specific gravity, about 7·4.

Optical.—Colour, brownish black. Streak, dark reddish brown. Lustre, submetallic. Microfragments translucent and brownish in colour.

Chemical and blowpipe.—Tungstate of iron and manganese $(Fe,Mn)WO_4$, with about 75 per cent. of tungstic oxide, and iron predominating over manganese. Fusibility, 3. Microcosmic bead deep-red. Yields a bluish green mass when fused with soda, indicating presence of manganese. Decomposed by hot hydrochloric acid and the solution when reduced by adding metallic zinc becomes deep blue in colour. This reaction is obtained very readily if the powder of the mineral is first fused with sodium carbonate.

Hübnerite (named after Mr. Hübner).

This mineral closely resembles wolframite, with which it is isomorphous. It differs from wolframite in consisting chiefly of manganese tungstate with a subordinate amount of iron tungstate. Its formula is $(MnFe)WO_4$. It is reddish brown in colour. Its microfragments are prismatic; they show straight extinction, and are more transparent and reddish than wolframite. Hardness, about 5½. Specific gravity, about 7·2. Fusibility, 4. Gives a good manganese reaction. Decomposed by boiling hydrochloric acid, and yields a yellow residue of tungstic oxide.

Ferberite (named after Mr. Ferber).

This name has been given to a variety of wolframite consisting of iron tungstate $(FeWO_4)$ and containing very little manganese. Colour, black. Streak, brownish black. Lustre, submetallic. Microfragments practically opaque. Hardness, about 5½. Specific gravity, about 7. Fuses readily to a magnetic globule. "Ferberite" is conveniently regarded as a variety of wolframite rather than as a separate species.

Scheelite (named after the Swedish chemist Scheele, who discovered tungstic acid in this mineral).

General.—Tetragonal (fig. 163), but usually found massive. Fracture, uneven. Hardness, about 4½. Specific gravity, about 6.

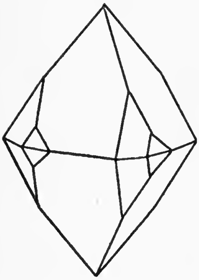

FIG. 163.—Scheelite.

Optical.—Colour and streak usually white. Lustre, sub-adamantine. Microfragments transparent, and have a high refractive index ($\omega = 1{\cdot}92$). Birefringence low ($\epsilon - \omega = 0{\cdot}016$). Optical sign, positive.

Chemical and blowpipe.—Calcium tungstate ($CaWO_4$) containing about 80 per cent. of tungstic oxide. Fusibility, 5; and can only be fused with difficulty on thin edges. Microcosmic bead colourless in oxidizing flame, blue in reducing flame, when cold. Decomposed by hot hydrochloric acid, and the solution reacts for lime when made alkaline with ammonia and treated with ammonium oxalate. Leaves a yellow residue when decomposed by hydrochloric acid, and this residue turns blue when metallic tin is added.

Occurrence and distribution of tungsten ores.—The countries of chief importance in the production of tungsten ores in recent years have been China, Burma and Malaya, the United States of America, Portugal, and Australia. China, the United States and Burma have been the leading producers. Argentina, Bolivia, Peru, Japan, Spain, and England have also yielded substantial supplies.

CHINA.—Wolframite is widely scattered in the sands and gravels of southern Hunan, southern Kwangsi, and Kwantung. The mineral is found also as small veins in granites over wide areas in these provinces. It is, however, from the gravels that the Chinese supplies have hitherto been mostly obtained.

BURMA AND MALAYA.—In Burma, tungsten ore is obtained chiefly in the Tavoy district of Lower Burma, but it occurs also in the Mergui and other districts. The ore mineral is wolframite, associated with cassiterite and various other minerals. The rocks of the Tavoy district are shales, sandstones, quartzites, schists, and intrusive biotite-granites. The granites themselves contain wolframite and cassiterite as segregation products. At the outer margins of the granite intrusions, and in the surrounding metamorphosed rocks, quartz-wolframite-cassiterite veins are abundant. Small amounts of fluorite, molybdenite, pyrite, pyrrhotite, chalcopyrite, galena, zinc-blende, arsenopyrite, native bismuth and bismuthinite occur in the veins. The wolframite occurs also in the alluvial gravels of the hill slopes, but unlike cassiterite it is non-resistant, and in consequence of its comparatively ready decomposition it does not occur, as cassiterite does, in the transported alluvium.

Tungsten ores also occur and are worked to some extent in the Southern Shan States and in the Federated Malay States.

In the Federated Malay States, wolframite is frequently associated with cassiterite in the contact zone where granite is intrusive in schist. In such cases it has been observed that where the quartz veins are enclosed by schist they contain fairly pure wolframite. At the actual contact the veins contain both cassiterite and wolframite, whereas in the granite the veins are rich in cassiterite and poor in wolframite, and it has been suggested that this indicates a higher temperature of deposition for cassiterite than for wolframite.

In the Kinta valley, F.M.S., where the granite is intrusive into limestones which it has metamorphosed, scheelite is one of the products of mineralization. Where the limestone has been dissolved away by weathering agents, the scheelite remains behind in the surface residues from which it can be separated cheaply.

United States.—Tungsten ores are found at numerous localities in the Western States, especially in Colorado, Nevada, Arizona, and California, where they occur in quartz and pegmatite veins in the Tertiary granite intrusions that abound in this region.

In Boulder County, Colorado, the predominant ore mineral is wolframite (ferberite), but hübnerite and scheelite also occur, and are associated with pyrite and molybdenite. The Boulder County ores can be concentrated to yield from 60 to 80 per cent. of tungstic oxide (WO_3).

In the Dragoon Mountains of Arizona, wolframite and hübnerite are found in quartz veins in granite, associated with scheelite; but the ore has been mined chiefly from the surface gravels, from which it is readily concentrated to yield a product containing 70 per cent. of tungstic oxide.

In Nevada, the chief deposits are about 12 miles south of Osceola; and the ore mineral is chiefly hübnerite with some wolframite, occurring in quartz veins that traverse granite.

A notable occurrence in California is that of Atolia in San Bernadino Co., where wolframite is a constituent of quartz veins in granite, Australasia.—In Australasia the chief contributors of tungsten ores are Queensland and New South Wales. Smaller amounts are obtained in New Zealand and Tasmania.

The chief Queensland localities are the Herberton and Chillagoe districts. Wolfram Camp in the Chillagoe district is an important locality; here wolframite is associated with bismuth minerals and molybdenite in quartz veins traversing granite.

In New South Wales, wolframite is mined at Torrington (Mole Tableland), and scheelite at Hillgrove. The tungsten minerals of New South Wales are associated with bismuth, stibnite, molybdenite, smaltite, chalcopyrite, cassiterite, monazite, fluorite, topaz, and lithium minerals.

At Macrae's flat in Central Otago, New Zealand, a vein of auriferous quartz containing scheelite occurs in schists; and the ore has yielded 18 dwt. of gold per ton.

In Tasmania, wolframite occurs in the Middlesex district in quartz veins traversing Silurian limestones and quartzites; these latter are penetrated by Devonian quartz-porphyry, and are overlain by Tertiary basalt. The wolframite is associated with cassiterite, bismuthinite, and molybdenite.

Portugal.—In northern Portugal, wolframite is a constituent of quartz veins and stringers occurring in the Lower Palæozoic slates and schists and their intrusive granites. In the Panasquiera mine, south-west of Guarda, the wolframite is associated with pyrite, chalcopyrite, arsenopyrite, and cassiterite.

Spain.—There are some notable occurrences of tungsten ore in various parts of western Spain, as in Las Cabezas Mountains, Cordova province, and San Finx near Santiago in Galicia. As in northern Portugal, the rocks of Las Cabezas consist of Cambrian slates with intrusive granites and are traversed by quartz veins. These veins contain wolframite associated with scheelite. The workings are open-cast, and good concentrates of both scheelite and wolframite are obtained.

England.—In Cornwall, wolframite is found in association with cassiterite and chalcopyrite, notably in the mines of the western part of the county near Camborne (for conditions of occurrence, see p. 247). For a long time no method was known whereby the wolframite and cassiterite could be profitably separated, and large dumps of mixed ore were accumulated at the mines. The introduction of the electro-magnetic method of ore separation enabled the magnetic wolframite to be separated from the non-magnetic cassiterite, and the mixed ore has consequently been rendered useful. Wolframite also occurs associated with cassiterite in the alluvial deposits of Bodmin moor, from which it can be readily concentrated. The wolframite of these alluvial deposits has been derived from the pegmatite veins that traverse the granite of this district.

ARGENTINA.—In Argentina, tungsten ore occurs in quartz veins traversing gneisses and schists which are invaded by intrusions of granite and andesite on the east side of the Sierra de San Luis. The ore mineral is chiefly wolframite (ferberite), but scheelite also occurs. Other minerals occurring in the veins are pyrite, chalcopyrite, arsenopyrite, molybdenite, bismuth, fluorite, tourmaline, and cassiterite. The ore in some places carries columbium and tantalum, and at one locality a sample of wolframite yielded 1·2 per cent. of columbic and tantalic oxides.

BOLIVIA.—In the Eastern Cordillera of Bolivia wolframite is associated with ore minerals of tin and bismuth (see pp. 164, 245). It is mined at Quimza Cruz and near Uyuni.

VANADIUM.

The chief ore minerals of vanadium are patronite (vanadium sulphide) carnotite ($2U_2O_3 . K_2O . V_2O_5 . 3H_2O$), roscoelite (vanadium mica), vanadinite ($3Pb_3(VO_4)_2 . PbCl_2$), and mottramite (a hydrated vanadate of lead and copper). Less important are endlichite, a variety of vanadinite in which vanadium is partly replaced by arsenic, and descloizite ($4PbO \cdot V_2O_5 \cdot H_2O$).

It is noteworthy that the ash of asphalt and coal sometimes contain considerable amounts of vanadium. Certain Peruvian asphalts contain one per cent. of vanadic oxide, and the ash left after burning the asphalt contains from 25 to 40 per cent. of vanadic oxide (V_2O_4). A specimen of Colorado coal from Rockvale was found to contain $1\frac{1}{2}$ per cent. of ash, and the ash contained 27 per cent. of vanadic oxide.

Vanadium is also found, but only in very small quantities, in titaniferous magnetites, presumably in close association with the mineral rutile (TiO_2). Rutile is frequently vanadiferous.

All vanadium minerals when dissolved in dilute sulphuric acid yield a solution that turns brown on the addition of hydrogen peroxide. Titanium solutions act much in the same way.

Uses.—Vanadium is used chiefly in the form of ferro-vanadium in steel manufacture. Like ferro-titanium, it has an affinity for nitrogen, and is useful for slagging off this impurity in molten steel. Moreover, it exerts beneficial effects on steel in quite small quantities. Not more than one per cent. of the metal is required to impart a high degree of tensile strength and elasticity to steel; and a much smaller amount (0·2 per cent.) suffices when used with chromium or manganese. Vanadium compounds are also used as dyes, and as colouring agents in glass manufacture.

Patronite (named after Antenor Rizo Patrón, who discovered the deposits in which it occurs). Patronite occurs as a black amorphous material rich in vanadium sulphide. The material is carbonaceous and complex in character. The real composition of the vanadium compound present is doubtful, but it is supposed to be a sulphide having a composition which corresponds to the formula VS_4. The ore has a specific gravity about 2·7. (For further remarks on patronite, see below).

Carnotite (named after A. Carnot). Carnotite is a hydrated vanadate of uranium and potassium of doubtful formula, but perhaps

$$2U_2O_3 . K_2O . V_2O_5 . 3H_2O,$$

corresponding to about 20 per cent. of vanadic oxide. It occurs as a yellow crystalline powder. It is found as an impregnation of sandstone in Colorado and Utah; and as an alteration product in the cracks and cavities of an impure ilmenite at Radium Hill, near Olary, in South Australia. For further details as to properties and occurrences of carnotite, see p. 432.

Roscoelite (named after Sir Henry Roscoe). Roscoelite occurs in minute scales and micaceous aggregates of a greenish to brownish colour. Basal cleavage perfect. Specific gravity, about 2·9. It is a variety of mica, in which aluminium is largely replaced by vanadium. Formula doubtful, but perhaps $H_8K(Mg, Fe)(Al, V)_4(SiO_3)_{12}$. It contains about 28 per cent. of vanadic oxide when pure. Examined microscopically the scales are transparent and biaxial, the acute bisectrix emerging almost at right angles to the cleavage as in muscovite. The optical sign is negative.

Fuses readily in blowpipe flame to a black glass. Borax and microcosmic beads yellow or colourless in oxidizing flame, green in reducing flame.

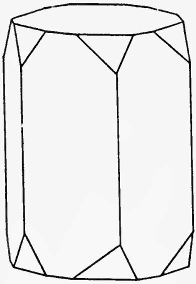
FIG. 164.—Vanadinite.

Vanadinite. *General.*—Hexagonal, the prism and basal pinakoid forms usually predominant (fig. 164). Often found as an encrustation. Fracture, uneven. Hardness, about 3. Specific gravity, about 7.

Optical.—Colour, red, yellow or brownish. Streak, yellowish or white. Lustre, resinous to adamantine. Microfragments transparent, irregular and yellowish. Refractive index very high (ω over 2·3). Birefringence, low. Optical sign, negative.

Chemical and blowpipe.—Chloro-vanadate of lead $\{3Pb_3(VO_4)_2 . PbCl_2\}$ with 19·36 per cent. of vanadic oxide. Fusibility, 1½. Microcosmic bead yellow in oxidizing flame, and green in reducing flame. With a little copper oxide in a microcosmic bead it yields an azure-blue flame, indicating presence of chlorine. Yields metallic lead when fused on charcoal with sodium carbonate. Dissolves in nitric acid, yielding a yellow solution which gives a precipitate of silver chloride with silver nitrate. Sulphuric acid solution turns brown on adding hydrogen peroxide.

Occurrence and distribution of vanadium ores.—The chief sources of vanadium ores are Peru and the United States. The comparatively small amounts of vanadium formerly required for chemical uses were obtained from various deposits of vanadinite, notably those of Spain, and those of Wanlockhead in Dumfriesshire, Scotland.

PERU.—At Minasragra near Cerro de Pasco in the Andes, patronite occurs as a constituent of a bed of ore 300 feet in length and from 3 to 6 feet in thickness, intercalated among highly inclined red shales of Cretaceous age. These shales are traversed by dykes of quartz-porphyry and dolerite, and the carbonaceous matter is in places converted into coke. The ore-stuff is highly carbonaceous, and is associated with vanadiferous asphalt. It contains pyrites and free sulphur in addition to patronite, and carries 35 per cent. of vanadium sulphide. The pyrites present is in part nickeliferous. When calcined, the ore yields a product containing about 52 per cent. of vanadic oxide (V_2O_5), and an appreciable percentage of nickel. The ferro-vanadium made from the ore is nickeliferous.

At various localities in Peru, vanadiferous asphalts and coals are mined.

UNITED STATES.—The Mesozoic sandstones of Colorado and Utah provide supplies of vanadium ore of considerable importance, especially those of the former State.

In Colorado, ore is mined in the San Miguel and Montrose counties. In San Miguel county, a bed of Jurassic sandstone 9 feet thick, and impregnated with roscoelite, is worked at Bear Creek near Newmire, and also at Placerville. A horizontal parting in this sandstone is marked by the presence of a thin vein of roscoelite and quartz less than an inch thick. The material of this vein carries as much as 8 per cent. of vanadium in places, but the sandstone as a whole does not average more than two per cent. of vanadium, and much of it does not carry more than one per cent. Here and there a little carnotite is associated with the roscoelite.

At Paradox valley in Montrose county, a sandstone impregnated with carnotite is mined; the sandstone outcrops in various places on the sloping sides of the valley and is readily worked.

Carnotite-bearing sandstone is found also in Utah at various localities. On the east side of San Rafael Swell, ore containing 3·87 per cent. of vanadic oxide and 2·24 per cent. of uranium oxide has been produced in quantity.

Vanadinite associated with wulfenite and endlichite occurs at various localities among the Sierra de los Caballos in New Mexico, in argentiferous galena veins, which yield ore containing from 40 to 60 per cent. of lead and 7 or 8 per cent. of vanadium. It also occurs in Arizona, where ore averaging about one per cent. of vanadic oxide is obtained.

OTHER LOCALITIES.—For note on vanadium ore at Olary, South Australia, see p. 432. Of other occurrences of vanadium ore those of mottramite are worthy of note. Mottramite is a hydrated vanadate of lead and copper, the exact composition and formula of which is doubtful. It is found in the form of black or brownish encrustations. It occurs as an impregnation of Keuper sandstone at Mottram St. Andrews and Alderley Edge in Cheshire, where it was formerly worked to a small extent as a source of vanadium compounds. Mottramite has also been mined as a vanadium ore in the Otavi district of South-West Africa, where it is found in substantial deposits associated with copper ore (see p. 184). Vanadinite has been mined in Santa Marta in Estremadura, Spain. Descloizite has been mined in Argentina, South America; and it has been obtained as a by-product in working the zinc ore of Broken Hill, Northern Rhodesia (see p. 267).

ZINC.

The chief ore minerals of zinc are zinc-blende (zinc sulphide), smithsonite (zinc carbonate), hemimorphite (hydrated zinc silicate), franklinite (ferrate of zinc and manganese). Other zinc minerals of note are willemite (zinc silicate) and zincite (zinc oxide), which occur associated with franklinite; and hydrozincite (hydrated zinc carbonate) which is a common alteration product of zinc-blende.

In deep-seated veins which have not suffered oxidation, zinc-blende is generally the ore mineral found. Smithsonite, hemimorphite, and hydrozincite arise from the alteration of zinc-blende in the oxidation zone. The name "calamine" is conveniently applied to the mixed oxidized ore consisting as a rule chiefly of impure smithsonite, though other oxidation products may be present. Franklinite, willemite, and zincite are of comparatively limited distribution and the only locality where these are of importance as ore minerals is Franklin in New Jersey, U.S.A.

Numerous minerals occur associated with zinc-blende in veins of zinc ore, one of the commonest of these being galena. The more important of the other associated minerals are calcite, dolomite, chalybite, pyrite, chalcopyrite, and barite. Zinc-blende frequently contains small amounts of cadmium sulphide, and the cadmium of commerce is obtained from zinc-blende and other zinc ores (see p. 165).

Zinc is used largely in the manufacture of galvanized iron, which consists of iron sheets covered with a layer of zinc. It is also used largely in making brass, which is an alloy of copper and zinc; other important alloys containing zinc include German silver, white metal, and antifriction metal. Slabs of zinc are used in desilverizing lead. Zinc dust is used in the chemical industries as a reducing agent. Zinc oxide (zinc white) is a useful pigment, as also is the precipitated mixture of zinc sulphide and barium sulphate known as "lithopone."

Ordinary commercial zinc, such as is used in the manufacture of sheet-zinc and for galvanizing purposes, contains one or two per cent. of impurities, chiefly lead, and is known as *spelter*. For such uses as the manufacture of brass, zinc of better quality is required; and for brass of the best quality (*e.g.* cartridge brass), high-grade metal consisting of almost pure zinc is used.

Zinc-blende (Ger. *blenden*, to blind or deceive, from its resemblance to galena, for which it was often mistaken. Frequently called blende. Also named sphalerite from Gr. *sphaleros*, meaning delusive or treacherous. Commonly called "black jack" by English miners).

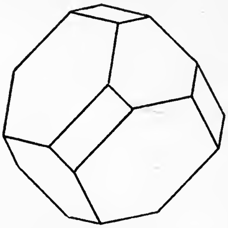

FIG. 165.—Zinc-blende.

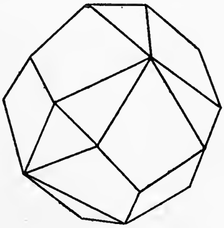

FIG. 166.—Zinc-blende.

General.—Cubic (figs. 165 to 167). Commonly massive, and usually coarse-grained, so that the cleavage can be readily observed. Cleavage, dodecahedral and perfect. Hardness, about 3½. Specific gravity, about 4.

Optical.—Colour variable, but usually yellow, brown or black. Streak, pale brown. Lustre, adamantine to resinous on freshly broken surfaces. Microfragments transparent and generally isotropic; occasionally they are abnormal and show some double refraction. Refractive index very high, about 2·37. In consequence of this high refractive index the microfragments show the metallic type of lustre when examined in reflected light.

Chemical and blowpipe.—Zinc sulphide (ZnS), containing 67 per cent. of zinc. Some crystals contain as much as 1½ per cent. of cadmium, due to admixture with cadmium sulphide. Fusibility, 5. On charcoal yields a sublimate of zinc oxide which is yellow when hot and white when cold; this sublimate turns green when moistened with cobalt nitrate and re-heated. Soluble in hydrochloric acid and gives off sulphuretted hydrogen.

FIG. 167.—Zinc-blende, Transylvania. (× ½). B.M.

Smithsonite (named after Smithson, the founder of the Smithsonian Institution of Washington, U.S.A. Also called calamine).

General.—Trigonal, but usually found in a massive earthy condition, and sometimes shows mammiform, botryoidal, or spherical forms (fig. 168). Cleavage, rhombohedral. Hardness, 5. Specific gravity, about 4·35.

Optical.—Colour variable, but often white or grey. Streak, white. Lustre, vitreous to pearly when crystalline. Microfragments rhomboidal in shape when crystalline. These fragments show a refractive index exceeding that of methylene iodide, and a symmetrical extinction. Birefringence extremely high ($\omega - \epsilon = 0{\cdot}20$) and negative.

Chemical and blowpipe.—Zinc carbonate ($ZnCO_3$), containing 52 per cent. of zinc. Infusible. When powder is heated in blowpipe flame on charcoal after moistening with cobalt nitrate it turns green. Dissolves with effervescence in warm hydrochloric acid and gives off carbon dioxide.

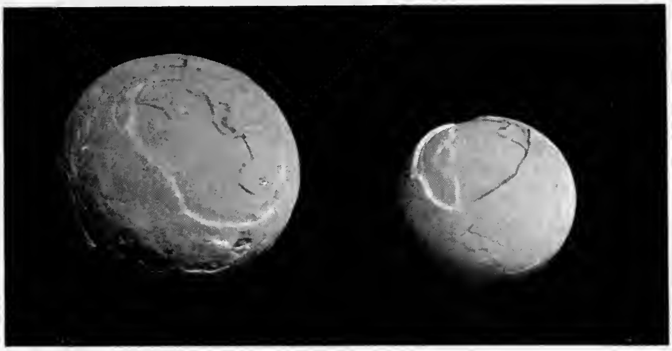

FIG. 168.—Smithsonite, Santander, Spain. (× ⅔). B.M.

Hemimorphite (named calamine by some authors. The name hemimorphite has reference to the hemimorphic habit of its crystals, and was introduced to avoid confusion with smithsonite. The name calamine may thus be used in an indiscriminate way for oxidized ore in which both carbonate and basic silicate of zinc may be present).

General.—Orthorhombic and hemimorphic (fig. 169). Occurs frequently in massive-granular, mammiform, and botryoidal shapes. Prism cleavages, perfect. Hardness, about 5. Specific gravity, about 3·4.

Optical.—Colour variable, but usually white or yellowish. Lustre, vitreous. Microfragments show prismatic shapes and straight extinction. Refractive index moderate ($\alpha = 1{\cdot}613$). Birefringence moderate ($\gamma - \alpha = 0{\cdot}023$). Optical sign, positive.

Chemical and blowpipe.—Basic silicate of zinc ($H_2Zn_2SiO_5$), with 54 per cent. of zinc. Fusibility, 6, *i.e.* fusible with extreme difficulty. Gives off water in closed tube, and decrepitates. Powder turns blue when moistened with cobalt nitrate and heated in blowpipe flame. Decomposed by hydrochloric acid, yielding a silica jelly.

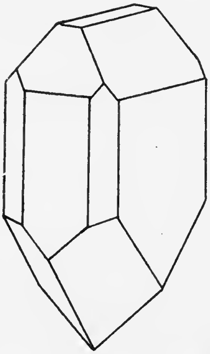

FIG. 169.—Hemimorphite.

Franklinite (named from its occurrence at Franklin, New Jersey).

General.—Cubic, crystallizing in octahedra (fig. 170). Often in massive-granular condition. Octahedral parting. Fracture, conchoidal to uneven. Hardness, about 6. Specific gravity, about 5·2.

Optical.—Colour, black or brownish black. Streak, dark brown. Lustre, metallic. Microfragments slightly translucent and brownish. Isotropic.

Chemical and blowpipe.—Oxide of zinc, iron and manganese,

$$(Zn, Fe, Mn)O \,.\, (Fe, Mn)_2O_3,$$

with usually about 20 per cent. of zinc oxide. Infusible. Bead reactions for manganese and iron, best observed in borax bead. On charcoal, leaves a magnetic residue, and yields an encrustation of zinc oxide which turns green after moistening with cobalt nitrate and reheating. Soluble in hydrochloric acid.

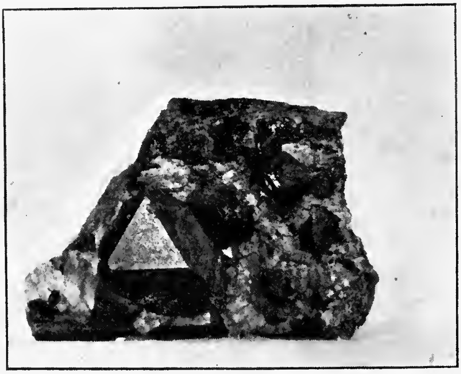

FIG. 170.—Franklinite, New Jersey. (× ½). B.M.

Willemite (named after William I., King of the Netherlands).

General.—Trigonal, but usually in a massive granular condition. Fracture, uneven. Hardness, about 5½. Specific gravity, 4·1.

Optical.—Colour variable, but mostly yellowish brown. Lustre, vitreous. Microfragments transparent, with a moderately high refractive index ($\epsilon=1{\cdot}71$). Birefringence, moderate ($\epsilon-\omega=0{\cdot}02$). Optical sign, positive.

Chemical and blowpipe.—Zinc silicate ($2ZnO \,.\, SiO_2$) with 58 per cent. of zinc. Fusible with difficulty (about 5). Gives no water in closed tube. The powder turns blue on charcoal after moistening with cobalt nitrate and re-heating (presence of a fusible silicate) whereas the sublimate of zinc oxide turns green. Decomposed by hydrochloric acid, yielding a silica jelly.

Zincite (Red zinc-ore).

General.—Hexagonal; crystals hemimorphic (fig. 171). Usually massive and granular. Perfect basal cleavage. Hardness, about 4½. Specific gravity, about 5·6.

Optical.—Colour yellow to blood-red. Streak, pale yellow to orange. Lustre, adamantine. Microfragments transparent. Refractive index, very high. Birefringence, low ($\epsilon - \omega = 0{\cdot}01$). Optical sign, positive.

Chemical and blowpipe.—Zinc oxide (ZnO) with 80 per cent. of zinc when pure. Some manganese is usually present. Infusible. Yields a white sublimate of zinc oxide on charcoal; this sublimate is yellow when hot, white when cold, and turns green on moistening with cobalt nitrate and re-heating. Darkens on heating in a closed tube, but regains its colour on cooling. Dissolves in hydrochloric acid without effervescence.

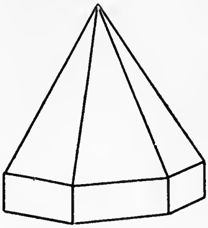

FIG. 171.—Zincite.

Hydrozincite (Zinc-bloom).

General.—Occurs in a massive, earthy or chalk-like condition, usually as an encrustation and sometimes as concretionary masses. Hardness, about 2½. Specific gravity, about 3·7.

Optical.—Colour white or yellowish. Lustre, dull. Microfragments show a cryptocrystalline structure and have a refractive index greater than that of methylene iodide. They are also doubly refracting.

Chemical and blowpipe.—Basic carbonate of zinc, $ZnCO_3 . 2Zn(OH)_2$ with 60 per cent. of zinc. Infusible. Gives off water in a closed tube. On charcoal yields a white sublimate and turns green on treatment with cobalt nitrate and re-heating. Dissolves in hydrochloric acid with effervescence.

Occurrence and distribution of zinc ores.—About 60 per cent. of the world's output of zinc ore is contributed by the United States, Australia, Germany, and Silesia. About 30 per cent. is produced by Italy, Spain, Sweden, France, Algeria, Tunis, Mexico, and Russia. The remaining 10 per cent. is produced chiefly by Austria and Hungary, Greece, China, Japan, Great Britain, and Canada.

UNITED STATES.—In the U.S.A. the districts chiefly concerned in the production of zinc ore are Franklin in New Jersey, and various districts in the States of Missouri, Colorado, and Wisconsin.

At Franklin, New Jersey, the ore-body occurs in pre-Cambrian crystalline limestones. It has the appearance of a bedded deposit, and is regarded by some authorities as having been formed contemporaneously with the limestone. Others regard it as an impregnation formed subsequently to the limestone, and hold the view that its origin is connected with the granitic intrusions which traverse the beds. The ore minerals are of a singular type, and consist chiefly of franklinite, willemite, and zincite. The average composition of the ore is stated to be as follows: franklinite, about 52 per cent., willemite 31½, calcite 12½, zincite ½, and other silicates about 3½ per cent.

See p. 208 with reference to the occurrences in Missouri and Colorado, where zinc-blende is associated with galena and various other minerals.

In south-western Wisconsin zinc ore occurs in an Ordovician limestone which is known as the "galena limestone." The ore-body consists of disseminations in the limestone. The ore minerals are zinc-blende and smithsonite associated with galena, pyrite, and calcite.

The percentage of zinc in the United States zinc-ore concentrates is variable, being less for the carbonate than for the sulphide ores, but the concentrated ores as a whole for the United States are stated to average about 49 per cent. of zinc.

AUSTRALIA.—One of the most productive zinc mines of the world is that of Broken Hill in New South Wales, where zinc-blende occurs associated with galena (see p. 210). The Broken Hill mines alone furnish about a fifth of the total world's production of zinc. The concentrated zinc ores of Australia contain on the average about 47 per cent. of zinc.

Zinc-lead ore deposits of some importance are worked in the Read-Rosebery district of western Tasmania. The chief ore-bodies have arisen by replacement of calc-schist, but there are also vein deposits, and the ore is oxidized at the surface. The concentrates contain on the average 43·3 per cent. of zinc-blende, 31 per cent. of pyrite, 10·4 per cent. of galena, and 1·2 per cent. of chalcopyrite, together with small amounts of quartz, barite, calcite, rhodochrosite and tetrahedrite. They contain also on the average 3 dwt. of gold and 10 oz. of silver per ton. The ore-bodies occur in calc-schists, and are supposed to be genetically connected with the Devonian granitic intrusion and associated tin ore deposits of North Dundas some three miles away.

GERMANY and SILESIA.—An important region concerned in the production of zinc ore is Silesia, where zinc-blende is found abundantly in association with oxidized zinc ores, galena, and pyrite. For a fuller account of this and German occurrences, see p. 209.

ITALY.—The zinc ore produced in Italy is obtained mostly from Sardinia, where zinc-lead ores are found abundantly in the Lower Palæozoic rocks of Iglesias. The veins occur chiefly in the Silurian slates and limestones, into which granites have been intruded in this area. The ore minerals are zinc-blende, galena, and the oxidation products of these sulphides, associated with quartz, barite, calcite, chalybite, and occasionally fluorite. Copper minerals are remarkably scarce in the veins.

At the Malfidano mines, north-west of Iglesias, a rich " calamine " ore consisting of smithsonite and hemimorphite, and containing 45 to 50 per cent. of zinc, has been worked extensively.

At Nebida, near the coast west of Iglesias, " calamine " (smithsonite and hemimorphite) occur in the form of pipes in limestone. Some of these pipes have a diameter of 60 feet ; they extend to a depth of 600 feet and yield ore containing 45 per cent. of zinc.

Spain.—The chief zinc-mining areas in Spain are in the provinces of Santander and Murcia. The zinc-lead ore deposits around Cartagena, in the latter province, in which zinc-blende is associated with argentiferous galena, have been already referred to on p. 209.

In Santander, the ore worked is chiefly of the oxidized type ; smithsonite is the chief ore mineral, and the ore is one of very good quality. The Santander deposits are found mostly in the Carboniferous limestone of the Cantabrian mountains. They occur in the form of pockets and irregular masses, in the vicinity of which the limestone is dolomitized. Zinc ores occur also in the Cretaceous strata of Santander. These oxidized surface ores of Santander have arisen in the usual way from the alteration of zinc-blende, which is the ore mineral below the zone of oxidation.

France.—Zinc ores are mined at Malines in Gard, Bormettes in Var, and Planioles in Lot. In all these localities zinc-blende is the predominant ore mineral, and the galena found in association with it occurs in comparatively small amounts. The most productive mines are those of Malines where the ore is found in dolomitic limestone of Jurassic age. Other notable French zinc ore deposits are worked in Hautes-Pyrénées, Ariège, and Lozère.

Algeria and Tunis.—Zinc ores have been mined extensively in the departments of Constantine and Alger in Algeria ; and zinc-lead ore is mined at numerous localities in Tunis. These Algerian and Tunisian ores are largely of the oxidized (calamine) type, but below the oxidation zone there is an abundance of zinc-blende and galena.

Mexico.—Zinc ores are abundant in northern Mexico, and have been mined chiefly in the States of Chihuahua and Coahuila, though they occur also in San Luis Potosi and other States. At some localities, as at Picachos, oxidized ores (calamine) are mined. At other localities the ore mineral is zinc-blende, obtained as a by-product in mining argentiferous galena, with which it is associated.

Russia.—Zinc ores are mined in Russian Poland. The ores worked there have been chiefly of the oxidized (calamine) type, which occur as replacements of Muschelkalk dolomite, and resemble those of Silesia.

An important deposit of zinc ore has been worked in recent years at the Tynticha mine near Olga Bay, 200 miles north-east of Vladivostok. The deposit is estimated to have contained over 200,000 tons of ore averaging 48 per cent. of zinc. Another and still more important Siberian deposit occurs at the Ridder mine in the Semipalatinsk district of south-western Siberia. This ore-body has been estimated to contain 883,000 tons of sulphide ore with 31 per cent. of zinc; and about 2½ million tons of lower-grade ore containing about 5½ per cent. of zinc.

Sweden.—Zinc ores are mined near Åmmeberg in southern Sweden, where lenticular deposits containing zinc-blende and galena occur in pre-Cambrian schists and gneisses. The zinc concentrates obtained at this locality contain about 40 per cent. of zinc and 3 per cent. lead. Another notable Swedish deposit is that at Sala, where zinc-blende associated with galena and pyrite occur in a dolomite formation.

Greece.—In the Laurium district of Attica in Greece, zinc ores occur as veins and irregular masses in a crystalline limestone which is interbedded with mica-schist. The schists and limestones are traversed by intrusions of granite and porphyry and other igneous rocks. The ore minerals are argentiferous galena, cerussite, zinc-blende, and smithsonite, associated with pyrite, chalybite, and copper minerals. The Laurium zinc-lead ores have yielded a large amount of silver.

British Isles.—Zinc ore is mined at various localities in the Palæozoic rocks of the British Isles, notably in Cumberland and Northumberland, where it occurs in veins that traverse Carboniferous strata; and in Wales and the Isle of Man, where it occurs in Ordovician rocks. The ore mineral is chiefly zinc-blende, which is usually associated with galena, pyrite, chalcopyrite, calcite, chalybite, barite, and fluorite. See also p. 211, dealing with the geological conditions of British occurrences of galena associated with zinc-blende.

Canada.—The zinc ores of Canada are obtained almost wholly from the West Kootenay District of British Columbia, notably in the Slocan, Nelson, and Ainsworth Divisions.

In the Slocan Division argentiferous galena and zinc-blende occur as veins and replacements in slates and limestones of Palæozoic age. The pipe-like masses occurring as limestone replacements have yielded concentrates containing 40 per cent. of lead, 10 per cent. of zinc, and up to 90 oz. of silver per ton. Chalybite, chalcopyrite, and tetrahedrite are associated with the zinc-blende and galena.

In the Ainsworth Division the zinc-lead ore occurs in schists and crystalline limestones of pre-Cambrian age. The ore minerals are zinc-blende and galena, associated with pyrrhotite and chalcopyrite.

Burma.—Argentiferous lead-zinc ores form large deposits at Bawdwin, in the Northern Shan States of Upper Burma, in a much-fractured zone of overthrust traversing felspathic grits and rhyolite tuffs of Cambrian age. The ore minerals are argentiferous galena and zinc-blende, and associated with these are chalcopyrite, pyrite, cerussite, smithsonite, anglesite, barite, and other minerals. The ore is thus of a complex type. The concentrates yield from 24 to 30 per cent. of lead, 14 to 30 per cent. of zinc, and up to 40 oz. of silver per ton.

Rhodesia.—An unusual type of zinc-ore deposit occurs at Broken Hill of Northern Rhodesia, where zinc-blende is found associated with galena, forming irregular masses and impregnations in dolomite of pre-Cambrian age. The ore is oxidized at the surface, being made up largely of lead carbonate and zinc silicate. The zinc phosphates, hopeite and tarbuttite, and the vanadium mineral descloizite occur in the oxidized ore.

Japan.—Zinc ore has been mined at numerous localities in Japan, but the most important of these are the Kamioka mines in Hida province. The ore mined here consists of zinc-blende associated with argentiferous galena. It contains about 13 per cent. of zinc, 2 per cent. of lead, and 4 oz. of silver per ton. The ore is dressed to yield zinc concentrates containing 45 per cent. of zinc.

CHAPTER X.

GEM MINERALS.

GEM minerals are those which, on account of certain physical characters, are regarded as objects of beauty, and are used for personal adornment or other ornamental purposes. Colour, refractive index, dispersive power, hardness, transparency, and the absence of inclusions, are as a rule the chief physical factors determining the qualities of gemstones. The value of the stones, however, depends largely on their rarity.

Most gem minerals are highly transparent and variable in colour. This variability is well exemplified in the several colour-varieties of the mineral corundum, of which the best known are the ruby (red), and the sapphire (blue). The diamond is a unique instance of a generally colourless gemstone in which the qualities of hardness, refractive index, dispersive power, and pellucidity are all developed to an extremely high degree.

In some instances, non-transparent minerals are used as gemstones. As examples of these, in which colour gives a value in the absence of transparency, turquoise, precious opal, jade, jasper and some other forms of silica, malachite, and pyrite may be mentioned. Most of these are practically opaque, and pyrite is quite so.

Gemstones as a whole show a wide range of chemical composition. The diamond is unique chemically as it is physically, for it is the only natural gemstone consisting of a single element. Many are oxides, *e.g.* ruby, sapphire, amethyst and other forms of silica. A large number are silicates, *e.g.* garnet, olivine, emerald, and tourmaline. Carbonates (malachite, chessylite, and calcite), phosphates (turquoise and apatite) and fluorides (fluorite) are also represented.

Gem minerals are often divided into two groups according to value, viz. (1) the more valuable or *precious gemstones*, the chief of which are diamond, ruby, sapphire, alexandrite, emerald, garnet, precious opal; other stones which are at times sufficiently valuable to be regarded as "precious" include spinel, zircon, chrysolite, tourmaline, turquoise;

(2) the less valuable or *minor gemstones,* the more notable of which are amethyst and other forms of silica, felspar, opal, spinel, zircon, chrysolite, tourmaline, turquoise, phenakite, topaz, jadeite, lapis-lazuli, and many others of which brief descriptions are given below.

For the sake of convenience of reference, gemstones will be dealt with here not in the order of their value, which in most cases is very variable, but in alphabetical order.

Adamantine Spar, a variety of corundum (see p. 282).

Agate, a variety of chalcedony (see p. 278).

Alexandrite, a variety of chrysoberyl (see p. 280, and fig. 180).

Almandine, a variety of garnet (see p. 297).

Amazonstone, a variety of felspar (see p. 295).

Amber (Succinite).—Amber or succinite is a fossil resin. It consists of the hardened resinous remains of coniferous trees, mostly *Pinus succinifer*, now extinct.

General.—Amorphous. Occurs in the form of rounded pieces of variable size. Hardness, $2\frac{1}{2}$. Specific gravity, about 1·1. Fracture, conchoidal. Very brittle. When rubbed it does not become sticky, but, owing to the fact that it is an extremely bad conductor, it becomes strongly electrified. The word "electricity" is derived from *electron*, which is the Greek name for amber.

Optical.—Colour, pale yellow to brownish. Isotropic. Refractive index, 1·54.

Chemical.—Amber has a composition corresponding to the formula $C_{10}H_{16}O$, but it is really incorrect to ascribe to it a formula, since it consists of a mixture of compounds. It differs from various other and less important amber-like substances in containing a small amount, on the average about 4 per cent., of succinic acid.

Occurrence and distribution.—The amber of commerce is obtained chiefly from the north-west Samland coast of the Baltic, in East Prussia, notably at the Anna mine near Palmnicken, which is the centre of an important industry. The amber occurs in beds of glauconitic sand and loam of Lower Oligocene age. It is found in the form of rounded pieces that vary from the size of a pea up to about 15 lb. in weight, though pieces so large are rare. The smaller pieces are of little value in their natural state, but they are heated and compressed into larger blocks of material that is distinguished from the natural amber by the name "amberoid" ("ambroid") or "pressed amber." Amberoid is less valuable than the natural product. It is stated that the cloudy effects often seen in natural amber can be produced in amberoid.

An amber-like material known as *burmite* occurs and is worked to a small extent in the Hukong valley, Upper Burma. Burmite differs from ordinary amber in containing no succinic acid.

Also closely similar to amber in their nature, occurrence, and mode of origin are *copalite* (fossil resin), which occurs abundantly in the surface gravels of Tanganyika Territory; and Kauri resin, which is found abundantly in New Zealand.

Though amber figures as a minor gemstone, it is used chiefly in the manufacture of beads, and the mouthpieces of pipes and cigarette holders. It is also used in the manufacture of amber varnish or colophony.

Amethyst (Gr. *amethystos* from *a*, negative, and *methyo*, to inebriate; so named because of its use as a charm to prevent drunkenness). A variety of quartz (see p. 311).

Andalusite (from Andalusia, in Spain).

General.—Orthorhombic, occurring in the form of elongated, but usually ill-defined and simple prisms. Common varieties are dull and useless as gemstones owing to the presence of carbonaceous impurities. In the variety *chiastolite*, these impurities are arranged in a more or less regular way in the crystal, a section of which at right angles to the prism edge shows the impurities in the form of a cross, hence the name of this variety (Gr. *chiastos*, crossed, and *lithos*, stone). Cleavage, prismatic but imperfect. Fracture, uneven. Hardness, 7½. Specific gravity, about 3·2.

Optical.—Colour, red or green in the gem varieties. Lustre, vitreous. Refractive index high, $\alpha = 1{\cdot}632$. Birefringence, low ($\gamma - \alpha = 0{\cdot}011$). Optical sign, negative. Pleochroism strong, the colour varying from red to green. Prismatic microfragments show straight extinction, and the axial pleochroism is such that the fragment shows a red or pink colour when the short diagonal of the nicol is parallel to the prism edge, and green or colourless when the short diagonal is at right angles to this edge. For irregular grains the vibration-direction which yields the pink colour is the fast-ray vibration-trace, *i.e.* the direction of compensation with a positive quartz wedge.

Chemical and blowpipe.—Aluminium silicate ($Al_2O_3 . SiO_2$). Insoluble in ordinary acids. Infusible. Powder yields a fine blue colour when heated in oxidizing flame of blowpipe after moistening with cobalt nitrate.

Occurrence and distribution.—Andalusite occurs as a product of the thermal metamorphism of argillaceous rocks, and is frequently abundant in places where these rocks have been altered by contact with granitic intrusions, though as a rule the material is too poor in quality to be used as a gemstone. The gem varieties have been obtained chiefly from Brazil, where they are found in the Minas Novas district associated with topaz in gem gravels. These are usually green to red in colour, and are strongly pleochroic, the prisms showing a green colour when viewed at right angles to the prism edge, and red when viewed along the prism edge. These two colours are most readily observed by examining a fragment of cut stone with a dichroscope.

Cut specimens of the chiastolite variety are worn as charms. Large and excellent specimens have been found near Bimbowrie in South Australia, where they occur as rounded prisms five or six inches long embedded in schist.

Andradite (named after d'Andrada, a Portuguese mineralogist), a variety of garnet (see p. 297).

Apatite (Gr. *apate*, deceit; so named on account of its confusion by the older mineralogists with aquamarine and some other minerals resembling it in colour).

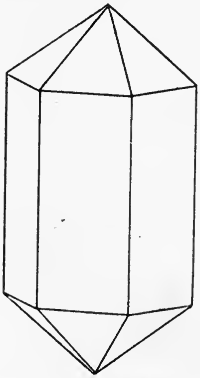

FIG. 172.—Apatite.

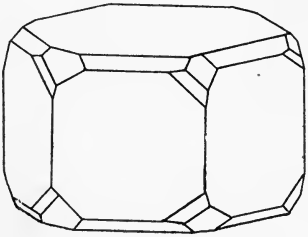

FIG. 173.—Apatite.

General.—Hexagonal, usually with a prismatic habit (figs. 172 to 174). No good cleavage. Fracture, conchoidal. Hardness, 5. Specific gravity, 3·2.

Optical.—Colour variable, but often pale green. Lustre, vitreous. Refractive index high, $\omega = 1{\cdot}638$. Birefringence, very low ($\omega - \epsilon = 0{\cdot}004$). Optical sign, negative. Microfragments irregular when obtained by crushing, but usually prismatic in sands and soils.

Chemical and blowpipe.—Phosphate of lime, with a little fluorine or chlorine, its composition corresponding to the formula $Ca_4(PO_4)_3 . CaF$, fluorine being replaceable by chlorine. Fusibility, about 5. Flame test bluish green, when powder is moistened with sulphuric acid, due to presence of phosphoric acid. Soluble in nitric acid, and the solution gives a yellow precipitate of ammonium phospho-molybdate when treated with a solution of ammonium molybdate.

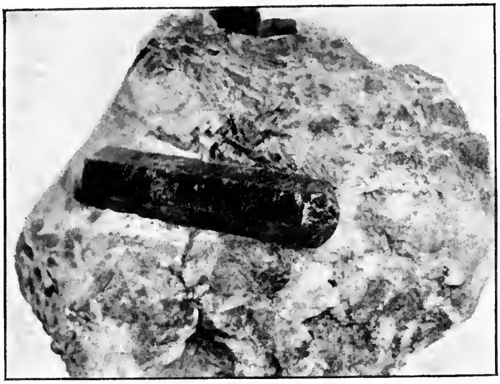

FIG. 174.—Apatite in crystalline dolomite, Renfrew Co., Ontario. ($\times \frac{1}{3}$). B.M.

Occurrence and distribution.—Apatite is widely distributed in rocks, but the common varieties are dull and useless as gemstones. Microscopically-small crystals of apatite are scattered through all kinds of igneous rocks, and are often abundant in masses of magmatically segregated iron ore. Basalts frequently contain a considerable amount of disseminated apatite, as also do the soils resulting from the disintegration of such basalts (fig. 175). Green apatite occurs at many localities. It occurs abundantly in association with phlogopite mica

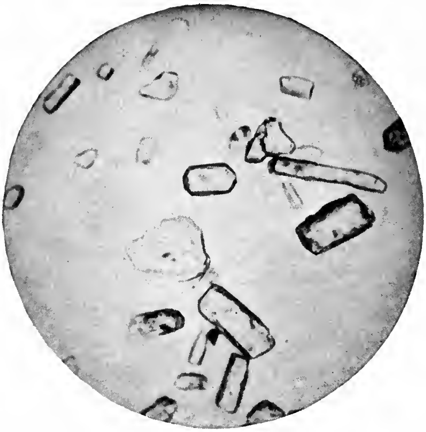

FIG. 175.—Apatite, from a residual soil on basalt.

in veins and pockets among the metamorphic rocks of Ottawa, Quebec, and other parts of Canada, where it has been obtained as a by-product in mica mining; though the chief use of the material thus obtained has been as a source of phosphate (see p. 395). Apatite is, indeed, on account of its softness, only rarely used as a gemstone. Sky-blue apatite occurs in the form of granules in crystalline limestones. Violet, pale red, and green varieties are found associated with tourmaline in granite at Mt. Apatite, near Auburn, Maine, U.S.A.

Aquamarine (L. *aqua*, water, and *marinus*, pertaining to the sea). Aquamarine, so named on account of its colour, is a variety of beryl (see p. 275).

Avanturine (Fr. *aventure*, chance; said to be so named because the method of making the artificial variety was discovered accidentally). The name avanturine is applied to certain varieties of quartz rock (see p. 312), and oligoclase felspar (see p. 295).

Axinite (Gr. *axine*, an axe).

General.—Triclinic. Usually found in the form of well-developed, flat crystals, to the axe-shaped edges of which the mineral owes its name (fig. 176). Also occurs massive. Fracture, conchoidal. Hardness, about 6½. Specific gravity, about 3·3.

Optical.—Colour usually clove-brown. Lustre, vitreous. Refractive index, high, $\gamma = 1{\cdot}68$. Birefringence, weak, $\gamma - \alpha = 0{\cdot}009$. Optical sign, negative. Strongly pleochroic in crystals and large fragments, showing pale green, brown, and blue colours when examined with a dichroscope. Microfragments irregular in shape and only feebly coloured.

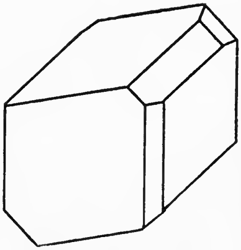

FIG. 176.—Axinite.

Chemical and blowpipe.—A boro-silicate of calcium and aluminium, with small amounts of iron and manganese, its composition being represented approximately by the formula

$$H_2O \,.\, 6CaO \,.\, B_2O_3 \,.\, 2Al_2O_3 \,.\, 8SiO_2.$$

Fusibility, about 2. Yields a quickly transient greenish colour due to boron when heated on platinum wire with acid potassium sulphate and fluorite in a Bunsen flame. Intumesces in blowpipe flame. Insoluble in ordinary acids.

Occurrence and distribution.—Axinite, like tourmaline and topaz, arises from the action of the exudations given off by granitic intrusions, and is usually found where granite occurs intrusive in calcareous rocks. Tourmaline, garnet and vesuvianite are commonly associated with it.

It is found as fine crystals in gneiss at Le Bourg d'Oisans in Dauphiné. Found also at Botallack near St. Just in Cornwall, and at various other localities.

Balas Ruby, a pale coloured, reddish or violet variety of spinel (see p. 314).

Benitoite (named from its occurrence in San Benito County, California).

General.—Trigonal. Occurs only as small crystals, usually not more than about 7 carats (1 metric carat = 200 milligrams). Fracture, conchoidal. Hardness, 6½. Specific gravity, 3·65.

Optical.—Colour, sapphire-blue. Lustre, vitreous. Refractive index very high, $\epsilon = 1{\cdot}804$. Birefringence, high, $\epsilon - \omega = 0{\cdot}047$. Optical sign, positive. Dichroism, strong; ϵ = sapphire-blue, ω = colourless. Microfragments irregular and to some extent sapphire-like in optical character, but distinguished readily from sapphire by its much higher birefringence and different optical sign.

Chemical and blowpipe.—A silico-titanate of barium, with a composition corresponding to the formula $BaO \cdot TiO_2 \cdot 3SiO_2$. Fusibility, 3, fusing readily in blowpipe flame to a transparent glass. Insoluble in ordinary acids.

Occurrence and distribution.—Benitoite is found in veins of natrolite (a hydrated silicate of sodium and aluminium), associated with neptunite (a silico-titanate of iron, sodium and potassium) near the head waters of the San Benito River in San Benito County, California. The natrolite veins occur in a lens of glaucophane-schist which is at least 1200 ft. long and 150 ft. thick, and the rock surrounding the schist is serpentine.

Beryl (including emerald, aquamarine, golden beryl, and rose beryl as varieties).

General.—Hexagonal, usually in the form of simple hexagonal prisms terminated by basal planes (fig. 31). Vertical striations on prism faces very frequent. No distinct cleavage. Fracture, uneven or conchoidal. Hardness, about 7½. Specific gravity, about 2·7.

Optical.—Common beryl is dull, yellowish or greenish white in colour, and opaque in large fragments. Emerald is of a brilliant grass-green colour and transparent. Aquamarine is pale greenish blue. Rose-pink and yellow varieties also occur. Lustre, vitreous. Refractive index, low, $\omega = 1{\cdot}584$. Birefringence low, $\omega - \epsilon = 0{\cdot}006$. Optical sign, negative. Microfragments irregular in shape.

Chemical and blowpipe.—Silicate of beryllium (glucinum) and aluminium, with a composition corresponding to the formula

$$3BeO \cdot Al_2O_3 \cdot 6SiO_2.$$

Fusibility, about $5\frac{1}{2}$; fuses only with difficulty on the edges in a blowpipe flame, yielding a white glass. Insoluble in ordinary acids, and not attacked appreciably even by hydrofluoric acid.

Common beryl is of fairly frequent occurrence among pegmatites and coarse-grained granites; but its dullness and lack of transparency render it of no value as a gemstone. It is used to a small extent in the manufacture of mantles for incandescent gas-lighting (see p. 411). Only the transparent varieties are of value as gemstones; and of these, emerald and aquamarine are the chief gem varieties, but rose beryl and golden beryl are also used.

Emerald.—The bright grass-green colour of emerald is probably due to the presence of chromium. As much as 0·2 or 0·3 per cent. of chromic oxide has been found in some emeralds, and this amount is quite sufficient to give a good green colour to glass. Emerald is slightly dichroic, the colour varying from a pure green or yellowish green to bluish green. Flawless and perfectly transparent specimens are very rare and extremely valuable, more so even than diamonds and rubies.

The most important locality for emeralds is Muzo in Colombia, where they are found in veins of calcite occurring in a black carbonaceous limestone of Lower Cretaceous age. The veins vary from an inch to two feet in thickness, but the best stones occur in veins less than six inches thick. The distribution of the veins is very irregular, and mining development is uncertain in its results, as the surface of the formation in which the emerald veins occur is overlain by a mantle of earthy matter, and is also jungle-covered. At Muzo, emerald is associated with quartz, pyrite, and gypsum.

Another important locality is on the Takovaya stream in the Ural mountains, about 57 miles east of Ekaterinburg, where emerald is found in mica-schist (fig. 177).

Another occurrence of emerald in mica-schist is that in the Eastern Desert of Egypt, where there are ancient workings of emerald in a dark mica-schist near the Red Sea at Sikait, Zabara and other places.

Emerald also occurs at various localities in North Carolina, U.S.A. A notable occurrence is that near Shelby in Cleveland County, where emerald occurs in pegmatite veins. It is thought that the granitic magma from which these pegmatites were derived obtained the chromium which the emerald contains by the absorption of chromium-bearing igneous rocks into which they intrude.

Aquamarine.—Aquamarine is a pale coloured transparent variety of beryl. The colour is typically a pale greenish blue, suggestive of the colour of clear sea-water—hence the name aquamarine. The colour is probably due to iron oxide. The deeper-coloured varieties show an appreciable pleochroism, one of the colours seen with the dichroscope being pale blue, the other almost colourless.

Aquamarine occurs in drusy cavities in granites. Notable among the more important localities are: the Minas Novas district of Minas Geraes, Brazil, where aquamarine occurs as pebbles in gravel, associated with topaz and chrysoberyl; the neighbourhood of Rio Janeiro, where it occurs in coarse-grained granite; and the Ural mountains, where it occurs associated with topaz in the drusy cavities of a coarse-grained granite.

FIG. 177.—Emerald in schist, Takovaya stream, Urals. (× ½). B.M.

ROSE BERYL is a transparent pink variety. It is found at Mount Bity in Madagascar, where it occurs in pegmatites that traverse metamorphic rocks, and is associated with amazonstone, tourmaline, lepidolite, and kunzite. Occurs also in San Diego Co., California, associated with topaz and lepidolite in pegmatites.

GOLDEN BERYL is the clear yellow variety. A clear yellow variety known in the gem trade as "heliodor" has been obtained from pegmatites near Rössing in South-West Africa.

Bloodstone, see plasma (p. 279).

Bone Turquoise (also named *odontolite* and *fossil turquoise*). Under these names are described certain varieties of fossil bone that have become coloured sky-blue by the absorption of iron phosphate. Most specimens of bone turquoise are fossil teeth of the Mastodon and other extinct vertebrates. Bone turquoise can be distinguished from genuine turquoise by its specific gravity, which varies from 3 to 3½ (turquoise is about 2·7); and by the fact that it effervesces with hydrochloric acid due to the presence of calcium carbonate, whereas true turquoise does not effervesce.

Cairngorm, a brown variety of smoky quartz (see p. 312).

Californite, a variety of vesuvianite (see p. 321).

Callaite = Turquoise (see p. 319).

Callainite.—A green stone with a composition closely resembling that of turquoise. A hydrated phosphate of aluminium, with a composition corresponding to the formula $Al_2O_3 . P_2O_5 . 5H_2O$. Microcrystalline in texture. Hardness, about 4. Specific gravity, about 2·5. It is probably the microcrystalline equivalent of variscite, a green orthorhombic phosphate of aluminium almost identical in composition with callainite. It differs from turquoise in being translucent. Found as rounded pieces in a Celtic grave in Brittany.

Carbuncle, a name given to various deep-red stones, chiefly the ruby and the deep-red garnets.

Carnelian, a variety of chalcedonic silica (see p. 279).

Cat's Eye.—The name cat's eye is given to certain varieties of quartz (see p. 313) and chrysoberyl (see p. 280) that show a peculiar wavy opalescence, or chatoyancy as it is sometimes called, and are supposed to resemble the eye of a cat.

Ceylonite = Pleonaste, a variety of spinel (see p. 314).

Chalcedony (name derived from Chalcedon, an ancient place-name in Asia Minor).

General.—Found only in the form of massive aggregates with a finely fibrous or cryptocrystalline texture. Frequently in mammiform or botryoidal shapes. Fracture, uneven. Hardness, 7. Specific gravity, about 2·6.

Optical.—Ordinary chalcedony is colourless, whitish or greyish. *Carnelian* is flesh-red; *sard* is brownish red; *chrysoprase* is apple-green; and *plasma* is leek-green. Refractive index, about 1·54. Birefringence, low. Always shows the aggregate polarization effect between crossed nicols, the radially fibrous masses showing a good cross.

Chemical and blowpipe.—Consists essentially of silica, having the same composition as quartz (SiO_2). Infusible. Insoluble in ordinary acids.

Occurrence and distribution.—Chalcedony and its different colour-varieties as enumerated below occur chiefly as infillings of cracks and other cavities in volcanic rocks. The amygdales found so abundantly in these rocks, especially in the basalts, consist frequently of some variety of chalcedony. The substance of the basalt weathers away under atmospheric influences with comparative ease; but the chalcedonic amygdales are very resistant, and remain behind in the earthy surface residue that results from weathering, or find their way into streams and beach deposits.

AGATE is a banded variety of chalcedony, the different bands differing in colour and transparency (fig. 178). *Onyx* is the variety in which milk-white bands alternate with darker bands, and if the latter are of a brownish red colour the stone is called *sardonyx*.

Agates occur abundantly as amygdales in basic volcanic rocks. These amygdales are formed by the infilling of cavities with silica that has been dissolved by water traversing the rock. and afterwards deposited in the cavities. In Scotland, the agates known as "Scotch pebbles" are derived from the Lower Old Red Sandstone andesites. An important European locality is the district traversed by the Nahe, a tributary of the Rhine in the Principality of Birkenfeld. In this part of Germany there is a large industry in cutting and polishing, mostly at Oberstein and Idar. These works, however, obtain comparatively little of their agate from Germany; most of it is imported from South America, which is now the chief source of this stone.

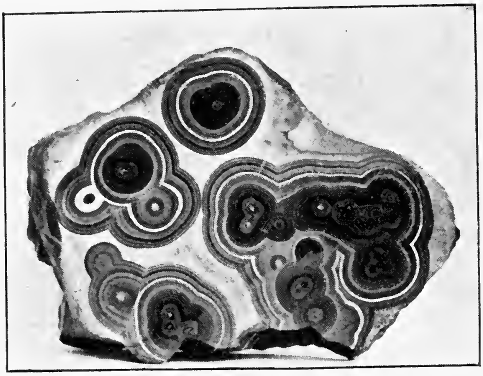

FIG. 178.—Agate, Uruguay. (×⅓). B.M.

Agate occurs abundantly in Brazil and Uruguay, where, as usual, it is found in the form of amygdales that are scattered through the basalts of the region. These basalts weather to a ferruginous clay from which the hard resistant agates are easily separated.

In India also, agates occur abundantly as amygdales in the basalts of the Deccan Trap, which covers an immense area in various parts of

Central India, where agate polishing has for long been an important native industry.

CARNELIAN and SARD.—Carnelian is a red and sard a brownish red translucent variety of chalcedony. The colour is due to iron oxide. The dull yellow variety of chalcedony, which also owes its colour to iron oxide, becomes red on heating. Many carnelians were originally yellow or brownish yellow stones, and have been reddened by heat, which dehydrates the iron oxide and converts it into the hæmatite variety. The mode of occurrence of carnelian is the same as that of agate. The Rajpipla Hills, to the south of Baroda, in India, is an important locality. Another important locality is Campo de Maia, Brazil, where carnelian occurs associated with agate.

CHRYSOPRASE is an apple-green variety of chalcedony, which owes its colour to the presence of a small amount (much less than 1 per cent.) of nickel. The natural stone becomes bleached on exposure to the sun, but the colour can be restored by treatment with nickel sulphate solution. Ordinary white chalcedony assumes the appearance of chrysoprase when treated with nickel sulphate solution, and such artificial chrysoprase is said to be more stable in colour than is the natural stone.

Chrysoprase occurs in the form of veins, and arises as a product of weathering in serpentine rock. It occurs in this way in serpentine at various localities in Silesia, associated with asbestos, magnesite, and pimelite (a silicate of nickel). There is a somewhat similar occurrence associated with nickel ore in serpentine near Riddle, in Oregon, U.S.A.

PLASMA is a leek-green variety of chalcedony. It is almost opaque owing to the presence of numerous and densely packed inclusions that give the stone its colour. Its mode of occurrence is the same as carnelian. It is worked at various localities in the Deccan Trap area of India; and occurs also near Oppenau in the Black Forest, Germany. A variety of plasma with small red spots is called *heliotrope* or *bloodstone*.

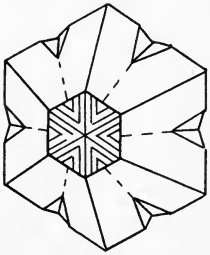

FIG. 179.—Chrysoberyl.

Chrysoberyl (Gr. *chrysos*, golden), including *Cymophane* and *Alexandrite*.

General.—Orthorhombic; often in the form of pseudo-hexagonal crystals due to repeated twinning on the prism face (fig. 179). Cleavage, imperfect. Fracture, conchoidal. Hardness, 8½. Specific gravity, about 3·7.

Optical.—Colour, yellow to green, red by transmitted light in alexandrite if suitably cut. Lustre, vitreous. Refractive index, high, $\gamma = 1{\cdot}75$. Birefringence low, $\gamma - \alpha = 0{\cdot}009$. Optical sign, positive. Pleochroism weak in the yellow varieties but strong in the green variety. Microfragments irregular in shape.

Chemical and blowpipe.—Aluminate of beryllium, with a composition corresponding to the formula $BeO . Al_2O_3$. Infusible. Insoluble in ordinary acids. Yields the characteristic blue due to alumina when heated on charcoal in oxidizing flame after moistening with cobalt nitrate.

Occurrence and distribution.—Considered as a gemstone, chrysoberyl may be regarded as comprising three varieties, viz. (1) Ordinary chrysoberyl, (2) Cymophane, and (3) Alexandrite.

ORDINARY CHRYSOBERYL is usually of a yellow or yellowish green colour; and is never more than faintly pleochroic. It is transparent or nearly so. It is found chiefly in the Minas Novas district of Minas Geraes, Brazil, where it occurs as small pebbles in alluvium, associated with amethyst, tourmaline, garnet, spinel, and topaz. It is found also in Ceylon gem gravels.

CYMOPHANE (Gr. *kyma*, a wave, and *phaino*, to show). Cymophane is the cat's eye variety of chrysoberyl. It is translucent, and owes its name to its wavy opalescence or chatoyancy, a property due to the presence of microscopic fibrous inclusions. The term cat's eye refers to the same feature, and is applied also to various other minerals which exhibit this property, but especially to a variety of quartz (see p. 313).

The chief locality for cymophane is Ceylon, where it is found as pebbles in the gem gravels, associated with sapphire.

ALEXANDRITE (named after Czar Alexander II. of Russia). This is a dark-green variety of chrysoberyl (fig. 180). It is strongly pleochroic, the colour varying from green to purplish red. In daylight the stone is green, and the red is not perceptible; but if suitably cut it shows the red colour in transmitted and artificial light, although green in daylight. Alexandrite occurs with emerald, in a mica-schist that has been metamorphosed by contact with granite, at a locality on the Takovaya stream in the Ural mountains. It is found also in the Ceylon gem gravels.

Chrysolite (Gr. *chrysos*, golden; and *lithos*, stone). Among mineralogists, chrysolite is a synonym for ordinary olivine; but users of gemstones apply the name to the yellow variety of olivine rather than to the green variety. The latter also often apply the name chrysolite to ordinary chrysoberyl. These two minerals closely resemble each other in general appearance, but differ considerably in hardness and specific gravity.

Chrysoberyl (3·7) sinks in methylene iodide, whereas olivine (3·3) just floats.

Chrysoprase, an apple-green variety of chalcedony (see p. 279).

Cinnamon Stone = **Hessonite**, a yellowish-red and ferriferous modification of grossularite, the lime-alumina variety of garnet (see p. 297).

Citrine (L. *citrinus*, from *citrus*, a lemon) a yellow variety of quartz (see p. 312).

Coral.—Like pearl, coral is an organic secretion consisting chiefly of calcium carbonate and it is not usually regarded as a mineral. Red coral gives its name to the species *Corallium rubrum* by which it is secreted. Black coral is secreted by the Antipatharian corals. Both these varieties of coral belong to the Actinozoa, the group of the Cœlenterata to which the common sea-anemone belongs.

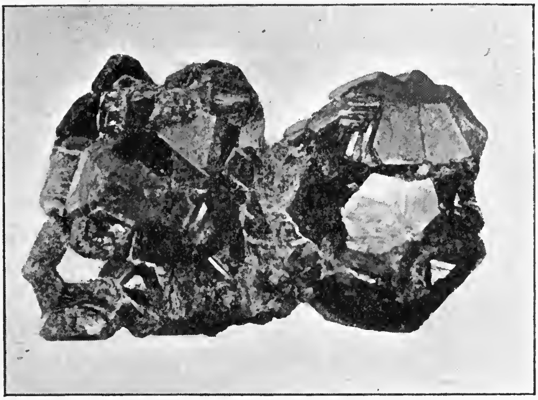

FIG. 180.—Alexandrite, Takovaya stream, Urals. ($\times \frac{1}{2}$). B.M.

Cordierite, so named after Cordier, the French geologist; also called *iolite* (see p. 300), *dichroite* (see p. 289), and *water-sapphire* (Fr. *sapphir d'eau*).

General.—Orthorhombic. No distinct cleavage. Fracture, conchoidal. Hardness, about $7\frac{1}{2}$. Specific gravity, about 2·6.

Optical.—Colour, blue. Lustre, vitreous. Refractive index, low, $\gamma = 1{\cdot}54$. Birefringence, low, $\gamma - \alpha = 0{\cdot}008$. Optical sign, negative. Microfragments irregular in shape. Pleochroism strong, blue to colourless or yellow.

Chemical and blowpipe.—A silicate of aluminium, magnesium, and iron, with a composition corresponding to the formula

$$2(Mg, Fe)O \,.\, 2Al_2O_3 \,.\, 5SiO_2.$$

Fusibility, 5, fusing with difficulty on sharp edges. Insoluble in ordinary acids, or nearly so.

Occurrence and distribution.—Cordierite is widely distributed in granites, gneisses, and schists, usually in the form of irregular grains, and is seldom of sufficiently good quality to be used as a gemstone. Material suitable for gems occurs at Haddam, Connecticut, U.S.A.; also in gneisses at Kragerö in Norway, and Bodenmais in Bavaria. At Bodenmais, cordierite is associated with pyrite, pyrrhotite, chalcopyrite and zinc-blende. In the Ceylon gem gravels, cordierite is found as small pebbles, which are transparent, and of an intense blue colour.

Corundum (Hind., *karand*), including the gem varieties *ruby* and *sapphire.*

General.—Trigonal, occurring frequently as six-sided prisms or pyramids (fig. 181). The basal plane frequently shows triangular striations (fig. 58). Flawless corundum shows no cleavage, and has a conchoidal fracture; and gem corundum is of this character. Parting planes along the basal and rhombohedral faces are frequently present in ordinary varieties, and crystals can often be split readily along these planes. Hardness, 9. Specific gravity, about 4.

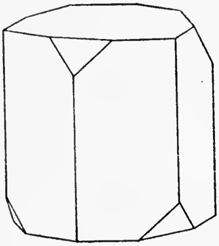

FIG. 181.—Corundum.

Optical.—Colour very variable, as indicated by the numerous names of its colour varieties; for in addition to the true or "*oriental*" *ruby* which is red, and the true or "*oriental*" *sapphire* which is blue, there are the "*oriental aquamarine,*" "*oriental emerald,*" "*oriental chrysolite,*" "*oriental topaz,*" "*oriental hyacinth*" and "*oriental amethyst,*" all of which are different colour-varieties named after other gemstones, the colours of which they resemble, with the qualification "oriental" by way of distinction. There is also a colourless, transparent variety, known as "*leuco-sapphire*" or "*white sapphire*" and a translucent, brown variety which receives the name "*adamantine spar.*" Another variety which shows the phenomenon known as asterism is called "*star sapphire.*" It exhibits a six-rayed star when viewed along the principal axis. This effect is accompanied by opalescence, and the phenomenon is supposed to be due to the presence of inclusions, which have a linear arrangement parallel to the faces of the prism; though by some mineralogists it is attributed to lamellar twinning on the faces of the rhombohedron. Lustre, usually vitreous. Refractive index, high, $\omega = 1{\cdot}767$. Birefringence, low, $\omega - \epsilon = 0{\cdot}008$. Optical sign, negative. Microfragments irregular, except when parting planes are present, and then platy in part. Pleochroic, the ordinary ray being the more absorbed.

Chemical and blowpipe.—Oxide of aluminium with a composition corresponding to the formula Al_2O_3. Infusible. Yields the characteristic blue, due to alumina, when heated on charcoal in oxidizing flame after moistening with cobalt nitrate. Insoluble in ordinary acids.

Occurrence and distribution.—Corundum occurs in a great variety of ways. It occurs as a product of crystallization from igneous magmas, as in syenites and peridotites. It also occurs as a product of thermal metamorphism in gneisses, schists, and crystalline dolomites; and in consequence of its highly resistant character it is found abundantly in the alluvial detritus arising from the denudation of these rocks. Of all these modes of formation it is the formation in crystalline dolomite or dolomitic limestone and pegmatite veins that has been most favourable for the production of stones of gem quality. The corundum of syenites is usually of an imperfectly transparent type, and suitable only for use as an abrasive, even when occurring as well-developed crystals. That occurring in peridotites and schists is usually massive and granular, and is likewise suited only for use as an abrasive. For further remarks on corundum as an abrasive, see p. 323. In the following remarks the occurrence and distribution of ruby and sapphire are dealt with separately, as these are by far the most important gem varieties of corundum.

Ruby.—The chief source of ruby is the Mogok district of Upper Burma, where it occurs associated with spinel, graphite, phlogopite, and pyrrhotite, as a product of thermal metamorphism in crystalline dolomitic limestone, the metamorphism having been produced by granite intrusions. The rubies have accumulated in the earthy residues that have been formed by the weathering of the limestone, and are found also as pebbles in the stream deposits. The earthy residue from the weathering of the limestone not only forms a surface sheet, but also fills up the pipes and caverns that occur in this as in most other limestone districts.

Other notable sources of ruby are the gem gravels of Siam and Ceylon, in both of which countries the ruby may have been derived in part from thermally metamorphosed dolomitic limestone much like that in which it occurs in Burma.

The best rubies of Burma have a characteristic red colour—the so-called " pigeon's blood " red. The cause of this colour is not exactly known, but it can be imitated artificially in synthetic corundum by the addition of chromic oxide, and this constituent is thought by some to be the colouring agent in the natural stone.

Synthetic gem corundum is made from precipitated alumina by fusion in an inverted blowpipe flame, and by allowing the fused drops of alumina to accumulate in a pear-shaped mass, which on cooling assumes a homogeneously crystalline condition, and has all the properties of crystalline corundum. When no colouring agent is used, the fused product is colourless, and is indeed artificial "leuco-sapphire," or "white sapphire," as it is more commonly called. By the addition of two or three per cent. of chromium alum to the ammonium alum from which the alumina is precipitated, it is found that the fused product assumes the colour characteristic of the best gem ruby. The only way in which such an artificial ruby can be distinguished from the natural ruby is by the presence in it of air-bubbles and curved streaks differing markedly from the inclusions with rectilinear boundaries that characterize the natural ruby.

Synthetic rubies made in this way should be distinguished from *re-constructed rubies,* which are made by fusing together small fragments of natural ruby to make larger stones.

Sapphire.—Sapphire and ruby are generally found together, sometimes one predominating, and sometimes the other. They occur together in Burma, Siam, and Ceylon; but whereas in Burma, sapphire is scarce in comparison with ruby, in Siam and Ceylon there is a great preponderance of sapphire.

The chief locality for sapphire is Battambang in Siam, where this gemstone is found in a loamy alluvial deposit. Ruby occurs in association with it, but is much less abundant and of poorer quality than the ruby of Burma.

Sapphire also occurs in the Ceylon gem gravels, notably in the Ratnapura district and the hilly region to the north. These Ceylon gem-gravels have been formed by the disintegration of the ancient metamorphic rocks that build up the mountainous mass of central Ceylon, and occur chiefly in the area to the south and west of the mountains. The pegmatites that traverse the metamorphic rocks contain a rich assortment of minerals, including sapphire. In the Ceylon gravels the sapphire is associated with ruby, topaz, amethyst, garnet, chrysoberyl, an abundance of zircon, and numerous rare-earth minerals, notably monazite, thorite, and thorianite.

Sapphire also occurs to a considerable extent in the alluvial deposits of the Zanskar Range of Kashmir in northern India. The parent rock at this locality is a granite which occurs as veins in a formation of schists, gneisses and crystalline limestone. The sapphire in this rock is associated with dark brown tourmaline.

Of the remaining sources of sapphire, the most notable are the surface gravels of Anakie in Queensland, Australia, and the alluvial deposits of various localities in Montana, U.S.A. The chief occurrence in Montana is at Yogo, in Fergus county, where sapphire occurs in a dyke of decomposed porphyrite. The dyke is from 8 to 20 feet thick. It traverses shales and limestones, and weathers readily at the surface, yielding a soft clayey mass.

Artificial sapphire can be made in the same way as artificial ruby, using iron and titanium oxides, or titanium oxide alone, instead of chromic oxide, as the colouring agents.

Cyanite = **Kyanite** (see p. 302).

Cymophane, a variety of chrysoberyl (see p. 280).

Demantoid, a variety of garnet (see p. 298).

Diamond (Fr. *diamant*, corruption of " adamant " from Gr. *adamas*, the name having reference to the extreme hardness of the mineral).

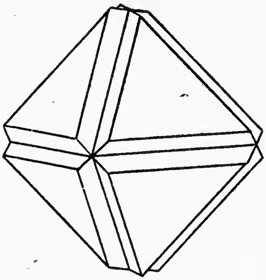

FIG. 182.—Diamond.

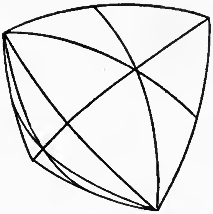

FIG. 183.—Diamond.

General.—Cubic, occurring frequently in the form of octahedral crystals (fig. 11), or hexakisoctahedron (fig. 8). The edges of the octahedron are sometimes grooved due to twinning (fig. 182), and the symmetry is really that of the tetrahedrite class (fig. 183). Crystal faces usually rounded. Also in the form of pebbles and irregular masses, especially so in the case of *carbonado*, the black, opaque and imperfectly crystalline variety. Cleavage, octahedral and perfect, except in carbonado, which has no cleavage. Hardness, 10. Specific gravity, 3·5.

Optical.—Generally colourless or slightly yellowish; occasionally blue, green, and red. Lustre, adamantine. Refractive index, extremely high, $\mu = 2{\cdot}417$. Microfragments are normally isotropic. Readily distinguished from other colourless stones by its extremely high refractive index. A feeble irregular birefringence is often seen in diamond, as in other cubic crystals, and in glass, due to a condition of strain; but this is not likely to be confused with the birefringence effect exhibited by normally anisotropic crystals such as quartz, corundum, and typical zircon. It is worthy of note that highly refractive artificial glass, which is isotropic in microfragments and is often made as a cheap imitation of diamond, cannot be made with a refractive index higher than 1·8, and is therefore readily distinguished from diamond by this fact, and by its softness.

Chemical and blowpipe.—Diamond consists of pure carbon. Infusible; but can be burned away slowly, forming carbon dioxide gas. Insoluble in acids.

The factors of importance in distinguishing the diamond from other precious stones and artificial imitations are its hardness, its extremely high refractive index, and the fact that it is isotropic or shows only a feeble anomalous birefringence. Quartz or rock-crystal, which is sometimes called "fool's diamond" on account of the frequency with which it is mistaken for diamond, is only likely to be confused with the latter mineral by those who are quite ignorant of minerals and their properties. Colourless zircon, on the other hand, owing to its high refractive index, often deceives people who have had some experience with minerals, although its hardness and refractive power are far inferior to those of the diamond. Moreover, such small crystals of zircon as are liable to be mistaken for diamond almost invariably show a strong birefringence (see p. 321) and can by this fact be readily distinguished even when their tetragonal crystal form is not obvious.

Origin, occurrence and distribution.—The chief source of diamonds is South Africa. India and Brazil, which formerly produced the world's supply, contribute now a comparatively small amount. There are also unimportant occurrences in North America, Borneo, and Australia.

Almost the whole of the world's supply at present comes from South Africa, where diamond occurs at numerous localities. In some of these localities, as at Kimberley in the northern part of the Cape province, at Jagersfontein in Orange River Colony, and near Pretoria in the Transvaal, the diamond is obtained by mining the parent rock. It is from this type of occurrence, and more especially that at Kimberley, that the supply of diamonds is chiefly obtained. At other localities, as in the Vaal River basin, the Orange River valley, and especially on the Great Namaqualand coast of South-West Africa, the diamond is obtained from alluvial deposits.

In recent years South-West Africa has contributed very largely to the output of diamonds in South Africa. The diamond deposits of the Great Namaqualand coast are found chiefly around and to the south of Lüderitz Bay. The diamonds are mostly in the form of small colourless or pale-tinted crystals scattered through the sand and gravel, though in some places they have been concentrated by wind action. The crystals are usually so small that four or five are required to make up one carat (one metric carat = 200 milligrams); but larger stones are found in the Bogenfels and Pomona districts, and at Pomona a stone weighing about 34 carats has been obtained.

The parent rock of the diamonds on the Namaqualand coast has not yet been discovered. It seems probable, however, that they have been derived from intrusive peridotites. Such intrusives in the form of pipes occur in this region, though hitherto no diamonds have been found in them.

The proportion of diamonds in the sand and gravel of the Namaqualand coast is very variable. At Kolmanskop the average yield over a period of a year was found to be about two-fifths of a carat per cubic metre. Further south, at Pomona, gravel containing 60 carats to the cubic metre has been worked.

Although diamonds are obtained in large quantities from alluvial deposits in South Africa, most of the gemstone is obtained from an altered basic igneous rock, which receives the name *kimberlite* from its occurrence at Kimberley, where intrusive pipes of this rock have been extensively worked and have yielded an immense number of diamonds.

Kimberlite, or "blue ground" as it is often called, is a complex rock consisting largely of serpentine, which has arisen from the hydration of olivine. It is thus an altered peridotite. Numerous other minerals mostly of a basic character are present, notably ilmenite, garnet (pyrope variety), diopside, enstatite, bronzite, phlogopite, picotite (chrome-spinel), and zircon.

The kimberlite occurs in the form of intrusive pipes and dykes traversing Karroo and older rocks. These intrusions are probably of Lower Cretaceous age. For some time only the pipe-like form of occurrence was known; but the pipes are now known to be connected with the more ordinary dyke type of intrusion, of which they are presumably local modifications. The diamond, however, occurs rarely in the dykes as compared with the pipes. These pipes vary considerably in their dimensions; as a rule they are not more than two or three hundred yards in width, and are often much less; but in one or two cases they are about half a mile in width. The famous Kimberley pipe has a roughly oval cross section, and an average surface width of about 260 yards, but the width diminishes with the depth. The material of this pipe has now been removed to a depth of over 1100 feet. The pipe has been developed down to a depth of over 3500 feet, at which depth it is still diamond-bearing; and there seems to be every probability that it will continue to be so down to the greatest depths at which mining can be carried on. The pipe-rock is considered good if it yields on the average one carat of diamond per ton.

Near the surface, where the kimberlite pipes are exposed to weathering, the rock becomes partially decomposed, forming what is termed "yellow ground," to distinguish it from the unweathered "blue ground" or kimberlite. In this partly decomposed condition the material of the pipes is much more friable and easily worked.

The largest diamond known, the "Cullinan diamond," was obtained from a kimberlite pipe at the Premier mine near Pretoria, Transvaal. It weighed 3106 metric carats, or about 1⅓ lb. avoirdupois (one metric carat = 200 milligrams).

The origin of diamond in kimberlite is a subject that has been very much discussed. Perhaps the view most widely favoured at the present time is that carbon was an original constituent of the kimberlite magma, and that it crystallized as diamond during the process of consolidation. The existence of diamond as a constituent of the ground-mass of kimberlite, the fact that diamond occurs embedded in olivine, and the further fact that diamond occurs in peridotites elsewhere, as in British Columbia, all give strong support to this view. Some have held the view that the kimberlite magma obtained its supply of carbon from the Karroo carbonaceous shales; but this view appears to be rendered untenable by the fact that diamonds occur in the kimberlite irrespective of the invaded rock, and are found in places and at depths where Karroo shales are absent. According to a third view, the diamond was formed originally at a great depth as a constituent of eclogite, and the presence of diamond in the kimberlite is due to the fact that this diamond-bearing eclogite became incorporated in the kimberlite intrusion. Eclogite is a rock consisting of garnet and omphacite, and it is of interest to note that diamantiferous eclogite occurs in the kimberlite.

The evidence as a whole undoubtedly supports the view that carbon is one of the constituents of certain deep-seated basic rocks. It seems highly probable that, in the case of South Africa, the diamond existed at great depths, possibly as a constituent of eclogite, prior to eruption; that the kimberlite magma was formed in part from an incomplete fusion of this eclogite; and that a portion of the diamond persisted in the residual fragments of eclogite, although the greater part of it was dissolved by, and re-crystallized from, the kimberlite magma.

In central and southern India, diamonds have been obtained at various localities. A notable locality is that near Panna, in the Bundelkhand region of central India, where the gemstone occurs in a bed of conglomerate that lies between shales and sandstones of Upper Vindhyan age (Older Palæozoic). The conglomerate is not more than two feet thick, and the diamond is associated with pebbles of jasper. The diamond is also found in detrital deposits derived from the Vindhyan beds.

In Brazil, diamond occurs near Diamantina in the State of Minas Geraes, in surface gravels and earthy deposits that are in part cemented with iron oxide. The rocks of the area consist chiefly of geologically ancient micaceous sandstones. These sandstones overlie the fundamental schists and gneisses which are traversed by quartz veins; but the diamond gravels are said to be found only in those areas where the micaceous sandstone occurs, and it is therefore inferred that the diamond-bearing gravels have been formed by the disintegration of the micaceous sandstones. The minerals associated with diamond in Brazil include gold, monazite, tourmaline, kyanite, rutile, magnetite and hæmatite. Of other Brazilian localities, the most important are those of the State of Bahia, where the mode of occurrence is the same as that at Minas Geraes, but where the diamond is chiefly of the carbonado variety.

Small crystals of diamond are found associated with chromite in peridotite at Olivine mountain on the south side of the Tulameen river, in British Columbia. The diamonds hitherto found at this locality are too small to be of any value; but the occurrence is interesting as one in which diamonds are found in a matrix of peridotite.

Another locality where diamonds are found in the parent rock is that near Murfreesboro, in Pike Co., Arkansas; at this locality diamonds have been mined from an altered intrusive peridotite.

Dichroite (so named because of its pleochroism) = **Iolite** = **Cordierite** (see p. 281).

Diopside (Gr. *dia*, through, and *opsis*, a view).

General.—Monoclinic, usually granular. Two good cleavages parallel to prism faces and intersecting at about 87°. Hardness, about $5\frac{1}{2}$. Sp. gr. about 3·3.

Optical.—Colourless to pale green. Lustre, vitreous. Refractive index, high, $\gamma = 1{\cdot}7$. Birefringence high, $\gamma - \alpha = 0{\cdot}030$. Optical sign, positive. Microfragments have prismatic shapes, and give an extinction angle of about 30°. Non-pleochroic.

Chemical and blowpipe.—A silicate of calcium and magnesium, usually with a little iron replacing magnesium; its composition corresponds to the formula $CaO\,.\,(Mg, Fe)O\,.\,2SiO_2$. Fusibility, 4. Insoluble in ordinary acids.

Occurrence and distribution.—Diopside is widely distributed in basic igneous, as well as in metamorphic rocks. It is one of the products of thermal metamorphism in crystalline dolomites and dolomitic limestones. Material of gem quality is, however, not frequently found. Good crystals occur associated with hessonite and talc in serpentine, in the Ala valley, Piedmont, and at various other localities, but the mineral is not much used as a gemstone.

Dioptase (Gr. *dia*, through; and *optazo*, I see; in allusion to the fact that the rhombohedral cleavage can be seen by looking through a crystal of this mineral).

General.—Trigonal, usually showing a hexagonal prism combined with a rhombohedron (fig. 184). Cleavage, rhombohedral. Hardness, 5. Specific gravity, about 3·3.

Optical.—Colour, emerald-green, but rather darker than the emerald. Lustre, vitreous. Refractive index, high, $\epsilon = 1{\cdot}72$. Birefringence, high, $\epsilon - \omega = 0{\cdot}056$. Optical sign, positive. Microfragments rhomboidal in shape, showing symmetrical extinction and an excentric uniaxial figure.

Chemical and blowpipe.—Hydrated copper silicate, with a composition corresponding to

$$CuO . SiO_2 . H_2O.$$

Infusible. Yields the copper flame test, copper beads in borax and microcosmic salt, and metallic copper with sodium carbonate on charcoal. Gives off water in a closed tube, and turns black. Decomposes in hydrochloric acid, yielding gelatinous silica.

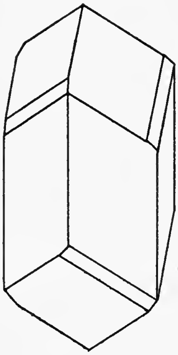

FIG. 184.—Dioptase.

Occurrence and distribution.—Dioptase has been found chiefly at Altyn Tübe in the Khirgiz Steppes, where it occurs with calcite in veins traversing a limestone. Another notable locality is Mindouli, in the French Congo. Dioptase occurs associated with copper ores at Otavi in South-West Africa, Clifton in Arizona, U.S.A., and at Copiapo in Chile; but it is not much used as a gemstone.

Disthene (Gr. *di*, twice; and *sthenos*, strong; in allusion to the fact that when the main face of a crystal or cleavage fragment is scratched, it is much harder across, than along, the length) = **Cyanite** = **Kyanite** (see p. 302).

Elæolite (Gr. *elaion*, oil, so named on account of its greasy lustre). A variety of nepheline occurring in syenite.

General.—Hexagonal, the prism being well developed in the vitreous variety nepheline, but not so often seen in elæolite, which is usually massive. No good cleavage. Fracture, sub-conchoidal. Hardness, about 5½. Specific gravity, about 2·6.

Optical.—Colour greyish or brownish. Lustre, greasy. Gem varieties are opalescent. Refractive index, low, $\omega = 1{\cdot}543$. Birefringence, very low, $\omega - \epsilon = 0{\cdot}005$. Optical sign, negative. Microfragments irregular in shape.

Chemical and blowpipe.—A silicate of sodium, potassium, and aluminium, with a composition corresponding to the formula

$$3Na_2O \, . \, K_2O \, . \, 4Al_2O_3 \, . \, 9SiO_2.$$

Fusibility, 4; fuses to a colourless glass. Decomposed by hydrochloric acid, yielding gelatinous silica, and under the microscope, the characteristic hopper-shaped crystals of sodium chloride are obtained.

Occurrence and distribution.—Occurs in syenites, notably in Norway. The opalescent variety has been used to a small extent as a gemstone, but is of very little value for this purpose.

Emerald, the brilliant grass-green variety of beryl (see p. 275).

Enstatite (Gr. *enstates*, an opponent, in allusion to its refractory character).

Enstatite constitutes with hypersthene the group of orthorhombic pyroxenes. These consist of magnesium silicate ($MgO \, . \, SiO_2$), with a variable amount of iron oxide replacing magnesia.

General.—Orthorhombic. Cleavage, good. Hardness, about 5½. Specific gravity, about 3·2.

Optical.—Colourless to brownish, lacking the deep colour of hypersthene. Refractive index, high, γ about 1·66. Birefringence, low, $\gamma - \alpha = 0{\cdot}009$. Optical sign, positive. Microfragments prismatic, showing straight extinction but weak pleochroism compared with hypersthene.

Chemical and blowpipe.—Silicate of magnesium ($MgO \, . \, SiO_2$) with some iron oxide replacing magnesia. Infusible or nearly so. Insoluble in ordinary acids.

Occurrence.—Enstatite has a widespread distribution as a constituent of basic igneous rocks, notably the gabbros. It occurs associated with the diamond in South Africa (see p. 287), where it is found in the form of small green stones that are locally known as "green garnet" and are cut to some extent for gems.

Compare description of hypersthene (see p. 300).

Epidote (Gr. *epidosis*, increase; in allusion to the fact that the base of the prism is longer on one side than the other).

General.—Monoclinic, the crystals being of prismatic shape (fig. 185), and elongated in the direction of the symmetry axis. Basal cleavage, perfect. Hardness, about $6\frac{1}{2}$. Specific gravity, about 3·4.

Optical.—Colour, dark green. Lustre, vitreous. Refractive index, high, $\gamma = 1{\cdot}767$. Birefringence, high, $\gamma - \alpha = 0{\cdot}040$. Microfragments partly irregular in shape; and partly prismatic, with a straight extinction. Strongly pleochroic. The microfragments are mostly basal plates and show an almost centric emergence of one of the optic axes, the interference figure in these being a single bar with closely packed concentric rings.

Chemical and blowpipe.—A silicate of calcium and aluminium, with small amounts of iron and water, its composition corresponding to the formula $4CaO \cdot 3(Al, Fe)_2O_3 \cdot 6SiO_2 \cdot H_2O$. Fusibility, about $3\frac{1}{2}$. Partially decomposed by hydrochloric acid.

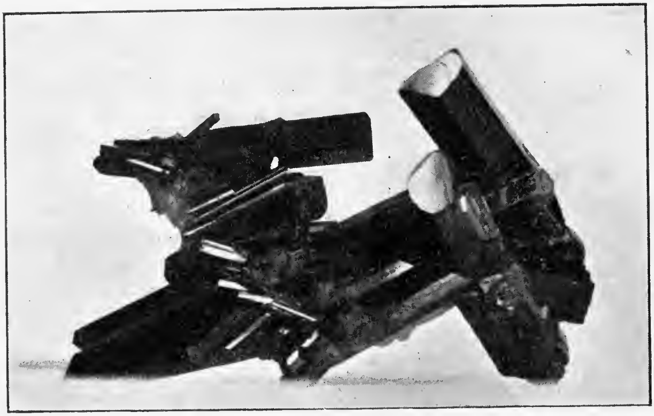

FIG. 185.—Epidote, Untersulzbachthal. (× ½). B.M.

Occurrence and distribution.—Ordinary epidote is widely distributed in gneisses and schists, but crystals of gem quality have been chiefly obtained on the Knappenwand, in the Untersulzbachthal, Salzburg, associated with apatite and tremolite asbestos in an epidote-schist. The mineral is not much used as a gemstone.

A red, manganese-bearing variety of epidote named *piedmontite* has also been occasionally cut as a gem.

Essonite = **Hessonite** (see p. 297).

Euclase (Gr. *eu*, well, and *klao*, break, in allusion to the perfect cleavage of the mineral).

General.—Monoclinic. Cleavage perfect, and parallel to the plane of symmetry. Hardness, $7\frac{1}{2}$. Specific gravity, about 3·1.

Optical.—Colour usually pale bluish, greenish, or yellowish, and closely resembling aquamarine; sometimes colourless. Lustre, vitreous. Mean refractive index about 1·66. Birefringence, moderately high, $\gamma - \alpha = 0{\cdot}019$. Optical sign, positive. Pleochroic.

Chemical and blowpipe.—Silicate of aluminium and beryllium, with a composition corresponding to the formula $2BeO \cdot Al_2O_3 \cdot 2SiO_2 \cdot H_2O$. Fusibility, about 5½, fusing with difficulty to a white enamel. Insoluble in ordinary acids.

Occurrence and distribution.—Euclase is of rare occurrence. It is found near Ouro Preto, Minas Geraes, Brazil, associated with yellow topaz in chlorite-schist. It is also found in the gravels of the Sanarka river in the southern Urals, associated with gold, topaz, corundum, and kyanite. Rarely used as a gemstone.

Felspar (Ger. Feldspath, *Feld*, field; and *Spath*, spar). Under the name felspar are included several silicates, all of which contain alumina, and various other constituents, chiefly potassium, sodium, or lime, or mixtures of these. Most of the physical properties vary with the chemical composition, but the hardness (6) is constant.

General.—Orthoclase is monoclinic (fig. 186), the plagioclases triclinic. The felspars frequently show twinning. In orthoclase the twinning is simple (fig. 54); in plagioclase it is repeated (figs. 187, 188). Two good cleavages; these are at right angles to one another in orthoclase, but deviate a few degrees from the right angle in the plagioclases, as these names imply (Gr. *orthos*, straight; *plagios*, oblique; *klasis*, fracture). Hardness, 6. Specific gravity, 2·56–2·76.

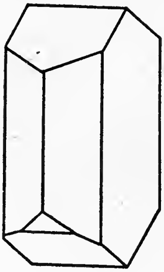

FIG. 186.—Orthoclase.

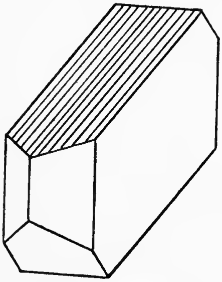

FIG. 187.—Plagioclase.

Optical.—Usually white or grey, but sometimes red or brown. The amazonstone variety of microcline is a brilliant green. Refractive index low, varying from $\alpha = 1{\cdot}519$ in orthoclase to $\gamma = 1{\cdot}588$ in anorthite. Birefringence low, $\gamma - \alpha$ varying from 0·006 to 0·013. Non-pleochroic, except in the amazonstone variety of microcline, which exhibits a fine pleochroism.

Chemical and blowpipe.—Silicates of aluminium, containing potash, soda, or lime, or mixtures of these. The silica percentage varies from 68·8 in albite to 43·3 in anorthite. Fusibility varies from 4 or 4·5 in the plagioclases (the soda-lime varieties) to 5 in orthoclase and microcline (the potash varieties).

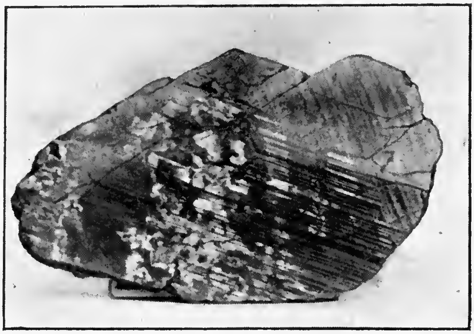

FIG. 188.—Labradorite showing twin-striation. (× ½). B.M.

The felspars are perhaps best and most readily distinguished from one another by their specific gravities, and the optical behaviour of the cleavage fragments. The following table shows the chief felspars, their composition, and their important physical characters:

Species.	Chemical formula.	Sp. gr.	Extinction on cleavage plates.		Refractive indices.
			Basal pinakoid (the better cleavage)	Side pinakoid (the poorer cleavage)	
Orthoclase	$K_2O \cdot Al_2O_3 \cdot 6SiO_2$	2·56	0°	5°	$\gamma=1{\cdot}525$, $\alpha=1{\cdot}519$
Microcline	$K_2O \cdot Al_2O_3 \cdot 6SiO_2$	2·56	15½°	5°	$\gamma=1{\cdot}525$, $\alpha=1{\cdot}519$
Albite	$Na_2O \cdot Al_2O_3 \cdot 6SiO_2$	2·62	4½°	19°	$\gamma=1{\cdot}539$, $\alpha=1{\cdot}529$
	Isomorphous mixtures of albite and anorthite, the ratio of albite to anorthite being in excess of 1 for oligoclase and andesine, and less than 1 for labradorite and bytownite.	2·65	1°	4½°	$\gamma=1{\cdot}547$, $\alpha=1{\cdot}540$
Oligoclase		2·68	5°	16°	$\gamma=1{\cdot}555$, $\alpha=1{\cdot}549$
Andesine					
Labradorite		2·71	18°	29½°	$\gamma=1{\cdot}563$, $\alpha=1{\cdot}555$
Bytownite					
		2·74	27½°	33½°	$\gamma=1{\cdot}570$, $\alpha=1{\cdot}562$
Anorthite	$CaO \cdot Al_2O_3 \cdot 2SiO_2$	2·76	37°	36°	$\gamma=1{\cdot}588$, $\alpha=1{\cdot}575$

Of these felspars orthoclase and microcline are frequently found as large crystals, and both occur extensively as constituents of granites, pegmatites, and gneisses. Albite and oligoclase also occur in granites. The other plagioclases occur in the more basic rocks, labradorite, bytownite and anorthite occurring in the gabbros and basalts, usually in small imperfect crystals or grains. The plagioclases usually show striation on the basal cleavage surfaces, due to lamellar twinning; this lamellar twinning is well seen between crossed nicols under the microscope, producing as it does a characteristic striped appearance in basal flakes. In microcline the twinning is more complex, and shows a cross-hatched appearance in basal flakes between crossed nicols. Microfragments of orthoclase between crossed nicols usually show no twinning.

The felspars used as gemstones are *moonstone* (usually opalescent orthoclase); *amazonstone* (green microcline); *sunstone* (usually spangled oligoclase); and *labradorite.*

MOONSTONE.—Moonstone is an opalescent felspar, and is usually orthoclase. The chief source is Ceylon, where it occurs as large crystals and lenticular masses of opalescent orthoclase in a kaolinized granulite (a fine-grained rock consisting of quartz and felspar) at various localities, notably in the Kandy district, Central Province, and at Ambalangoda, Southern Province. Moonstone of inferior quality is found in the Ceylon pegmatites. The mineral also occurs at Amelia, Virginia, U.S.A.

AMAZONSTONE.—This is the bright-green variety of microcline. Microcline is readily distinguished from the other felspars by the cross-hatched appearance of basal cleavage fragments between crossed nicols, due to compound twinning. The amazonstone variety, moreover, shows a strong pleochroism, the colour varying from a fairly deep green to pale green or almost colourless. Fine specimens have been obtained at Pike's Peak, Colorada, U.S.A., where they occur in coarse-grained granite or pegmatite. Another notable occurrence is near Amelia, Virginia, again in coarse-grained granite. Fine specimens have also been obtained near Miask, in the Urals, and in Madagascar.

SUNSTONE.—This is usually a variety of oligoclase, sometimes orthoclase, containing microscopic inclusions of scaly haematite. The presence of these inclusions gives to the felspar a brilliant red sheen, somewhat resembling that of avanturine, for which reason sunstone is sometimes called *avanturine felspar.* Sunstone of the oligoclase variety occurs at Tvedestrand in Norway, associated with quartz in a vein traversing gneiss. Sunstone also occurs at various localities in North America, at some of which the mineral is of the orthoclase variety.

LABRADORITE and andesine-labradorite often show a peculiar sheen or " schillerization " due to microscopic linear inclusions which show a parallel arrangement. Felspar of this kind was first found in the coarse gabbros of Labrador (fig. 188), hence the name. It occurs also in Russia and in the United States and is sometimes used as a gemstone. It can be obtained in large pieces at and near Nain, a Moravian mission station on the coast of Labrador, and these yield slabs showing a fine play of colours when suitably cut and polished. Its ready cleavage and brittleness militate against its use in a large way as an ordinary gemstone.

Fluorite (see also p. 371). This mineral assumes a great variety of colours, and is sometimes used in imitation of emerald, sapphire, topaz, amethyst, and other stones, the colours of which it resembles. The comparative softness of fluorite, however, renders it of little use or value as a gemstone, and its perfect octahedral cleavage renders it liable to break readily. The massive variety used in making ornaments is purplish blue with streaks of white and yellow, and is called "blue john." Fine specimens of fluorite are found in England, especially near Castleton in Derbyshire, where "blue john" is obtained.

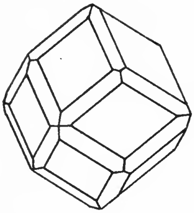
FIG. 189.—Garnet.

Garnet (L. *granatus*, grain-like; name given in allusion to the granular form of the mineral).

General.—Cubic, in rounded crystals with the dodecahedron and icositetrahedron as the common forms (figs. 189, 190). Cleavage dodecahedral, but imperfect. Fracture, uneven. Hardness, about 7. Specific gravity, 3·4 to 4·3.

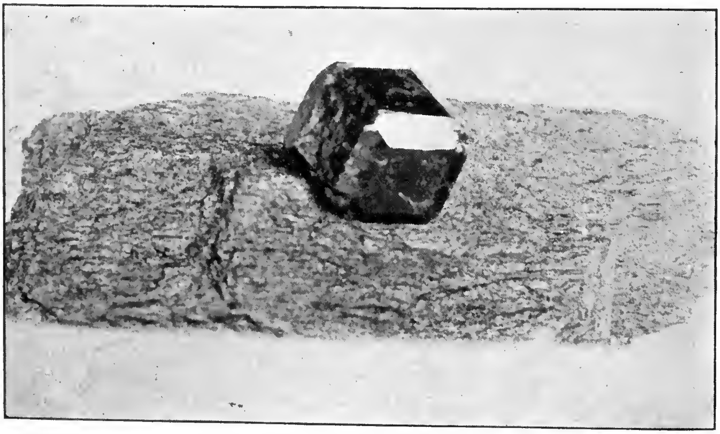
FIG. 190.—Garnet in schist, Fort Wrangell, Alaska. ($\times \frac{2}{3}$). B.M.

Optical.—Colour variable, but typically red; dull green and yellow in some grossularites, black in melanite, and emerald-green in uvarovite.

Lustre, vitreous. Refractive index varies from about 1·75 to 1·89. Generally isotropic, and therefore non-pleochroic. Microfragments usually irregular, but tending to a rounded form.

Chemical and blowpipe.—Garnets vary largely in composition ; but their composition in all cases corresponds to the formula

$$3RO \, . \, R'_2O_3 \, . \, 3SiO_2,$$

where R may be Ca, Mg, Fe, or Mn, and R′ may be Al, Fe, or Cr. Fusibility, about 3, except in pyrope which is about 4, and uvarovite which is practically infusible.

The following list shows the chief chemical varieties of garnet, their composition, specific gravities, and refractive indices :

	Composition.	Sp. gr.	Refractive index.
Grossularite -	$3CaO \, . \, Al_2O_3 \, . \, 3SiO_2$	3·5	1·76
Pyrope - -	$3MgO \, . \, Al_2O_3 \, . \, 3SiO_2$	3·7	1·77
Almandine -	$3FeO \, . \, Al_2O_3 \, . \, 3SiO_2$	3·5-4·3	1·78
Spessartite -	$3MnO \, . \, Al_2O_3 \, . \, 3SiO_2$	3·8	1·81
Andradite - -	$3CaO \, . \, Fe_2O_3 \, . \, 3SiO_2$	3·8-4·1	
Uvarovite - -	$3CaO \, . \, Cr_2O_3 \, . \, 3SiO_2$	3·4	1·83

It is rare, however, to find garnets with composition corresponding exactly to the formula here given. One or another of the above-mentioned molecules usually predominates, but there is generally an admixture of other molecules, owing to isomorphous replacement.

The garnets used chiefly as gemstones are almandine, hessonite, spessartite, pyrope, rhodolite, and demantoid.

ALMANDINE (a corruption of *alabandicus*, from Alabanda, a locality in Asia Minor) has a deep purplish-red colour. It is widely distributed in schists and gneisses (fig. 190). The chief sources are the gem gravels of Ceylon and the Minas Novas district of Brazil ; and the mica-schists of various parts of India, notably those of the Sarwar district of Kishangarh State, and those of Rajmahal in Jaipur State.

HESSONITE or CINNAMON STONE is a variety of grossularite and is pale brown or yellowish red in colour, differing in colour from pure grossularite owing to the presence of iron and manganese. The chief and almost the only source of gem hessonite is Ceylon, where it occurs in the gem gravels, notably in the Matura district.

SPESSARTITE (from Spessart, a locality in Bavaria) which is deep red or brownish red in colour, is used only to a small extent as a gemstone ; it occurs as specimens of gem quality associated with muscovite in granite at Amelia, Virginia, U.S.A., and also in Ceylon gem gravels.

Pyrope (Gr. *pyropos*, fiery-eyed, in allusion to its fiery appearance). This is a crimson variety of garnet frequently used as a gemstone. It occurs in peridotite and serpentine rocks. Pyrope of gem quality occurs abundantly in the serpentine rocks of northern Bohemia, as near Teplitz and other parts of the Mittelgebirge. The Bohemian garnets have been found in large quantities in a gravelly earth that has been formed by the disintegration of serpentine.

Other sources of pyrope are Santa Fé in New Mexico; also north-eastern Arizona, where the mineral is found in the surface gravels along the course of the San Juan river, and is known locally as the "Arizona ruby." Pyrope is also obtained in South Africa, where it occurs associated with diamond in kimberlite, and is there known as the "Cape ruby."

Rhodolite is a pale-red variety of garnet with a violet tinge. It is intermediate in composition between pyrope and almandine, its composition corresponding to an admixture of these two varieties in the proportion of two molecules of pyrope to one of almandine. It has a brilliant lustre, and a specific gravity 3·84. It occurs in an altered basic igneous rock associated with ruby in Macon County, North Carolina, U.S.A., and is found also in a decomposed micaceous band in a gneissic rock at Dewalegama in Ceylon.

Demantoid is a yellowish-green to emerald-green variety of andradite, and received its name from the fact that its brilliant lustre and dispersive power recall the appearance of the diamond. The emerald-green variety owes its colour to the presence of chromium. It has a higher refractive index (1·88) than any other garnet. The yellowish green variety is liable to be confused with chrysolite, and the emerald-green variety with emerald; but demantoid is easily distinguished from these minerals by its isotropic character and its higher specific gravity. Demantoid occurs in serpentine at Bobrovka in the Urals, and is there chiefly restricted to veins of chrysotile asbestos that traverse the mass of serpentine.

Other garnets sometimes used as gemstones are *melanite*, a black titaniferous variety of andradite found in alkali syenites and phonolites; and "*topazolite*," a honey-yellow or topaz-coloured variety of andradite.

Golden Beryl, a name given to the clear yellow variety of beryl, including "heliodor" (see p. 276).

Greenstone, a loosely-used name applied among jewellers to nephrite, jadeite, and certain other stones (*e.g.* bowenite, a variety of serpentine) that resemble these in being green and of a compact texture. The term "greenstone" is also used among petrologists in a vague way for certain porphyrites and some other rocks, especially when altered; and the term is thus of little if any scientific value.

Grossularite (L. *grossula*, a gooseberry), the lime-alumina variety of garnet (see p. 297).

Hæmatite, which is chiefly an ore of iron (see p. 194) is occasionally used as a gemstone.

Haüynite (also named haüyne, after the French mineralogist Haüy). A blue, cubic mineral, crystallizing in rhombic dodecahedra. Hardness, $5\frac{1}{2}$. Specific gravity, 2·4. Refractive index, 1·5. Isotropic. Composition represented by the formula $Na_2Ca(NaSO_4Al)Al_2(SiO_4)_3$. Fusibility about $4\frac{1}{2}$, fusing with some difficulty to a white glass. Yields sulphide reaction on silver after reducing with sodium carbonate on charcoal. Decomposes with hydrochloric acid, yielding gelatinous silica; and the filtrate gives a good sulphate reaction (heavy white precipitate) with barium chloride solution.

Haüynite occurs in certain volcanic rocks rich in soda. It is the blue constituent of lapis-lazuli (see p. 303). The ultramarine formerly made from lapis-lazuli by crushing and separation of the blue ingredient, consisted partly of haüynite. Haüynite has been used occasionally as a gemstone.

The mineral *sodalite* (see also p. 314), which has a composition corresponding to the formula $Na(AlCl)Al_2(SiO_4)_3$ is closely related to haüynite. It is colourless or blue, occurs as dodecahedra, and it also is one of the constituents of lapis-lazuli. Sodalite may be distinguished from haüynite by its lower specific gravity (2·3 or rather less), and its failure to give the sulphate reaction.

Heliodor, a yellow variety of beryl (see p. 276).

Heliotrope, a red-spotted plasma, a variety of chalcedony (see p. 279).

Hessonite, a variety of garnet (see p. 297).

Hiddenite, an emerald-green variety of spodumene (see p. 315).

Hyacinth = Jacinth, a yellowish-red variety of zircon (see p. 321). The name hyacinth is from *Hyakinthos*, the name given in Greek mythology to a youth who was slain by Apollo and transformed into a flower.

Hydrophane (Gr. *hydro*, water; and *phaino*, to show). A whitish or dull-coloured variety of opal which has the property of absorbing water or oil, and exhibits opalescence when immersed in these liquids.

Hypersthene (Gr. *hyper*, beyond; and *sthenos*, strength, in allusion to its toughness as compared with hornblende, with which it was formerly confused under the name Labrador hornblende).

General.—Orthorhombic, but usually found in irregular pieces. Good prismatic cleavage. Hardness, about 5½. Specific gravity, about 3·4.

Optical.—Brown in colour, frequently showing a bronzy sheen, and for this reason occasionally cut as a gemstone. Refractive index, high, $\gamma = 1{\cdot}705$. Birefringence low, $(\gamma - \alpha = 0{\cdot}013)$. Optical sign, negative. Microfragments prismatic, showing straight extinction and strong pleochroism, reddish brown to green. The green colour corresponds to the fast-ray vibration direction, which is at right angles to the prism edge.

Chemical and blowpipe.—Silicate of magnesium and iron with a composition corresponding to the formula $(Mg, Fe)O . SiO_2$. Fusibility, 5, fusing with difficulty to a black magnetic glass. Slightly decomposed by hydrochloric acid.

Occurrence.—Hypersthene is a mineral of common occurrence in basic igneous rocks, especially norites, and is of little value as a gemstone. It occurs abundantly associated with labradorite in the norites of Labrador, where material of gem quality occurs as pebbles on the coast.

Compare description of enstatite (see p. 291).

Idocrase (Gr. *eidos*, form, and *crasis*, mixture ; so named on account of the similarity of its crystal form to that of some other minerals, especially garnet, with which it had been confused) = **Vesuvianite** (see p. 320).

Ilmenite.—This mineral has already been dealt with as an ore of ferro-titanium (see p. 247). It is sometimes found in fairly large crystals ; and these, on account of their deep black and highly lustrous character, and the good polish they take, have been used to some extent as gemstones.

Indicolite (L. *indicum*, indigo), the indigo-blue variety of tourmaline (see p. 318).

Iolite (Gr. *ion*, violet, and *lithos*, stone) = **Cordierite** (see p. 281).

Iron Pyrites (see **Pyrite**, p. 309).

Jacinth = **Hyacinth** (see p. 299).

Jade = **Nephrite** (see p. 304) ; but also used loosely by some writers to include jadeite (see below) and bowenite (a variety of serpentine). Also called " greenstone " and " axe-stone."

Jadeite, frequently confused with nephrite under the names " jade," " greenstone," and " axe-stone." Jadeite differs from spodumene (see p. 315) in having sodium in place of lithium.

General.—Monoclinic ; but like nephrite, it does not show crystalline form, being found in the form of tough, compact masses of interlacing crystalline fibres. No cleavage. Fracture, splintery. Hardness, 7. Specific gravity, about 3·3

Optical.—Colour whitish, pale reddish, or pale greenish; sometimes spotted with a more brilliant green due to the presence of patches containing chromium. Microfragments irregular in shape, translucent, and show a compact structure between crossed nicols. Refractive index high, the mean value being about 1·66.

Chemical and blowpipe.—Jadeite is a silicate of sodium and aluminium, with sometimes a little iron, its composition corresponding approximately to the formula, $Na_2O \cdot Al_2O_3 \cdot 4SiO_2$. Fusibility, $2\frac{1}{2}$; its easy fusibility as compared with nephrite being a useful distinctive test. Fuses to a bubbly glass. Gives a strong yellow flame coloration due to sodium. Insoluble in ordinary acids.

Occurrence and distribution.—The most important occurrence of jadeite is that near Tawmaw in the Myitkyina district of Upper Burma, where the mineral occurs as a constituent of a dyke rock intrusive in serpentine, and is regarded as an alteration product of the sodium aluminium silicates albite and nepheline. The alteration is attributed to thermodynamic metamorphism. Jadeite quarrying is an important industry in Upper Burma; the stone is quarried from the dyke as well as obtained in the form of boulders from the bed of the neighbouring Uru river, and much of it is sent to China, where it is highly valued as an ornamental stone.

Another occurrence of jadeite is that near Gulbashen, in the Karakash valley, Eastern Turkestan, where the mineral is found associated with nephrite.

Jadeite is often confused with nephrite, but is readily distinguished from the latter by its easier fusibility, its higher specific gravity, and its rather greater hardness.

Jargon = Jargoon, a variety of zircon (see p. 321).

Jasper is compact silica impregnated with ferruginous and sometimes also with some clayey matter. It assumes various colours, including red, yellow, brown, and banded varieties. A variety known as "riband jasper," found in the Urals, consists of alternating green and brown layers, which show a banded appearance in cross-section. The red variety owes its colour to hæmatitic iron oxide, the yellow and brown varieties to hydrated iron oxides, though some clayey matter may be present.

Jasper is often found associated with iron ores in ferruginous sedimentary rocks that have been metamorphosed. Many of the jaspers of commerce are collected as loose pebbles from alluvial deposits.

Jet (Fr. *jayet*, Gr. *gagates*, from Gages in Lycia, Asia Minor, where it was first obtained).

Jet is a form of coal, and from a crystallographic standpoint it is amorphous. Jet proper is a compact deep-black variety of lignite. It is rather soft, its hardness being only about $3\frac{1}{2}$; and it is, indeed, to some extent sectile; but it is tough, and can consequently be worked on the lathe without falling to pieces. It takes a good polish. It burns readily with a smoky flame.

Notable occurrences of jet are those of the Whitby district on the Yorkshire coast, where it is found in the form of irregular lumps in a bed of shale about 30 ft. thick. The shale is locally named "jet rock," and is of Upper Lias age. Much of the jet carved at Whitby has in the past been imported from Spain; and for many years previous to the recent war jet was not mined in the Whitby district. During and since the war, however, there has been a larger demand for jet ornaments and mourning jewellery, and jet mining has been resumed on the Yorkshire coast.

Cannel coal is sometimes sufficiently tough and lustrous to permit it to be worked and polished and used for the manufacture of jet ornaments. Anthracite has also been used to some extent as a substitute for jet.

Jet proper is distinguished from cannel coal by its woody structure. It is distinguished from anthracite by the fact that it burns with a long and smoky flame. It can readily be distinguished from black glass imitations by its comparative softness and low specific gravity (sp. gr. 1·35).

Kunzite, a lilac-coloured or pink variety of spodumene (see p. 315).

Kyanite (Gr. *kyanos*, blue; so named because the colour is usually blue).

General.—Triclinic. Occurs in the form of long blade-shaped crystals (figs. 191, 192). Shows a perfect pinakoidal cleavage, and two others not so good. Hardness, 5, along the line of intersection of the two chief cleavages, and 7 along the direction at right angles to this. Consequently, a crystal can be scratched on the main cleavage face by a knife if scratched along, but not across, the intersection of the two chief cleavages. Specific gravity about 3·6.

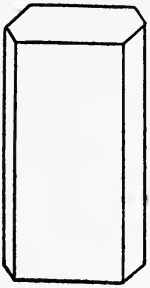

FIG. 191.—Kyanite.

Optical.—Colour usually blue and often irregularly distributed; but colourless, yellow, and green varieties occur. Lustre, vitreous, with a pearly tendency. Refractive index, high, $\alpha=1{\cdot}717$. Birefringence, weak, the maximum being $\gamma-\alpha=0{\cdot}012$; but of greater practical significance when crushed fragments are examined is the birefringence due to $\gamma-\beta=0{\cdot}007$, seen on the main cleavage face. Optical sign, negative. Microfragments prismatic. The main-cleavage plates show a pronounced oblique extinction the angle of which is about 30°, and they show a good biaxial figure. Pleochroism weak except in the strongly coloured varieties.

Chemical and blowpipe.—Aluminium silicate ($Al_2O_3 . SiO_2$), identical in chemical composition with andalusite (see p. 270). Infusible. Insoluble in ordinary acids.

Occurrence.—Kyanite occurs frequently in gneisses and schists and the alluvial deposits derived from these rocks. Gem kyanite of a pale blue colour occurs associated with staurolite (a brown orthorhombic silicate of aluminium and iron) in a finely foliated mica-schist at Monte Campione, St. Gothard district, Switzerland. It occurs also among the alluvial deposits of Brazil, and in many parts of Africa. A noteworthy occurrence is that of the Zanzibar gravels, in which kyanite of various colours occurs in association with garnet and black tourmaline.

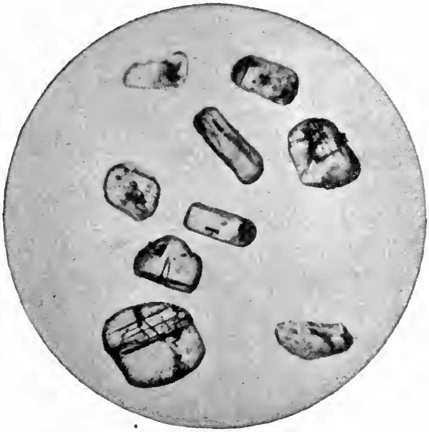

FIG. 192.—Water-worn grains of kyanite.

Lapis-lazuli occurs massive, and is compact in texture. It is really a rock and consists essentially of a mixture of calcite (see p. 342), haüynite (see p. 299), and sodalite (see p. 299) ; small amounts of pyrite, dolomite, hornblende, and augite are also usually present. Lapis-lazuli owes its value to its beautiful blue colour. The colouring matter, which is haüynite, was formerly separated from lapis and used as a blue pigment, but it is no longer possible to produce this natural pigment in competition with artificial ultramarine. In addition to its use in this way lapis-lazuli has always been highly prized as an ornamental stone.

Lapis-lazuli occurs at Badakshan in north-east Afghanistan, in a limestone which has presumably suffered thermal metamorphism. Other notable occurrences are those in the district at the west end of Lake Baikal in Siberia, and in the Chilian Andes, at both of which localities it occurs in limestone that has been metamorphosed by granite intrusions.

Labradorite, a soda-lime felspar (see p. 295).

Lumachella.—This is more properly regarded as a rock than a mineral. It is a variety of shelly limestone, containing some organic and other impurity. It owes its value as an ornamental stone to the fact that it exhibits a fiery appearance, suggesting that of fire opal.

Malachite.—This mineral has already been dealt with as one of the ore minerals of copper (see p. 176). Malachite rarely shows definite crystalline form; but the compact or fibrous masses usually assumed by the mineral are highly prized on account of their good colour, in spite of their lack of transparency.

Though soft, malachite is fairly tough, and can be worked readily on a lathe.

The chief source of ornamental malachite is the Urals, where it has been found as large nodular masses, sometimes embedded in limestone, and sometimes in clay. A single mass weighing 330 tons is recorded as having been worked at the Medno-Rudiansk mine in 1836. In the museum of the Institute of Mines at St. Petersburg, there is a large mammiform mass of nodular malachite weighing about 1½ tons. Exceptionally fine specimens of malachite have also been found in Queensland at the Peak Downs copper mine; and in South Australia fine specimens have been obtained at the copper mines of Wallaroo and Burra-Burra (see p. 181).

Moonstone, an opalescent variety of felspar (see p. 295).

Morganite = Rose beryl (see p. 276).

Nephrite (Gr. *nephros*, a kidney; in allusion to its supposed virtue as a specific for kidney disorders). Frequently called "jade," "greenstone," and "axe-stone." Nephrite is a form of *actinolite*, which is one of the amphibole group of minerals.

General.—Monoclinic, but shows no crystalline form, being found in the form of a tough, compact mass of interlacing crystalline fibres. No cleavage. Fracture, splintery. Hardness, about 6½. Specific gravity, about 3.

Optical.—Colour, usually green, of various shades. A white variety, free from iron, has the composition of tremolite (see p. 330). Microfragments irregular in shape, translucent, and show the characteristic compact structure between crossed nicols. Refractive index high, $\gamma = 1{\cdot}636$. Birefringence fairly high, $\gamma - \alpha = 0{\cdot}025$.

Chemical and blowpipe.—A silicate of calcium and magnesium, usually with a little iron. Its composition corresponds to the formula $CaO \,.\, 3MgO \,.\, 4SiO_2$ in the white variety. In the green variety a little iron replaces magnesium. Fusibility, 4, a factor of importance in distinguishing it from *jadeite* (see p. 301). Insoluble in ordinary acids.

Occurrence and distribution.—Nephrite occurs among metamorphosed rocks, especially among hornblende-schists and serpentines that have suffered from intense metamorphism. It has been found in various European localities, but the chief sources of the stone are New Zealand and Eastern Turkestan.

In New Zealand, nephrite was formerly in extensive use among the Maoris, by whom it was employed in a variety of ways. They obtained their supply from the gravels of the Teremakau and Arahura rivers, and the neighbouring country, in the northern part of the Westland province. The mineral has, however, also been found among the serpentine rocks of the Griffin Range, in the same region. Here the nephrite occurs in the form of nodules and veins that vary from a few inches to a foot or more in thickness, and is associated with talc and calcite. It is from these rocks that the nephrite pebbles of the river gravels have been derived.

Nephrite is obtained at several localities in the region of the Kuen-Len mountains in eastern Turkestan, where it frequently occurs associated with pyroxene rocks ; and near Gulbashen, in the Karakash valley in this region, it occurs in a bed more than 20 feet thick, between gneiss and hornblende-schist, associated with jadeite.

Nephrite occurs associated with graphite in schists near Lake Baikal in Siberia, where large boulders of nephrite weighing more than half a ton have been obtained.

Nephrite is often confused with jadeite, but can be readily distinguished from the latter by its more difficult fusibility, its lower specific gravity, and its inferior hardness.

Odontolite (Gr. *odontos*, tooth, and *lithos*, stone) = **Bone Turquoise** (see p. 276).

Olivine (name due to the olive-green colour of the mineral ; includes also *chrysolite* and *peridot*).

General.—Orthorhombic, occurring as tabular crystals (fig. 193), but usually found in rounded grains and irregular granular masses. Cleavage, imperfect. Fracture, conchoidal. Hardness, about 6½. Specific gravity, about 3·4.

Optical.—Colour usually yellowish green to bottle-green. Lustre, vitreous. Refractive index, high; $\gamma=1{\cdot}697$. Birefringence, high; $\gamma-\alpha=0{\cdot}036$. Optical sign, positive. Microfragments irregular, transparent, showing very little or no colour and pleochroism.

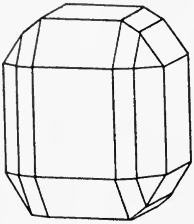
FIG. 193.—Olivine.

Chemical and blowpipe.—Silicate of magnesium and iron, with a composition corresponding to the formula $2(Mg,Fe)O \cdot SiO_2$. Infusible. Decomposed by hydrochloric acid, yielding gelatinous silica.

Occurrence and distribution.—Olivine is found widely distributed in basalt, which is one of the most abundant of volcanic rocks. It occurs also in other basic igneous rocks, sometimes forming rock-masses alone, as in the case of the rock *dunite.* Though widely distributed, however, it is very rarely found in flawless pieces sufficiently large to be cut as gems. Olivine suitable for gem purposes occurs among the basalts and peridotites of Arizona, U.S.A. Peridot is mined on St. John's Island in the Red Sea, where crystals of good quality as gemstones occur in an altered olivine rock. Olivine of value as a gemstone has also been obtained from the basalts of Toowomba Range in Queensland, Australia, where it occurs in pieces usually of not more than one carat in weight and is of the chrysolite variety.

Among users of gemstones, it is customary to restrict the name *chrysolite* to the yellowish varieties, and the name *peridot* to the bottle-green varieties of olivine; but some mineralogists use the three names synonymously.

Onyx (Gr. *onyx,* the nail; so named from its resemblance to the finger nail). True onyx is a variety of agate (see p. 278). The stones known as " onyx marble " and " Mexican onyx " are onyx-like varieties of stalagmitic limestone.

Opal (Skt. *upala,* a gemstone; Gr. *opallios,* an opal).

General.—Amorphous. Fracture, conchoidal. Hardness, about 6. Specific gravity, about 2·1, ranging from 1·9 to 2·3.

Optical.—Colour variable, but mostly white, yellow, or red. The more valuable varieties show a play of colours of the type known as opalescence, because of the fact that it is best exemplified by precious opal. This play of colours is due to physical irregularities in the constitution of the stone. Lustre, vitreous with a slightly resinous tendency. Refractive index low (about 1·45). Isotropic.

Chemical and blowpipe.—Hydrated silica (SiO_2+nH_2O), the amount of water being variable, but usually from 5 to 10 per cent. Infusible, and becomes opaque when heated in blowpipe flame. Usually gives a little water when heated in a closed tube. Soluble in caustic potash.

Varieties and their occurrence.—The chief varieties of the mineral opal are precious opal, fire opal, hyalite or glassy opal, milk opal, hydrophane, and wood opal.

Opal occurs almost invariably as an infilling of cracks and cavities in volcanic rocks, especially andesites and basalts. It is associated in these cavities with chalcedony and quartz. Indeed the silica amygdales of these rocks often consist partly of chalcedony and partly of opal, some of them consisting of a kernel of opal with thin outer crust of chalcedony; so that a superficial inspection of these amygdales is apt to mislead one as to their real character. These amygdales have been formed by the solution of silica in the water percolating through the rock, and its re-deposition in a gelatinous condition in the cracks and cavities, the gelatinous silica afterwards becoming desiccated to form opal.

Precious Opal.—This variety of opal owes its value as a gemstone to the fact that it is imperfectly transparent and shows a beautiful play of colours in reflected light. Together with this play of colours precious opal generally shows a milky translucency, but black varieties also occur. The play of colours is due to irregularities of constitution developed during the solidification of the opal. It is attributed by some mineralogists to differences in state of hydration and consequent differences in refractive index in the substance of the mineral. By others it has been explained as due to the presence of cracks formed during solidification.

An important locality in Europe for precious opal is Vörösvágás near Kaschau in northern Hungary. There precious opal occurs with common opal in an andesite containing mica and hornblende. It is now found as a rule in small pieces only; and pieces as large as a hazel nut are said to be scarce. Larger pieces were found formerly; and in the Vienna Museum there is a large piece weighing about 3000 carats (600 grams).

Precious opal also occurs in considerable quantity among the altered volcanic rocks of Mexico and other parts of Central America.

Other occurrences of note are those of Queensland and New South Wales in Australia. In both these States, as in the Whitecliffs field, N.S.W., opal occurs in a matrix of white sandstone (Desert Sandstone Series) of Cretaceous age. At Rocky Bridge Creek, N.S.W., opal occurs in a decomposed basalt; and at Lightning Ridge, Wallangulla, in the same State, black opal is obtained.

Fire Opal.—Of the several varieties of opal that are less important than precious opal, the most valuable is fire opal. As its name implies, fire opal has usually a fiery-red colour, and in addition to its intrinsic colour it may also show a play of colours in reflected light. This variety of opal is found chiefly in a trachyte near Zimapan in Mexico.

Common Opal.—Under this name may be included all varieties of opal other than precious opal and fire opal, the chief of which are the transparent hyalite or glassy opal, milk opal, hydrophane, and wood opal.

"Oriental Amethyst"; "Oriental Aquamarine"; "Oriental Chrysolite"; "Oriental Emerald"; "Oriental Hyacinth"; "Oriental Topaz."—These are different colour-varieties of corundum, named after other gemstones the colours of which they resemble, and qualified by the adjective " oriental " by way of distinction.

Peridot is the bottle-green variety of olivine (see p. 305).

Pearl.—Though highly valued as a precious stone, the pearl is not regarded as a mineral. It consists mainly of fibrous calcium carbonate and is formed as a secretion on the inner surface of certain lamellibranch (bivalve) shells, notably those of *Meleagrina margaritifer.*

Phenakite (Gr. *phenax*, a deceiver ; so named on account of its having been mistaken for quartz).

General.—Trigonal. Crystals show a hexagonal prism capped by a rhombohedron (fig. 194). Fracture, conchoidal. Hardness, about 7½. Specific gravity, about 3 (compare with quartz).

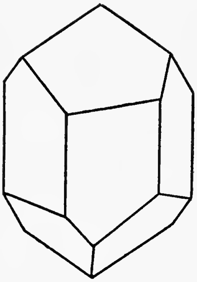

Fig. 194.—Phenakite.

Optical.—Usually colourless, and liable to be mistaken for quartz. Like quartz its lustre is vitreous, but it has a higher refractive index ($\omega = 1{\cdot}654$) and birefringence ($\epsilon - \omega = 0{\cdot}015$). Optical sign, positive.

Chemical and blowpipe.—Beryllium silicate ($2BeO \cdot SiO_2$). Infusible, and remains unaltered in blowpipe flame, but yields a white enamel when fused with sodium carbonate. Not decomposed by hydrochloric acid.

Occurrence.—Phenakite occurs associated with emerald and chrysoberyl in mica-schist at the Takovaya stream in the Urals. It also occurs associated with amazonstone at Pike's Peak ; and with amazonstone and topaz in veins traversing granite at Topaz Butte near Florissant, Colorado, U.S.A.

Plasma, the leek-green variety of chalcedony (see p. 279).

Prase (Gr. *prason*, a leek), a leek-green variety of quartz that owes its colour to inclusions of actinolite (see p. 313). Actinolite is a fibrous silicate of magnesium and lime, containing a little iron oxide.

Precious Opal, see Opal (p. 307).

Prehnite (named after Col. Prehn, who found the mineral in Cape Colony).

General.—Orthorhombic, but usually found in the form of compact masses or globular aggregates with a radiate structure. Hardness, about 6½. Specific gravity, about 2·9.

Optical.—Colourless, yellow, or green, but usually pale green. Lustre, vitreous. Refractive index, high, γ about 1·649. Birefringence high, $\gamma - \alpha = 0{\cdot}033$.

Chemical and blowpipe.—Hydrated silicate of lime and aluminium $2(CaO \,.\, Al_2O_3 \,.\, 3SiO_2 \,.\, H_2O)$. Fusibility, 2. Fuses very readily with intumescence to a white bubbly glass. Yields water in a closed tube. Decomposed by hydrochloric acid without gelatinization.

Occurrence.—Prehnite occurs in the form of amygdales, associated with zeolites, in basalts and other basic igneous rocks. Good specimens occur at Bourg d'Oisans in Dauphiné, associated with felspar, axinite and epidote.

Prehnite closely resembles chrysolite in appearance, and the green variety has been used to a small extent as a gemstone. It can be readily distinguished from chrysolite by its lower specific gravity, and its fusibility.

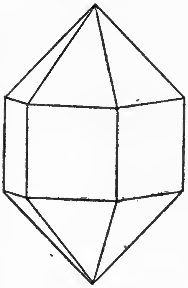

Fig. 195.—Quartz.

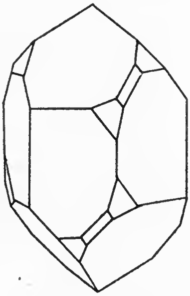

Fig. 196.—Quartz.

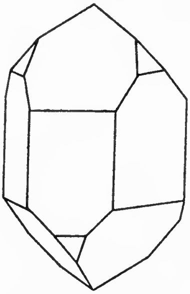

Fig. 197.—Quartz.

Pyrite, the cubic disulphide of iron, FeS_2, is chiefly important as an ore of sulphur, and is described in that connection on p. 424. Its brilliant metallic lustre and yellow colour have led to its use to some extent as a gemstone, but only to a very small extent.

Pyrope, a variety of garnet (see p. 298).

Quartz (Ger. *quarz*; origin of term unknown).

General.—Trigonal; frequently found in the form of hexagonal prisms capped by hexagonal pyramids (figs. 195 to 198), though more often found in the massive-crystalline and massive-granular condition. No cleavage. Fracture, conchoidal. Hardness, 7. Specific gravity, 2·65.

Optical.—Colour variable; usually colourless or white. Lustre, vitreous. Refractive index, low, $\epsilon = 1{\cdot}553$. Birefringence, low, $\epsilon - \omega = 0{\cdot}009$. Optical sign, positive. Microfragments irregular in shape.

Chemical and blowpipe.—Silica (SiO_2). Infusible. Dissolves with effervescence when fused in a bead of sodium carbonate. but insoluble in microcosmic salt. Insoluble in ordinary acids. Dissolves readily in hydrofluoric acid leaving practically no residue when evaporated to dryness.

FIG. 198.—Quartz, Delabole, Cornwall. ($\times \frac{1}{3}$). B.M.

Varieties and their occurrence.—Quartz is the commonest of minerals. It is one of the essential constituents of granites, whilst sandstones and quartzites consist almost wholly of this mineral.

The ordinary clear and colourless variety of quartz is named *rock-crystal.* Among the many coloured varieties those of chief importance are *amethyst*, *smoky quartz* (including *cairngorm*), *citrine*, *avanturine*, *rose quartz*, *prase*, *cat's eye*, and *tiger's eye*.

ROCK-CRYSTAL.—This clear and colourless variety of quartz is abundantly distributed, though fine flawless crystals are less commonly found than one might expect. The crystals are found well developed in the drusy cavities of certain granites. Large crystals, some of them weighing several cwt., have been found near Grimsel in Switzerland.

The chief supplies for commercial purposes come from Brazil and Madagascar, in both of which countries rock-crystal occurs as loose surface blocks and pebbles weighing up to more than 50 lb. each. It is from these large blocks that crystal spheres are cut and spectacle lenses obtained.

Optical quartz is widely distributed in Brazil. Notable localities are those of the Serra des Crystaes in Goyaz, and near Diamantina in Minas Geraes. In this region, large crystals of quartz, some very clear and useful for optical purposes, are scattered sporadically among the ancient quartzites and other rocks, in which they have been formed by the solution and re-crystallization of silica. As a result of the weathering and disintegration of these rocks, the large crystals have been left in the surface residues from which they have been washed into stream-courses, where they have become water-worn and rounded. The boulders and pebbles thus formed have been collected freely in the past for commercial purposes, with no consciousness on the part of the collector of the long ages and slow-acting forces that have been involved in their production. Supplies are more difficult to obtain now than formerly; and the demand has increased.

The river gravels along the east and north-east coast of Madagascar, especially those between Vohemar and Mahanoro, contain an abundance of boulders and water-worn crystals of clear quartz, which have been derived from quartz veins associated with granite intrusions in the schists and gneisses of this region.

Rock-crystal is also often found as very perfect doubly-terminated crystals in limestone. Such crystals are frequently confused with diamond by people who lack a knowledge of mineralogy. This is scarcely excusable, and the name "fool's diamond," by which rock crystal is sometimes called, is perhaps not unjustly reproachful. Nor should rock-crystal be confused with zircon. More excusable is its confusion with topaz, white sapphire, and phenakite, but its low specific gravity (2·65) is a property by which it can be effectively distinguished from all these stones.

AMETHYST is violet, the crystals being sometimes partly coloured and partly colourless, coloured sectors alternating with colourless ones. The violet colour is supposed to be due to a trace of manganese, and is destroyed by heating.

Amethyst occurs associated with agate in the amygdales of basic volcanic rocks (basalts, etc.). Brazil and Uruguay are the chief sources and a large amount is sent from those countries to Europe to be cut, especially to Oberstein, in the neighbourhood of which locality large amounts were formerly obtained (see p. 278).

Amethyst is also found in quartz veins occurring in granites and gneisses. It occurs abundantly in this way in the Urals. Specimens of amethyst of good quality also occur in the Ceylon gem gravels; and these have probably been derived from quartz veins in the old crystalline rocks of the island.

SMOKY QUARTZ is usually brownish in thin pieces, but it is often quite black in large crystals. It becomes colourless and transparent after heating to redness, due to the decomposition or volatilization of the organic material to which its smokiness is due.

Large crystals of smoky quartz have been found near the Tiefen glacier in Switzerland. There is a group of exceptionally fine specimens of these in the Berne Museum, the largest of which is about a yard in height (87 cm.), and weighs 2½ cwt. (127·5 kilos).

The brownish "*cairngorm*," formerly found in some abundance in the drusy granite of Cairngorm in the north of Scotland, is a variety of smoky quartz.

CITRINE is the yellow variety of quartz. It is found associated with amethyst, but is less abundant than the latter. Amethyst loses its violet colour and turns yellow or colourless when heated; it is then indistinguishable from natural citrine, and much of the citrine used as a gemstone is obtained in this way.

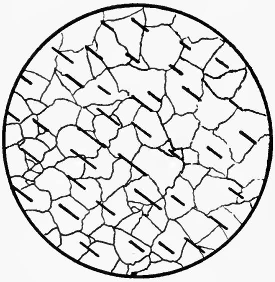

FIG. 199.—Section of avanturine, magnified.

AVANTURINE is a massive variety of quartz spangled with platy inclusions. These inclusions are usually of microscopic dimensions, and it is to them that the colour of the stone is due.

The commoner and most appreciated variety is that with a reddish brown or coppery sheen, which owes its colour to inclusions of iron oxide. There is also a bright green variety which is really a quartz-schist, and in which the colour is due to the presence of small plates of a bright green chromium-bearing mica (fuchsite), the plates being arranged roughly parallel to one another (fig. 199).

Avanturine is found in many localities, but the only place where it appears to have been extensively mined is in the Urals, where it occurs as a metamorphic rock associated with mica-schists. The green variety has been found in many localities and large lumps have been obtained in the Bellary district of Madras, India.

An artificial variety of avanturine is made by incorporating finely-divided metallic copper in glass. This is done by mixing copper oxide with glass containing iron. On cooling from a fused condition, the ferrous silicate in the glass becomes oxidized at the expense of the copper oxide, finely-divided metallic copper in a crystalline condition being formed. Most of the avanturine used is made in this way.

Less important are the other varieties of quartz, including *rose quartz*, the colour of which disappears on heating and is possibly due to titanium dioxide; *prase*, a green variety that owes its colour to the presence of actinolite inclusions; and the chatoyant varieties comprising the blue *cat's-eye quartz*, the grey *hawk's-eye*, and the golden-yellow *tiger's-eye*, which are usually pseudomorphs after asbestos. These latter owe their chatoyant lustre to their fibrous condition.

Rhodolite (Gr. *rhodon*, a rose, and *lithos*, a stone), a variety of garnet (see p. 298).

Rhodonite, the silicate of manganese ($MnO . SiO_2$), which has been already described as an ore mineral of manganese (see p. 215) is used to a limited extent as an ornamental stone.

Rock-Crystal. See quartz (p. 310).

Rose Beryl. See beryl (p. 276).

Rose Quartz.—See quartz (above).

Rubellite, the red variety of tourmaline (see p. 318).

Rubicelle, a yellowish or orange-red variety of spinel (see p. 314).

Ruby (Fr. *rubis*, Low L. *rubinus*, L. *ruber*, red), a variety of corundum (see p. 283).

Ruby Spinel, a deep-red variety of spinel (see p. 314).

Rutile, a tetragonal dioxide of titanium (TiO_2), has been already described as an ore mineral of titanium (see p. 247). The high refractive index of rutile gives stones cut from this mineral a strongly adamantine lustre; but on account of its dark colour it is seldom used as a gemstone.

Quartz containing fine hair-like inclusions of rutile is sometimes cut for ornamental use under the names of "Venus's hair stone" and "flêches d'amour."

Sapphire (Gr. *sappheiros*; L. *sapphirus*), a variety of corundum (see p. 284).

Sardonyx (Gr. *sardonyx*, *i.e.* Sardian onyx), a variety of agate (see p. 278).

Satin-spar, a name given to massive fibrous varieties of gypsum ($CaSO_4 . 2H_2O$), calcite (rhombohedral calcium carbonate—$CaCO_3$) and aragonite (orthorhombic calcium carbonate). Owing to its fibrous structure, satin-spar exhibits a chatoyant (cat's eye) lustre when cut and polished, and is for that reason used to some extent as an ornamental stone.

Smoky Quartz (see p. 312).

Sodalite (see p. 299) is a constituent of lapis-lazuli. A blue sodalite is the essential ingredient of a sodalite-syenite that is quarried for use as an ornamental stone at Dungannon, Ontario, Canada (see p. 337).

Spessartite, a variety of garnet (see p. 297).

Sphene (Gr. *sphen*, a wedge; so named on account of the wedge-shaped form of the crystals) = Titanite (see p. 316).

Spinel (Fr. *spinelle*; origin doubtful, but possibly from Gr. *spinos*, a spark, owing to its fiery-red colour.

General.—Cubic. Usually shows good crystal form, the common form being the simple octahedron (fig. 11). Fracture, conchoidal. Hardness, 8. Specific gravity, about 3·6.

Optical.—Colour variable, but usually pink or red. Yellow, orange, green, blue, and violet varieties also occur. Lustre, vitreous. Refractive index high, $\mu = 1{\cdot}72$. Isotropic and non-pleochroic. Microfragments irregular in shape.

Chemical and blowpipe.—Magnesium aluminate ($MgO . Al_2O_3$). Magnesia is replaceable by ferrous oxide, whilst alumina may be replaced by ferric and chromic oxides. In the greenish-black variety, *pleonaste*, there is more ferrous oxide than magnesia. The dark-brown variety, *picotite*, contains a considerable quantity of both ferric and chromic oxides, and graduates through a series richer in chromium up to the spineliferous chromites and chromites proper, which are ores of chromium (see p. 166). Infusible. Insoluble in ordinary acids.

Varieties and their occurrence.—The gem varieties of spinel are the paler-coloured varieties, of which the following are of chief importance :

Almandine spinel, violet.
Balas ruby, pale bluish-red.
Rubicelle, yellowish and yellowish red.
Spinel ruby or *ruby spinel*, deep red.

Ceylon and Burma are the chief sources of spinel of gem value, of which the spinel ruby is the commonest variety. The mineral has been formed generally as a product of the thermal metamorphism of limestones. In the limestones of Burma and Siam balas ruby occurs in association with the true ruby. Fine violet and blue spinels occur together with spinel ruby in the gem gravels of Ceylon. Rubicelle occurs associated with topaz in the gravels of Minas Novas, Brazil (see p. 317).

The colour of the balas ruby is supposed to be due to chromium; that of rubicelle to a mixture of iron and chromium; that of almandine spinel to manganese.

Spodumene (Gr. *spodos*, ashes, in allusion to the ash-coloured appearance of the mineral).

General.—Monoclinic. Good prismatic cleavage. Hardness, 6½. Specific gravity, about 3·1.

Optical.—Colour variable, but frequently greyish. Gem varieties green, pink, or yellow. Refractive index fairly high, $\gamma = 1{\cdot}67$. Birefringence fairly high, $\gamma - \alpha = 0{\cdot}021$. Optical sign, positive. Microfragments are prismatic in shape and show oblique extinction, the angle of extinction being about 22°.

Chemical and blowpipe.—Silicate of lithium and aluminium

$$(Li_2O \,.\, Al_2O_3 \,.\, 4SiO_2).$$

Fusibility about 3½, fusing readily to a clear glass. Good lithium flame-coloration (red). Insoluble in ordinary acids.

Ordinary ash-grey spodumene is of no value as a gemstone; it is used as a source of lithium salts, and as a constituent of pegmatites, in which it often occurs associated with lepidolite and tourmaline, it is mined for that purpose (see p. 379). The best-known gem varieties are *hiddenite* and *kunzite*. There is, however, a yellow transparent variety of spodumene; specimens of this variety occur associated with chrysoberyl in Brazil, and are sometimes sold as chrysoberyl, from which, however, they can readily be distinguished by their inferior hardness and lower specific gravity.

HIDDENITE (named after W. E. Hidden). This is the emerald-green variety of spodumene. It occurs at Stony Point, Alexander Co., North Carolina, in cavities of a gneissoid granite, associated with beryl, monazite, rutile, and other minerals.

KUNZITE (named after G. F. Kunz, an American gem expert). This is a pale-pink or lilac-coloured variety of spodumene, first found in a pegmatite vein on Pala Mt., San Diego Co., California, associated with muscovite, lepidolite, and tourmaline. The tourmaline occurring with it is represented by red, blue, green and black varieties and is in part of gem quality. Kunzite is also found in the pegmatites of Madagascar associated with lepidolite, tourmaline, and rose beryl (see p. 276).

Star Sapphire, a variety of sapphire showing the phenomenon of asterism (see p. 282).

Sunstone, a variety of felspar (see p. 295).

Tiger's Eye, a golden yellow and chatoyant variety of quartz (see p. 313).

Titanite = Sphene (Gr. *sphen*, a wedge).

General.—Monoclinic, occurring, as the name sphene implies, in the form of wedge-shaped crystals (fig. 1). Cleavage, imperfect. Fracture, sub-conchoidal. Hardness, about 5. Specific gravity, 3·5.

Optical.—Colour usually brown or reddish brown, but green and yellow varieties also occur. Lustre, sub-adamantine. Refractive index, very high, γ = about 2·00. Maximum birefringence very high, $\gamma - \alpha = 0{\cdot}121$. Optical sign, positive. Microfragments irregular in shape, and show strong pleochroism when deeply coloured, especially the reddish brown varieties; these fragments are apt to be mistaken for irregular fragments of reddish brown cassiterite under the microscope, but the appeal to blowpipe tests furnishes a decisive means of distinction.

Chemical and blowpipe.—Silicate and titanate of calcium

$$(CaO \,.\, SiO_2 \,.\, TiO_2).$$

Fusibility, 3 to 4. Violet bead with microcosmic salt in reducing flame. Decomposed by hydrochloric acid, and the solution becomes violet when reduced with a little metallic tin if sufficient of the mineral has been decomposed.

Occurrence.—Titanite occurs frequently in both igneous and metamorphic rocks, and is frequently associated with hornblende. It is often found in crystalline limestones. It is used to only a small extent as a gemstone, the green variety being the one usually cut.

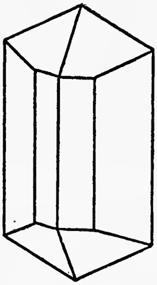

Fig. 200.—Topaz.

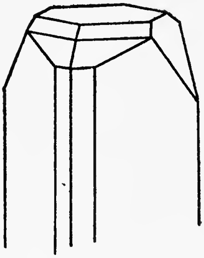

Fig. 201.—Topaz.

Topaz (L. *topazus*; Gr. *topazos* from Topazas, the name of an island in the Red Sea).

General.—Orthorhombic, frequently found in well-defined orthorhombic prisms capped by pyramids (figs. 200, 201). Perfect basal cleavage. Fracture, sub-conchoidal. Hardness, 8. Specific gravity, about 3·5.

Optical.—Often colourless; often also yellow, but blue and pink varieties occur. Slightly pleochroic when coloured. Lustre, vitreous. Usually very clear and transparent. Refractive index high, $\gamma = 1{\cdot}622$. Birefringence low, $\gamma - \alpha = 0{\cdot}009$. Optical sign, positive. Microfragments platy, and show a good biaxial figure. The birefringence effect seen on these basal flakes is very low, being due to $\beta - \alpha = 0{\cdot}003$.

Chemical and blowpipe.—Silicate and fluoride of aluminium

$$(2AlF_3 . 2Al_2O_3 . 3SiO_2).$$

Infusible, and gives a blue colour after moistening with cobalt nitrate and re-heating. Not decomposed by hydrochloric acid.

Occurrence and distribution.—Topaz occurs in granites and the veins formed in connection with granite intrusions. The minerals most frequently associated with it are tourmaline, lepidolite (lithia mica), quartz, orthoclase, albite, beryl, and cassiterite.

Brazil is an important source of topaz. In the State of Minas Geraes, yellow, blue, and colourless topaz occur. Near Diamantina, blue and colourless topaz occur associated with diamond (see p. 289). In the Minas Novas district, blue and colourless topaz occur associated with chrysoberyl, garnet, aquamarine, and amethyst in stream deposits. Yellow topaz occurs abundantly near Ouro Preto in nests and pockets in a mass of decomposed schist. These nests of topaz are supposed to have been formed along with the quartz veins that occur abundantly in the schists.

Other notable localities include Schneckenstein in Saxony, where topaz occurs as a constituent of a quartz-tourmaline schist; the Urals, notably at Mursinka, where it occurs associated with lepidolite in granite; and the Transbaikal region, where it occurs associated with beryl in quartz veins and pegmatites.

Colourless topaz bears a superficial resemblance to quartz and phenakite; but it can be readily distinguished from these minerals by its specific gravity, its perfect basal cleavage and the fact that cleavage plates show a good biaxial figure.

It is noteworthy that the dark yellow varieties, which occur abundantly in Brazil, become pink or reddish when heated; and much of the pink topaz used for gems has been obtained in this way.

Topazolite, a variety of garnet (see p. 298).

Tourmaline (from *turamali*, the Cingalese name).

General.—Trigonal, frequently showing well-developed crystals; these consist of prisms capped by pyramids and are hemimorphic, *i.e.*

differently terminated at the two ends of the crystal (fig. 202). No good cleavage. Fracture, sub-conchoidal. Hardness, about 7½. Specific gravity, about 3·1.

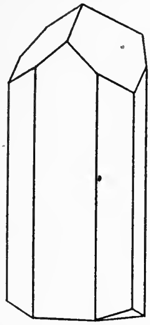

FIG. 202.—Tourmaline.

Optical.—Colour variable, but usually brown, green, or black. A colourless variety is called "achroite." The pink or red variety is known as "rubellite," and the indigo-blue variety "indicolite." Some tourmalines show zones of different colour. Some crystals show a rubellite nucleus surrounded by a shell of green tourmaline, and others are differently coloured at the two ends. Lustre, vitreous. Refractive index high, $\omega = 1{\cdot}64$. Birefringence high, $\omega - \epsilon = 0{\cdot}020$. Microfragments obtained by crushing are irregular in shape, but microscopic prisms are not uncommon. Pleochroism exceptionally strong, especially, in the dark-coloured varieties, in which the ordinary ray is completely or almost completely absorbed, whereas the extraordinary ray shows comparatively little absorption (fig. 203).

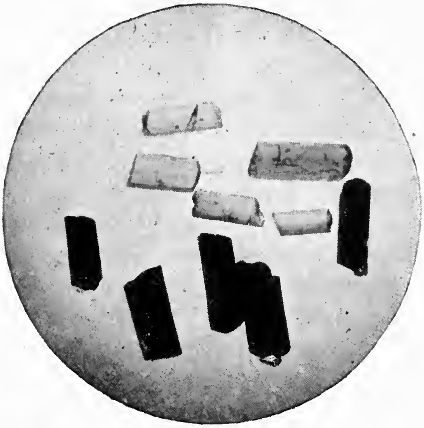

FIG. 203.—Microscopic prisms of tourmaline (×20), seen in polarized light, and showing pleochroism.

Chemical and blowpipe.—A complex borosilicate of aluminium and alkalies, containing also iron, magnesium, fluorine, and water. The black varieties are rich in iron oxide (10 to 15 per cent.); the brown varieties are rich in magnesia (about 15 per cent.). The pink and pale green varieties contain from 1 to 2 per cent. of lithia. Fusibility, variable, but usually from 3 to 5, the most easily fusible being those rich in magnesia—usually the brown variety. The rubellite variety is practically infusible. Gives a transient green flame-coloration when heated on platinum wire with a mixture of potassium bisulphate and calcium fluoride. Insoluble in ordinary acids.

Occurrence and distribution.—The varieties chiefly used as gemstones are the green and red tourmalines. Green tourmaline has usually a yellowish shade. It is obtained chiefly from Ceylon and Brazil, where it occurs in the gem gravels, associated with the other colour-varieties of tourmaline. In Brazil there occurs a deeper-coloured and purer-green variety of tourmaline known as the "Brazilian emerald."

Rubellite occurs in the cavities of drusy granite near Mursinka and Shaitanka in the Urals. At both localities it is associated with lepidolite. At Mount Mica, and other localities in the State of Maine, rubellite is associated with other varieties of tourmaline and with lepidolite in granite druses. Rubellite also occurs associated with ruby and sapphire in the gem gravels of Ceylon and Burma.

The brown and blue varieties of tourmaline are little used as gemstones.

Turquoise (name said to be derived from the fact that the stone was introduced into Europe through Turkey).

General.—Amorphous or cryptocrystalline; usually in the form of veins and encrustations. No cleavage. Fracture conchoidal. Hardness, 6. Specific gravity, about 2·7.

Optical.—Colour, sky-blue to bluish green. Refractive index about 1·62. Isotropic or feebly birefringent, with aggregate polarization effect between crossed nicols. Microfragments irregular in shape and translucent.

Chemical and blowpipe.—A hydrated phosphate of aluminium, with a composition corresponding approximately to the formula

$$2Al_2O_3 . P_2O_4 . 5H_2O.$$

A variable but small amount of copper is usually present, the amount in some cases being about 4 per cent., and it is to the presence of this copper as phosphate, together with a little iron, that the colour of the stone is attributed. Infusible, but darkens when heated in blowpipe flame. Flame-coloration green when treated alone, but blue with hydrochloric acid, due to the presence of copper. Darkens and gives off water in a closed tube. Soluble in hydrochloric acid.

Occurrence and distribution.—Turquoise occurs in the form of veins and irregular masses in volcanic rocks, in which it is formed as a product of alteration by atmospheric agencies. The chief sources are Persia, the Sinai Peninsula, and several of the south-western United States.

In Persia, turquoise is found in the Nishapur district in trachytes that have been erupted through a series of Tertiary sediments. These trachytes have been brecciated, and the cracks thus produced have been filled in with limonite and turquoise. Pseudomorphs of turquoise after felspar are found in the trachyte.

In the Sinai Peninsula, turquoise occurs and is mined at Gebel Maghara and Serabit el Khadim, where it is found in the joint planes of a purplish-grey Carboniferous sandstone, the best stones being found in streaks and pockets of ochreous sand. The main workings are in the Wadi Qenaia, and are carried on by Arabs. At other localities in the Sinai Peninsula, turquoise occurs in small veins that traverse porphyry.

Turquoise occurs as nodules and infillings of cracks in altered and much-brecciated andesite at Mount Chalchihuitl, in the Cerrillos district of New Mexico, U.S.A., associated with kaolin and limonite. At Turquoise Hill, in the same region, turquoise is found in a fractured and much-decomposed monzonite-porphyry, again associated with kaolin and limonite.

In all cases turquoise appears to have formed by the interaction of the products of weathering in felspathic rocks containing apatite, the felspars having supplied the alumina, and apatite the phosphatic matter.

Verdite.—A green chromiferous serpentine occurring at Barberton in the Transvaal, and used as an ornamental stone (see p. 339).

Vesuvianite (so named from its occurrence at Vesuvius, where the first specimens were obtained. Also called *idocrase*).

General.—Tetragonal. No distinct cleavage. Fracture, uneven. Hardness, $6\frac{1}{2}$. Specific gravity, about 3·4.

Optical.—Colour yellow, brown or green. Lustre vitreous, with a resinous tendency. Refractive index high, $\omega = 1{\cdot}722$. Birefringence extremely low, $\omega - \epsilon = 0{\cdot}001$. Optical sign, negative. Microfragments irregular in shape.

Chemical and blowpipe.—Essentially a silicate of calcium and aluminium, with a composition corresponding approximately to the formula $12CaO \cdot 3Al_2O_3 \cdot 10SiO_2 \cdot 2H_2O$, usually with small amounts of magnesium and iron. Fusibility, 3. Fuses readily in the blowpipe flame to a greenish or brownish glass. Scarcely affected by ordinary acids, except after fusion, when it is readily decomposed, yielding gelatinous silica, the filtrate from which gives good lime reactions.

Occurrence.—Vesuvianite occurs chiefly as a product of thermal metamorphism in limestone; but it is also found in serpentine. It occurs in thermally metamorphosed blocks of limestone ejected by volcanic eruption at Vesuvius, where it was first found; the vesuvianite of these blocks occurs on the walls of cavities in the rock and is yellow to brown in colour.

Fine crystals occur on the Mussa Alp in the Ala valley, Piedmont, associated with chlorite and diopside in a band of serpentine.

CALIFORNITE is a compact variety of vesuvianite. It is greenish in colour and somewhat resembles nephrite, with which it was at first confused. It occurs near Happy Camp in Siskiyou County, California, U.S.A., as lenticular masses in a sheared serpentine. It is also found near Pulga in Butte County.

Zircon (name probably corrupted from *jargon*, under which name the Ceylon specimens of this mineral were known long before the term zircon was introduced).

General.—Tetragonal. Occurs in the form of prisms capped with pyramids (figs. 204, 205); also as rounded pebbles in gravels. No good cleavage. Fracture, conchoidal. Hardness, $7\frac{1}{2}$. Specific gravity 4·7 in the ordinary brown variety, but falls as low as 4 in the smoky varieties.

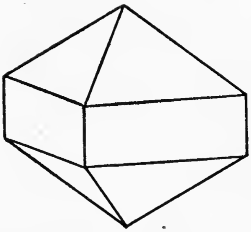

FIG. 204.—Zircon.

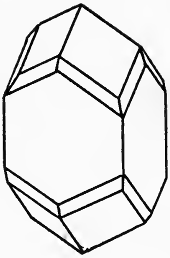

FIG. 205.—Zircon.

Optical.—Colour variable, but usually brown. Colourless, red, yellow, greenish, and smoky black varieties also occur. Lustre, subadamantine. Refractive index, very high, $\epsilon = 1{\cdot}99$. Birefringence very high, $\epsilon - \omega = 0{\cdot}062$, except in certain smoky varieties with low specific gravity which may be isotropic or nearly so. Optical sign, positive. Microfragments irregular in shape when obtained by crushing.

Chemical and blowpipe.—Silicate of zirconium ($ZrO_2 \cdot SiO_2$). Infusible. Brown varieties usually turn reddish, and smoky varieties colourless or pale green, after heating in a Bunsen flame. When powder is fused with sodium carbonate and the fused mass dissolved in hydrochloric acid solution, the solution thus obtained imparts to turmeric paper an orange colour.

Varieties and their occurrence.—The gem varieties of zircon are *hyacinth* or *jacinth*, and *jargon* or *jargoon*. Hyacinth is the red or yellowish red variety. Under the name jargoon are described the pale-green, pale yellow and grey varieties, which are frequently obtained artificially by heating the darker coloured varieties. The pale green is perhaps the commonest variety of jargoon, and is obtained by heating the smoky variety which occurs abundantly in the Ceylon gravels.

There is also a colourless and transparent variety, which, in consequence of its high refractive power, and the fact that it sometimes occurs in crystals with a stumpy habit suggesting a cubic form, is often mistaken for diamond. Such zircon is readily distinguished from diamond by its birefringence, its inferior hardness, and its specific gravity.

Zircon is widely distributed in igneous rocks, notably in the coarse-grained orthoclase varieties, and the pegmatites associated with them; and owing to its extremely high power of resisting the action of solvents, it is found almost universally among detrital sediments, especially in sands, though usually in small amount and in very small crystals. Zircon is very abundant in the Ceylon gem gravels, and these constitute the chief source of gem zircon. The zircon of these gravels is very variable in character. Much of it is of a dull stony-looking type, often strikingly zoned and opaque, and of no value for gem purposes. Large zircon pebbles, with a vitreous lustre, but dark-coloured or smoky in character, are also abundant. These usually become pale green in tint when heated in a Bunsen flame, and sometimes yield good stones of the jargoon type when cut. The *hyacinth* type of zircon in Ceylon occurs in much smaller pieces, the largest not much exceeding a centimetre in diameter, and the average size is much less.

The *hyacinth* variety of zircon is commonly confused with *hessonite*; and as both occur in Ceylon, the latter is frequently sold under the name of hyacinth, from which, however, it can readily be distinguished by its lower specific gravity and its isotropic character.

For further notes on zircon, see p. 437.

CHAPTER XI.

MISCELLANEOUS ECONOMIC MINERALS.

ABRASIVES.

Abrasives include corundum, emery, diamond (boart and carbonado varieties), garnet and quartz. These materials are employed in a variety of ways. They are used extensively in a crushed condition, and can be obtained in various grades from coarse gritty material down to fine powder. Corundum is largely used for grinding purposes in the form of slabs, discs, and wheels, which are made by cementing together angular grains of the crushed mineral.

The effectiveness of an abrasive depends upon its hardness and toughness, and the angularity of its particles. Corundum and diamond possess these properties in a high degree; but owing to its comparative abundance and cheapness, corundum has been the more widely used. For cutting purposes, however, the diamond is far more valuable on account of its superior hardness. Garnet and quartz are less effective owing to their lower degree of hardness, but for certain purposes, as in wood and leather work, they are preferred to other abrasives.

In addition to these should be mentioned the abrasives diatomite and pumice; the former of these is of organic origin, and the latter is a volcanic rock.

Artificial abrasives have competed very successfully with natural corundum in recent years, and both carborundum (silicon carbide) and artificial corundum (alundum or aloxite), are now used extensively. Both these artificial abrasives are electric furnace products, carborundum being made from silica and coke, and alundum from bauxite.

Corundum.—For an account of the properties of corundum, see p. 282, where the gem varieties are described. The common variety of corundum used for abrasive purposes is dull and non-transparent. It occurs abundantly in various rocks, both as crystals disseminated in syenites and schists, and as large masses of block corundum formed by segregation in peridotites (olivine-rocks).

Corundum-syenite has been quarried extensively in eastern Ontario, Canada, notably in the townships of Raglan and Carlow. These Ontario syenites are intrusive in the pre-Cambrian rocks of the Hastings-Grenville series. The corundum is scattered through the syenites in large and fairly pure crystals. The concentration of the corundum is an elaborate process. After the larger pieces of corundum have been hand-picked from the broken rock, the remainder is crushed, screened, concentrated hydraulically to eliminate felspar and mica as far as possible, and afterwards submitted to magnetic treatment to separate the iron oxide, hornblende, and other magnetic impurities. The heavy non-magnetic residue thus obtained consists of fairly pure corundum. The amount of corundum in the syenite averages about 6 per cent., and as about 2 per cent. of this is lost in dressing, the finished product represents on the average only about 4 per cent. of the original rock.

Corundum-syenites occur also in Montana, U.S.A., at Salem in India, and at many other localities.

A large amount of corundum has been obtained for commercial purposes during recent years in Transvaal and Madagascar, from surface gravels and weathered rocks. In the Zoutpansberg and Pietersburg districts of the Transvaal, where large amounts have been obtained, the parent rocks of the corundum are coarse-grained diorites and diorite-pegmatites. The deposits containing the corundum near Ambositra and other localities in Madagascar are described as decomposed pegmatite.

Massive granular corundum (block corundum) occurs at many localities in the eastern United States, where it has been formed as a product of magmatic segregation from a peridotite magma. It occurs along a belt of basic rocks stretching from Alabama to Maine. The occurrence at Corundum Hill in North Carolina is on this belt, and has yielded a large amount of corundum. The peridotite is intrusive in gneiss, and the corundum occurs at the outer margin of the intrusion.

Emery.—(Gr. *smeris* from *smao*, to rub; Fr. *emeri*). Emery is a black massive-granular admixture consisting chiefly of dark blue corundum and magnetite (for the properties of magnetite, see p. 194.) It has for long been used as an abrasive in the form of emery paper, emery cloth, and emery wheels. The chief producing localities are Asia Minor, and Naxos in the Grecian Archipelago. It has also been quarried at Chester in Massachusetts and near Peekskill in New York State.

Naxos was for several centuries the almost exclusive source of emery, the mineral being obtained originally in the form of loose masses in the soil. It occurs also in this way at Gumuch-dagh near Ephesus in Asia Minor, which is now the chief producer of emery. The parent rock of the emery, both in Naxos and Asia Minor, is a crystalline limestone, which is associated with schist, gneiss, and granite, and which owes its condition to thermal metamorphism. When the limestone is dissolved away by atmospheric agencies, the masses of enclosed emery are left behind as weathering residues. At Naxos the emery occurs in lenticular masses of variable size up to 100 yards in length and 50 yards in thickness, and the material obtained there has for some time been quarried from the limestone.

At Chester in Massachusetts, emery occurs as a bed about six feet thick in hornblende-schist. At Peekskill, in Westchester Co., New York, emery occurs associated with gabbro and is supposed to have been formed by magmatic segregation from a gabbro magma.

Diamond.—For a description of the properties of diamond, see p. 285. A considerable amount of ordinary diamond is obtained in the form of small fragments as waste in the gem-cutting industry, and this is of value for cutting purposes in lapidary work. In addition to this, however, there is used a considerable amount of diamond which is of no value for gem purposes, but which is valuable for rock drilling. The varieties of diamond known as *bort* or *boart* and *carbonado* are used in this way.

Boart is a dark nodular variety of diamond, usually having a radially fibrous structure. The name boart is, however, used by some in a rather loose way to include all kinds of diamond other than the gem variety.

Carbonado is a black massive-granular variety of diamond, found in Brazil. It is somewhat porous, and its texture suggests that of charcoal. It has therefore a lower specific gravity than ordinary diamond; but it is rather tougher and more resistant, and is for that reason highly appreciated by manufacturers of diamond drills.

Garnet.—For a description of the properties of garnet, see p. 296. Garnet of the almandine variety occurs in granites, gneisses, and schists, and is used to some extent, especially in North America, for the manufacture of garnet paper. It is chiefly in the Adirondack region that the garnetiferous rocks are quarried for this purpose.

Garnet occurs abundantly in association with hornblende and felspar in a gneissoid rock in the North River district of Warren Co., New York, and is separated from these minerals by wet concentration, chiefly by the use of jigs.

A granite containing 40 to 50 per cent. of garnet is quarried at Currier Hill in North Wilmot, Merrimac Co., New Hampshire. The garnet crystals are about half a centimetre in diameter, but they have incorporated in them a considerable amount of quartz and biotite. In order to obtain the garnet in a clean condition the rock is crushed, screened, and submitted to a process of dry concentration to separate the garnet from associated minerals, which are chiefly quartz, felspar, and biotite (black mica).

Garnet is found abundantly in many parts of India. At Cape Comorin in Travancore, it occurs as an ingredient of the beach and river sands, from which it is obtained by the natives and sent to Bombay, whence it is exported for use as an abrasive.

Garnet for use as an abrasive is obtained also from alluvial deposits in the Province of Almeria in Spain.

Quartz.—For a description of the properties of quartz, which is used to a small extent as an abrasive, see p. 309. Quartz is used in the manufacture of " sand paper," which is employed to some extent in wood polishing. It is also used in the form of sand in stone cutting and polishing. Quartz in a gritty condition is the essential ingredient of many millstones and burrstones.

In the form of fine silt grains, moreover, quartz is the essential constituent of various polishing earths, notably those known by the names *Bath brick* and *rotten-stone*, which are dark brown or greyish in colour. Both these polishing earths are characterised by a high percentage of silica (80 per cent. or more), largely in the form of silty quartz, and the remainder consists chiefly of finely divided argillaceous or calcareous matter, or both.

Bath brick is made by baking the calcareous silt of the River Parret at Bridgewater in Somersetshire. An interesting constituent of the Parret silt is detrital coal, of which the writer found over 1 per cent. in one sample. A white clayey silt, of the type that may be obtained by washing certain pipe-clays or kaolins, and containing some 85 per cent. or so of silica, is also used as a polishing powder. On account of its whiteness, fineness, and clean appearance, such clayey silt is preferred for some purposes to the darker coloured and rather coarser Bath brick. Rotten-stone is usually a weathering product of limestones. The material known as " tripoli " is a siliceous powder of this nature. " Tripoli " should not be confused with tripolite (see p. 367). The " tripoli " worked at Seneca in Newron Co., Missouri, contains 98 per cent. of silica, and has the consistency of a fine silt. It is used for filtering purposes and as a polishing powder. It is associated with mudstone and limestone of Carboniferous age, and is regarded as a leached residue of the limestone.

The stones known under the names of *whetstone*, *hone*, *oilstone*, and *water of Ayr stone* are really siltstones or consolidated polishing earths, characterized by a high percentage of silica in the form of silt grains of quartz. These stones are neither sandstones nor mudstones, but something intermediate between the two. The term siltstone is here used as the most suitable descriptive name for them, and one that merits a place in the terminology of petrographers.

Diatomite.—Under the name of diatomite or tripolite are included those polishing earths that consist essentially of the opaline frustules of diatoms, usually in a fragmentary condition. Diatomite owes its economic value chiefly to its porosity and high absorptive capacity. For a fuller description, see p. 367.

In connection with fragmentary diatomites mention may be made of radiolarian or Barbados earth, with which it is frequently confused. Radiolarian earths are of rare occurrence, though they are found in beds of considerable magnitude in Barbados. They lack the absorptive capacity of ordinary diatomite of good quality, but they should be equally effective for polishing purposes.

Pumice is a very porous volcanic rock, containing a fairly high percentage of combined silica. It is a well-known abrasive, being used chiefly in the form of lumps, though it is used also in the form of powder in scouring soaps, etc. It is obtained chiefly from the Lipari Islands in the Mediterranean. The pumice of Lipari is whitish or light grey in colour. A darker-coloured and cheaper variety has been exported from Teneriffe.

In Harlan Co., Nebraska, U.S.A., large deposits of fine white pumice powder occur in lakes into which it is supposed to have been drifted by wind currents. These natural pumice powders of Nebraska have been used extensively for polishing purposes, and in the manufacture of scouring soaps.

ASBESTOS.

The term asbestos (Gr. *asbestos*, inextinguishable) is not restricted to one mineral. It is applied to fibrous varieties of several minerals, the fibres of which are readily torn asunder and possess sufficient strength and flexibility to permit them to be used for textile purposes, *i.e.* to be spun into threads and woven into cloth. These fibres are bad conductors of heat and are also very refractory. Hence, asbestos is used as a jacketing material for steam pipes, etc. It is the best material available for the manufacture of fire-proof cloth and rope, and various other refractory articles.

There are five varieties of asbestos, viz., chrysotile (fibrous serpentine), tremolite, crocidolite, amosite, and anthophyllite. Of these, by far the most important, on account of the strength of its fibres, is chrysotile. Tremolite occurs in much longer fibres, but is not so valuable for textile purposes, because its fibres are weaker. Its freedom from iron, however, and its acid-resistant properties, make it the best variety of asbestos for filtering purposes.

Both chrysotile and tremolite are whitish in appearance in masses of teased fibre. Crocidolite has the disadvantage of a high percentage of iron oxide (about 36 per cent.), and in consequence of this it is of a dark colour and is more readily fusible. Its fibres, however, are very flexible, and suitable for textile purposes.

The disadvantage of anthophyllite is that its fibres are brittle, and it is of no use for textile purposes. Though less valuable than other varieties of asbestos, there are various purposes for which it is useful, and the quarrying of anthophyllite has been carried on successfully for some years in Georgia, U.S.A.

Chrysotile, crocidolite, and amosite are usually of the "cross-fibre" type, having been formed with their fibres at right-angles to the walls of the vein, whilst tremolite and anthophyllite fibres lie along the foliation-plane of the enclosing rock.

Chrysotile (Gr. *chrysos*, golden, and *tilos*, fibrous ; not to be confused with *chrysolite*, the yellow variety of olivine).

General.—System of crystallization doubtful ; but possibly orthorhombic. Occurs as a mass of fine fibres with a close-set parallel arrangement (fig. 206). Fibres flexible and strong, except when weathered. Hardness, about 4. Specific gravity, about 2·5.

Optical.—Colour, yellowish, greenish, or brownish. Lustre, silky. Refractive index low, about 1·57. Birefringence also low, $\gamma - \alpha$ about 0·010. Straight extinction.

Chemical and blowpipe.—Hydrated silicate of magnesium

$$(3MgO . 2SiO_2 . 2H_2O).$$

Fusibility, about $5\frac{1}{2}$. Gives off water in a closed tube. Readily decomposed by hydrochloric acid, and more readily still by sulphuric.

Occurrence and distribution.—The chief source of chrysotile asbestos is Canada, where it is quarried chiefly in the eastern townships of the Province of Quebec. The most important deposits are those of Thetford and Black Lake. In this region the productive belt of serpentinized peridotite has a length of about 23 miles, and a width varying from 100 feet to over a mile. This peridotite intrusion is associated with pre-Cambrian schists and Ordovician sediments, and is supposed to be of Ordovician age. The chrysotile, which itself is a fibrous variety of serpentine, occurs in massive granular serpentine that has been formed by the alteration of peridotite (olivine-rock). It occurs in the form of veins varying in size from mere streaks up to about three inches in thickness (as shown in fig. 206), though occasionally veins five or six inches thick are found. The veins are numerous, and often densely crowded. The rock has to be crushed, and the asbestos is then separated by means of screens and fans.

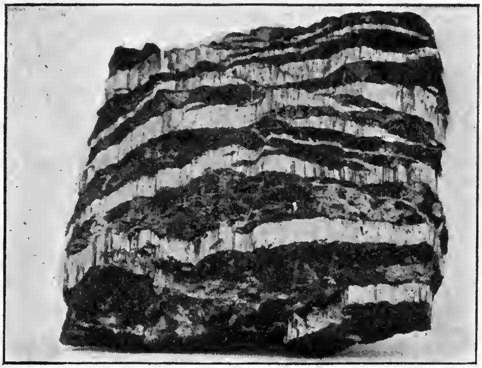

FIG. 206.—Chrysotile (karystiolite) asbestos.

The Canadian serpentine belt crosses the boundary, and extends into Vermont, U.S.A., where deposits of chrysotile asbestos are quarried on the slopes of Mount Belvidere, near Lowell.

Other notable localities for chrysotile asbestos are the Urals in Russia and the Victoria district in Rhodesia, where the conditions of occurrence resemble those in Canada.

Tremolite (named after Val Tremola in Switzerland, at which locality the specimens first described were obtained). A monoclinic member of the amphibole group.

General.—Monoclinic. The fibres of tremolite asbestos are usually loosely aggregated as compared with chrysotile, and they are commonly much longer (fig. 207), but they are not so strong. Hardness, $5\frac{1}{2}$. Specific gravity, about 3.

Optical.—Colour, white to grey. Lustre, silky. Refractive index high, $\gamma = 1{\cdot}636$. Birefringence high, $\gamma - \alpha = 0{\cdot}028$. Optical sign negative;

compensation across length of fibres with a positive quartz wedge. Extinction oblique, with a maximum angle of extinction about 15°.

Chemical and blowpipe.—Silicate of magnesium and calcium

$$(CaO \,.\, 3MgO \,.\, 4SiO_2).$$

Fusibility, 4 ; fuses more readily than chrysotile, yielding a glassy bead. Gives no water in closed tube. Not decomposed by ordinary acids.

Occurrence and distribution.—Tremolite asbestos is often called Italian asbestos, to distinguish it from the Canadian or chrysotile variety. It was formerly the only variety used, and was first quarried for commercial use in Italy, where there are large deposits of tremolite asbestos, notably at Valtellina in Lombardy, and in the Aosta and Susa valleys in Piedmont. The tremolite asbestos here occurs in talc-schists and mica-schists. Unlike chrysotile, its fibres are not regularly arranged at right angles to the plane of a definite vein, but lie along foliation surfaces of the rock. Fibres of tremolite asbestos often exceed a yard in length. Since the discovery and development of the Canadian chrysotile asbestos, there has been comparatively little demand for the tremolite variety, especially for textile purposes, but it is still quarried on a considerable scale in Italy.

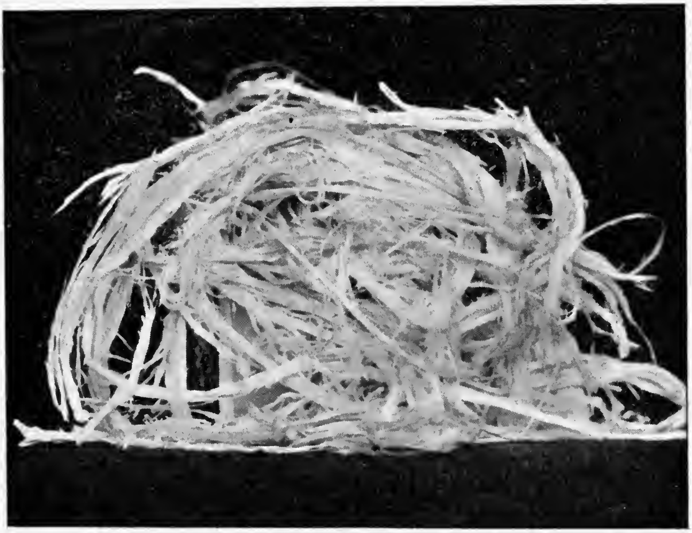

FIG. 207.—Tremolite asbestos.

Anthophyllite (L. *anthophyllum*, a clove ; the name has reference to the clove-brown colour of the specimens first described).

General.—An orthorhombic member of the amphibole group. The fibrous variety is readily distinguished from chrysolite and tremolite asbestos by the brittleness of its fibres, which are unsuitable for textile purposes. Hardness, about $5\frac{1}{2}$. Specific gravity, about 3·1.

Optical.—Colour, greyish or brownish. Lustre dull as compared with chrysotile and tremolite. Refractive index high; $\beta = 1{\cdot}63$. Birefringence high, $\gamma - \alpha = 0{\cdot}024$. Optical sign positive. Straight extinction.

Chemical and blowpipe.—Silicate of magnesium and iron, with a composition corresponding to the formula $(Mg, Fe)O . SiO_2$. Fusibility, about $5\frac{1}{2}$; a small fibre fuses with some difficulty to a black globule. Like tremolite, anthophyllite is not decomposed by ordinary acids.

FIG. 208.—Crocidolite asbestos.

Occurrence and distribution.—In its mode of occurrence, anthophyllite resembles tremolite, with which it is often associated. It does not form definite veins, but occurs with its fibres lying along the foliation surfaces of thermodynamically metamorphosed rocks. It is frequently found in irregularly fibrous masses in talc- and tremolite-schists. At Sall Mountain in White Co., Georgia, U.S.A., it occurs as large lenticular masses in gneiss, and these have been quarried for many years as a source of asbestos. Though of no use for textile purposes, it can be used in admixture with cement in the manufacture of shingles for building purposes and in other ways.

Crocidolite = **Krokidolite** (Gr. *krokis*, woof).

General.—Monoclinic. The fibres are flexible. Hardness, about 4. Specific gravity, about 3·2.

Optical.—Colour, blue. Lustre, silky. Refractive index and birefringence near those of tremolite; $\gamma - \alpha = 0{\cdot}025$. Optical sign positive. Compensate with quartz wedge along the length of the fibres. Extinction oblique, the maximum angle being about 20°. Slightly pleochroic.

Chemical and blowpipe.—Silicate of iron and sodium

$$(Na_2O \cdot Fe_2O_3 \cdot 2FeO \cdot 6SiO_2).$$

Fusibility, $3\frac{1}{2}$, fusing readily to a black magnetic globule. Strong yellow flame coloration due to sodium. Not decomposed by ordinary acids.

Occurrence and distribution.—Crocidolite is found in Griqualand West, South Africa, where it has been mined successfully at various places in Prieska and Hay. The Griqua Town beds in which it occurs are of uncertain age, but they are very old and are either early Palæozoic or pre-Cambrian. The crocidolite occurs in the form of thin veins (fig. 208) in a green slaty rock, forming layers that are interbedded with hard banded jaspers and ironstones. The veins run parallel to the bedding planes of the rocks, and are developed in places where the enclosing rocks have been bent and folded, being thickest in the troughs and crests of the folds. As in the case of chrysotile the fibres are arranged at right angles to the walls of the veins. The fibres range up to 3 inches in length, and are commonly $1\frac{1}{2}$ inches long.

Although adapted for textile purposes, crocidolite asbestos is used to only a comparatively small extent, and is less in demand than the chrysotile variety.

Crocidolite *cat's-eye* is a replacement of crocidolite by quartz. When, in addition to this replacement, oxidation also takes place, the yellow *tiger's-eye* is produced (see p. 313).

Amosite is a monoclinic amphibole variety of asbestos, closely similar to crocidolite in mode of occurrence. It consists essentially of ferrous silicate, with about 39 per cent. of iron oxide and a small amount of magnesia. The mineral is greyish or greenish in colour when fresh, and turns brown when weathered. Its fibres are longer than those of crocidolite, and range up to 11 inches in length, though as a rule the length is from 4 to 7 inches. Amosite occurs extensively in banded siliceous ironstone near the base of the Pretoria Series, in the Lydenburg and Pietersburg districts of the north-eastern Transvaal. The name is derived from " amosa," a word made up of the initials of " Asbestos Mines of South Africa " the title of the firm that developed the deposits.

BARIUM MINERALS.

Barite or **Barytes** (barium sulphate), see p. 415.
Witherite (barium carbonate), see p. 351.

BORATES.

Borax and boric acid are now obtained chiefly from the minerals *colemanite* (hydrated calcium borate) and *ulexite* (hydrated borate of calcium and sodium). Formerly, the supply was obtained wholly from the natural borax (hydrated sodium borate) deposited from lake waters in Tibet, California, and elsewhere; but since the discovery of large deposits of colemanite, the value of the natural borax deposits has become comparatively insignificant. More insignificant still is the supply obtained from boracite (borate and chloride of magnesium), which occurs in small amount scattered through carnallite and kainite in the salt deposits of Stassfurt in Germany.

The origin of borates is intimately connected with volcanic activity. Boron compounds are given off in many volcanic districts in the vapours escaping from fumaroles and solfataras. These vapours get dissolved in the waters of lakes or lagoons, and in arid climates the salts accumulate to such an extent that they are deposited at the bottom or on the margin of the lake. Borates thus differ from rock-salt and some other salts in that they are not of marine origin, and that they arise from inland waters in intimate association with volcanic activity.

Colemanite (named after Mr. W. T. Coleman, of San Francisco).

General.—Monoclinic. Occurs as well-developed crystals and crystalline masses (fig. 209). Cleavage perfect, parallel to the plane of symmetry. Hardness, about $4\frac{1}{2}$. Specific gravity, about 2·4.

Optical.—Colourless and transparent, or whitish. Lustre, vitreous. Refractive index low, $\gamma = 1{\cdot}61$. Birefringence high, $\gamma - \alpha = 0{\cdot}030$. Microfragments platy, with irregular outlines.

Chemical and blowpipe.—Hydrated calcium borate

$$(2CaO \,.\, 3B_2O_3 \,.\, 5H_2O).$$

Fusibility, $1\frac{1}{2}$; fusing with extreme readiness in an ordinary flame. Flame coloration green. Yields water in a closed tube. Decomposed by hydrochloric acid.

Occurrence and distribution.—The most important deposits of colemanite are those occurring at Death valley in Inyo Co., and in the Calico district of San Bernardino Co., in California. They occur in beds of lake origin and of Tertiary age. In Death valley, these beds consist of pale shales with lenticular masses of sand. The colemanite occurs in massive crystalline beds of variable thickness, up to 18 feet. The best material is so pure that it can be shipped as mined; but much of the material obtained contains clayey and shaly impurity from which it has to be separated. This is done by roasting, which causes the colemanite to decrepitate and fall to powder; and the separation of the powder from the lumps of clay and shale is effected by screening.

The colemanite beds are supposed to have been formed by the interaction of borate solutions (of volcanic origin) and masses of limestone, and to have accumulated in lake beds under arid conditions.

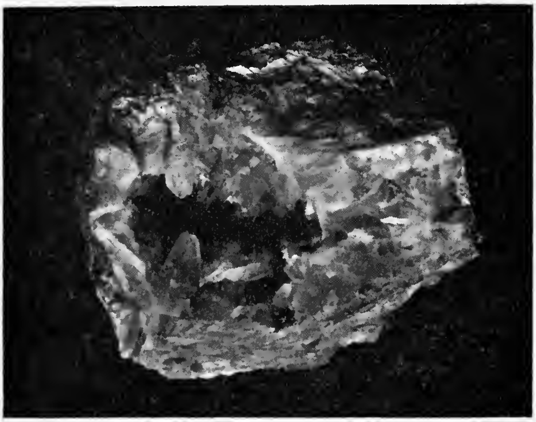

FIG. 209.—Colemanite. (× $\frac{1}{3}$). B.M.

Important deposits of a nodular variety of calcium borate known as pandermite occur near Panderma, a port on the Sea of Marmora in Asia Minor. Pandermite is closely similar to colemanite in composition, and may be regarded as a concretionary form of that mineral, hardened by impregnation with silica. The borate beds occur in a basin of Tertiary sediments including shales of Miocene age. The pandermite nodules are embedded in clay and gypsum. Underlying and surrounding the basin of Tertiary sediments are volcanic and other igneous rocks.

Ulexite (named after the chemist Ulex, who analysed it).

General.—Occurs in the form of rounded masses consisting of a loose aggregate of fine silky fibres. Hardness, about 1. Specific gravity, 1·65.

Optical.—Colour, white. Lustre, silky. Refractive index low, about 1·5. Birefringence low. Straight extinction. Sign of elongation negative.

Chemical and blowpipe.—Hydrated borate of calcium and sodium ($Na_2O \cdot 2CaO \cdot 5B_2O_3 \cdot 16H_2O$). Fusibility, 1. Fuses with intumescence to a clear glass, and yields a strong-yellow flame due to sodium. Yields water in a closed tube. Slightly soluble in hot water, yielding an alkaline solution. Soluble in hydrochloric acid.

Occurrence and distribution.—Ulexite nodules are known as "cotton balls" in Nevada and California, where they occur in a saline crust covering dry marshes in various localities.

Ulexite also occurs plentifully in Chile and Peru, where it is known as *tiza*; and the borate exported so largely from Chile is said to consist entirely of this mineral, which is found abundantly in various lakes near the Bolivian border. Some of these lakes contain fairly pure ulexite, which only requires to be dried before it is sent to the market. A large deposit of the mineral occurs in Peru, forming a bed up to a metre in thickness, in a region of volcanic rocks near Arequipa, at an altitude of about 14,000 feet.

Borax (Arabic, *buraq*, from *barak*, to shine).

General.—Monoclinic. Frequently shows good crystalline development, with a prismatic habit. Cleavage, perfect. Hardness, about $2\frac{1}{2}$. Specific gravity, about 1·7.

Optical.—Colour usually whitish or greyish. Lustre, vitreous or earthy. Refractory index low, γ=about 1·47.

Birefringence high, $\gamma-\alpha=0·026$. Optical sign, negative. Microfragments prismatic, with straight extinction.

Chemical and blowpipe.—Hydrated borate of sodium

$$(Na_2O \cdot 2B_2O_3 \cdot 10H_2O).$$

Fusibility, 1, swelling up considerably on fusion and yielding a clear glass. Flame coloration intense yellow. Soluble in water.

Occurrence and distribution.—Borax occurs in solution in certain borax lakes, and on the drying up of the lakes forms an efflorescence or crystalline deposit. It is found in solution in the waters of Borax Lake and Lake Hachinama in California, and also in the form of borax crystals embedded in mud at the bottom of the lakes.

It occurs under similar conditions in the borax lakes of Tibet, from which region it was formerly exported under the name of *tincal*. It occurs also in the Puga valley, Kashmir, where it is formed as a hot spring deposit.

More notable than any of these occurrences at the present time are those of Italy. At various localities in Tuscany, notably at Larderello, boric acid is emitted from steam jets (*soffioni*) which probably represent a declining phase of volcanic activity. The vapours are passed into water, and the solutions thus obtained are evaporated. The residue contains a small amount of boric acid and borax, mixed with sulphates of calcium, ammonium, and magnesium, and requires refinement to separate the boric acid and borax from these impurities.

BUILDING AND DECORATIVE STONES.

Certain of the stones already dealt with under the head of gem minerals are used for ornamentation in the construction of buildings, more particularly in a small way for internal decoration. Building stones proper, however, include the more abundant and cheaper materials that occur as rocks. They are usually quarried in open workings, but in some cases they are obtained by underground mining, as for example in the case of the Purbeck marble of Dorsetshire, and the slate mines at Festiniog in North Wales. Building stones are as a rule used with natural or roughly chiselled surfaces; but they are frequently smoothed or polished, notably so when used in the form of ornamental slabs and columns.

The characteristics which merit attention in building stones are colour; texture; hardness; toughness; readiness with which they can be quarried and dressed; resistance to weathering agents, especially to the chemical action of smoky atmospheres; power to resist compression and transverse strain; and lastly, but not by any means least, readiness of access and consequent cheapness.

The importance of cheapness is not more obvious in the morphology of buildings than it is in the stones of which many of them are built. Indeed, the building stones of a locality give as a rule a very evident expression of local geological conditions; and localities are very variously favoured or disfavoured in this respect. In many instances, however, notably in road making, the importance of durability and a good surface makes it worth while to transport suitable igneous rocks over long distances. The stones used in the form of polished slabs and columns for decorative purposes are also transported over long distances, as for example the white marbles of Italy, the green marble of Connemara, the syenites of Norway, and the sodalite-syenite of Ontario. The following are the principal varieties of building and decorative stones:

Granite.—Granite is chief of the igneous building stones. It is a plutonic rock, and is made up essentially of the minerals quartz and felspar (chiefly orthoclase); other minerals that may be present in notable quantities include muscovite, biotite, and hornblende, and these give the variety-name to the rock; thus we have muscovite-granite, biotite-granite and hornblende-granite. Granites vary in texture from coarse-grained to fine-grained types. The variation in colour is due largely to the felspar, which may be white, grey, pink, or reddish brown. Hornblende and biotite give the rock a dark appearance when present in considerable quantities, especially if the rock has a fine-grained texture.

Granites of use as rough building stones and as setts are of common occurrence and are widely used. Examples of these in the British Isles are the light-grey granites of Leinster, the dark-grey of Newry, the grey of Aberdeen, and the red of Peterhead. Notable and attractive varieties of granite for decorative uses are the porphyritic types, *i.e.* those in which certain of the felspar crystals are large in comparison with the main mass of the crystalline grains. Among porphyritic granites those of Shap in Westmorland, with a reddish brown felspar, and those of various parts of Cornwall (*e.g.* Penryn) with a white felspar, are well-known examples, both of which are frequently to be seen in polished slabs and columns, and are very attractive.

Other plutonic rocks with a granitoid texture that are often referred to by builders and architects as "granites" are *syenites*, *diorites*, and *gabbros*. Of these, syenites are by far the most important.

Syenites.—The chief difference between syenites and granites is that syenites contain little or no quartz. Chief among the syenites are those used as decorative stones in the form of polished slabs and columns. One of the best known of these is the augite-syenite known as *laurvigite*, from its occurrence at Laurvig in Norway. It consists chiefly of schillerized felspar with some augite, and has a fine bluish-black or bluish-grey appearance when polished. It has been quarried extensively at Laurvig and neighbouring localities in Norway, and exported for use as a decorative stone.

Of all syenites used as decorative stones, however, perhaps the finest is the sodalite-syenite of Dungannon in Ontario, Canada. The fine blue colour of the sodalite in this syenite gives polished slabs of the rock a very handsome appearance. This sodalite-syenite of Dungannon forms part of a large intrusive mass of nepheline-syenite, and has been obtained in blocks weighing several tons.

Diorites differ from syenites in having plagioclase as the dominant felspar, instead of orthoclase, and the plagioclase is usually one of the soda-lime type, with soda in excess of lime. The dark-coloured mineral of diorites is typically hornblende, but biotite is frequently present. A long-known and attractive type of diorite for use as a decorative stone is the orbicular diorite or napoleonite of Corsica, which is characterized by the presence of spheroids showing a concentric arrangement of green hornblende and felspar.

Gabbros differ from diorites in that augite instead of hornblende is usually the dark-coloured mineral of the rock; and the plagioclase felspars are dominantly those in which lime preponderates over soda (labradorite to anorthite). Gabbros frequently contain olivine and are then distinguished as olivine-gabbros. Gabbros are seldom used as building stones.

Microcrystalline Igneous Rocks, which occur typically in the form of dykes and sills, are used to some extent as building stones. Of these the chief varieties are quartz-porphyries, compact syenites, porphyrites and dolerites, which correspond fairly closely in mineral and chemical composition to granites, syenites, diorites, and gabbros respectively.

Of these finer-grained igneous rocks the green porphyrite (" Lambay porphyry ") of Lambay Island and the red porphyrite (" red porphyry " or " *rosso antico* ") of Djebel Dokhan in Egypt are good examples of decorative porphyrites.

Fine-grained plagioclase-augite or plagioclase-hornblende rocks of the dolerite and porphyrite types are the best materials for use as road-metal in macadamizing. The products of decomposition of these minerals are effective binding agents, and instead of softening by the action of the weather, these stones produce a tough and durable road surface. Dolerites that have been quarried extensively for road making materials are those of Clee Hills in Shropshire, Rowley Regis in Staffordshire, Penmaenmawr in North Wales, and Atherstone and Nuneaton in Warwickshire.

Volcanic Rocks.—The commoner types of volcanic rocks are rhyolites, trachytes, andesites, and basalts. These correspond respectively in their mineral and chemical composition to the four granitoid and the four compact or microcrystalline types already mentioned, and they also are used to some extent as building stones.

Serpentine.—Of special interest as an altered igneous rock is serpentine, which is one of the most valued of ornamental building stones. It is a dark-green rock arising from the hydration of peridotite. Peridotites are rocks consisting chiefly of the mineral olivine. They readily take up water and become converted into serpentine (hydrated silicate of magnesium). Iron oxides also arise as a consequence of this change, and the red mottling of serpentines is due to iron oxide. It is in such serpentines that the chrysotile asbestos of commerce occurs, but the variety used as a decorative stone is the compact, non-fibrous variety. A notable decorative serpentine of igneous origin is that of the Lizard district in Cornwall, where the rock occurs in large masses. Such serpentines of igneous origin should not be confused with serpentinous limestone (see p. 341). A bright-coloured chromiferous serpentine of Barberton in Transvaal, South Africa, is known by the name of "verdite."

Steatite, also known as *soapstone* and *potstone*, the compact variety of talc (see p. 413), is a mineral closely related in nature and mode of origin to serpentine, and the two minerals are frequently found associated. Steatite has been used to some extent as a building stone, and is readily carved on account of its softness. Although it is so very soft it is a very durable stone; it offers great resistance to atmospheric agencies, and its highly refractory character makes it practically fireproof.

Sandstones.—Sandstones and their allies are detrital rocks consisting chiefly of quartz with a variable admixture of other minerals such as are usually found in loose sands; felspar and mica are often present, and pyrite is a frequent impurity. The colour of sandstones is due chiefly to the nature of the cement. Pure siliceous and calcareous cements give to a sandstone a white or light-coloured appearance. Argillaceous cement imparts a grey or dark-coloured appearance, whilst ferruginous cement gives the warmer and more pleasing reddish or brownish colour.

Sandstones that split along the bedding planes to yield slabs, are known as flagstones, on account of their suitability for use as paving-flags. Sandstones which, on account of their regularity of grain and moderately cemented condition are easily worked with a chisel, are called "freestones," a term which is also often applied to oolitic limestones. When the cement of a sandstone has become hardened or grown into a homogeneous mass with the sand grains, as for example in the case of quartzite, there results a less-readily worked rock, which forms a contrast with the type known as "freestone."

Sandstones are very common rocks, and occur in practically all strata from the pre-Cambrian onward. Types in which the sand grains are coarse are known as grits. If pebbles are present the rock is known as a conglomerate.

In the British Isles, it is in the industrial and Carboniferous areas that sandstones are chiefly worked. The chief outputs are in Yorkshire, Lancashire, Stirlingshire, and Glamorganshire. These Carboniferous sandstones are as a rule very durable, but not very attractive. More attractive are the Permian red sandstones of Cumberland, and the Triassic red sandstones of the Midlands, though these are lacking in durability.

Slates.—Slates are typically black or bluish in colour. They are mudstones or shales, usually of great geological age, that have developed a secondary fissility in consequence of the intense earth-pressure (other than that of the mere pressure of superincumbent strata) to which they have been subjected. This pressure has squeezed the argillaceous substances of the rock and developed planes of weakness by shearing effects. These planes of weakness are continuous over a considerable area, and constitute what is known as "slaty cleavage." It is this secondary fissility, arising from pressure due to earth movement, and the hardening mineralogical changes that have accompanied it, that gives to slate its economic value.

The relation of the plane of fissility in a slate to the plane of bedding is variable, and depends on the direction of the earth pressures that have produced it. The fissility of a slate thus differs from that of shale, which is always parallel to the bedding. Slates in which the fissility is parallel to the bedding are described as flaggy slates.

Slates of the best quality are not found as frequently as one would expect, and they occur mostly among the older Palæozoic rocks. Those of North Wales are the most famous. Slates of excellent quality are worked extensively in open quarries at Penrhyn quarry near Bangor, and Dinorwic quarry near Carnarvon ; and there are large underground workings in slate at Festiniog.

Limestones and Marbles.—These include the massive bedded deposits of calcium carbonate that have been formed chiefly by the accumulation of the shelly remains of organisms. Other constituents are frequently present, notably magnesium carbonate, mud and sand. Red or brownish-red colours are due to ferruginous matter. Magnesium carbonate, when present, is usually in the form of the mineral dolomite, and limestones containing an appreciable quantity of this constituent mixed with calcite are known as dolomitic limestones. In some instances the rock is made up entirely of dolomite.

Limestone shows a great variety of textures. In ordinary limestones that have not been subjected to thermodynamical metamorphism, the rock is usually compact, with a dull and earthy fracture. Such limestones are often fossiliferous and include the shelly and encrinital marbles. They are frequently oolitic, *i.e.* the calcium carbonate is largely in the condition of small spherical bodies that show a concentric structure. These oolitic limestones are commonly called " freestones " on account of the ease with which they are worked. They include the well-known Portland and Bath oolites of Jurassic age, which are among the most attractive building stones, though unfortunately they are not very durable, and readily suffer attack by atmospheric agents, especially in the sulphurous atmospheres of smoky towns.

Limestones that have been thermodynamically metamorphosed become highly crystalline, and lose all trace of fossil remains. Moreover, the argillaceous and siliceous impurities become transformed into a variety of minerals. It is to crystalline limestones of this type that the term marble is perhaps most properly applied, though it is frequently applied also to the earthy fossiliferous type of rock.

The statuary marbles of commerce, including the famous white Carrara and Parian marbles, are fairly pure crystalline limestones of this type. The serpentinous limestones, including the well-known Connemara marble of Galway are also of this type. Olivine and pyroxene are among the commonest products of the thermodynamical metamorphism of limestones containing magnesia and siliceous impurity, and when the olivine or pyroxene becomes hydrated, serpentine marbles are formed. In this way were formed the Eozoon marbles, the peculiar textures of which were formerly supposed to be due to a foraminiferal organism (Eozoon, or dawn of life animal) ; but these textures are now known to be inorganic, and to have arisen from the hydration of thermodynamically metamorphosed magnesian limestones. Fibrous tremolite is also a common but undesirable constituent in crystalline dolomitic limestones.

Limestones and marbles occur at all geological horizons ; but crystal line varieties are especially abundant in the pre-Cambrian and other old rocks, though the marbles of Carrara are supposed to be of Jurassic age.

Alabaster.—Satin-spar has already been referred to under gemstones as a fibrous variety of gypsum used to a small extent as a gemstone and to a larger extent for making ornaments. The compact variety is known as alabaster, and has the appearance of a marble, but it is much softer. It is used largely in sculpturing, and still more largely in the form of wall slabs, etc., as a decorative building stone. The white compact alabaster of the province of Pisa in Italy has been used extensively in the manufacture of statuary, as a substitute for Carrara marble, owing to the fact that it is more readily worked.

Colour in Building Stones.—The most important colouring agent in rocks is iron oxide. Whiteness in a rock is due to the absence of iron oxide, but it is rarely that this constituent is altogether absent. The yellowish or brownish colour due to hydrated ferric oxide is a stable colour. Ferrous oxide, which is sometimes present in the form of magnetite, is unstable, and forms a rusty alteration product when exposed to the weather. The black appearance of many limestones ("black marbles") is due to carbonaceous matter. Finely-divided sulphides of iron are supposed to be responsible for the bluish colour in certain rocks, though these sulphides themselves are usually yellowish in colour. Pyrite, pyrrhotite, and marcasite are frequently present in building stones, and are undesirable constituents. They readily oxidize when exposed to the weather; especially is this the case with marcasite, the rhombic disulphide of iron, which is very unstable. These sulphides give rise on oxidation to acid products which attack the stone, in some cases with severe results. Limestones are particularly susceptible; and magnesian limestones suffer very badly under these conditions, owing to the ready solubility of the magnesium sulphate arising from the action of decomposing pyrites. The action of the sulphurous vapours of a smoke-laden atmosphere has a similar effect.

CARBONATES.

Carbonates effervesce when treated with hydrochloric acid, some in the cold, others on heating. They also give off carbon dioxide when heated to a high temperature. Some carbonates have been dealt with already as ore minerals. There remain to be considered several carbonates that find uses in their natural condition.

Calcite (L. *calx*, *calcis*, lime).

General.—Trigonal. Crystalline form frequently well developed, the scalenohedron, rhombohedron, and prism being the common forms

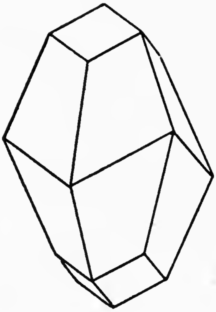

FIG. 210.—Calcite.

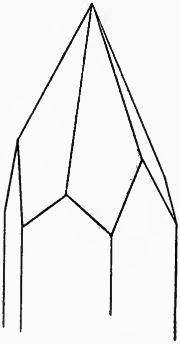

FIG. 211.—Calcite.

(figs. 210, 211). Cleavage, rhombohedral and perfect (fig. 212). Most commonly found in massive granular form constituting the rock known as limestone, the white crystalline varieties of which are used as statuary marble. Hardness, 3. Specific gravity, 2·72 for pure calcite, but rather less for the earthy limestones.

FIG. 212.—Cleavage rhomb of Iceland spar. (× ½). B.M.

Optical.—Usually colourless or white and sometimes perfectly transparent. Lustre, vitreous. Refractive index shows a wide range ; high for the ordinary ray ($\omega = 1{\cdot}658$), low for the extraordinary ray ($\epsilon = 1{\cdot}486$). Birefringence extremely high ($\omega - \epsilon = 0{\cdot}172$). Optical sign, negative.

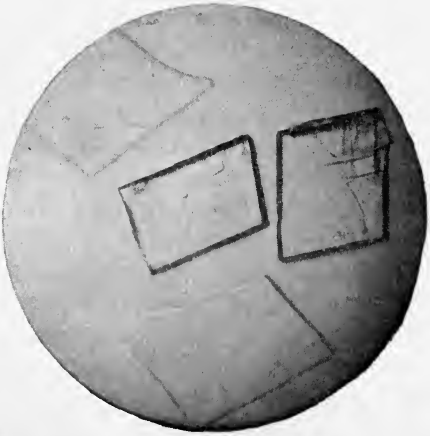

FIG. 213.—Microfragments of calcite in Canada balsam, showing strong relief due to ordinary ray (1.658), and weak relief due to extraordinary ray (1.56).

Microfragments rhomboidal in shape (fig. 213) and show symmetrical extinction. The refractive index of the extraordinary ray, as seen when examining cleavage plates, is about 1·56, but these plates show a striking variation in relief when mounted in cedar oil or Canada balsam and rotated over the lower nicol.

Chemical and blowpipe.—Calcium carbonate ($CaCO_3$). Infusible. Yellowish-red flame coloration when moistened with hydrochloric acid. Loses transparency and whitens when heated in a closed tube, giving off carbon dioxide. Dissolves with much effervescence in cold dilute hydrochloric acid. On adding dilute sulphuric acid to the solution, radiating groups of calcium sulphate crystals are obtained (fig. 242).

Occurrence and distribution.—Although calcite is one of the commonest minerals among the rocks of the earth's outer crust in the form of limestone and marble, and also in the form of a vein mineral, it is very rarely found as large transparent and flawless pieces such as are required for making polarizing prisms. Material of this character has only been found in any quantity in Iceland, and is for that reason known as Iceland spar.

Iceland spar occurs at Helgustadir near Eskifjord on the Reydarfjord in Iceland, where it is found in the form of irregular intersecting veins in a basalt. Much of the material, especially that near the surface, is imperfectly transparent and of no value for optical purposes. The best material is found at some depth in the quarries, and is embedded in a ferruginous clay that has been formed by decomposition of the basalt. The spar has been got chiefly from a mass 36′ × 15′ × 10′ in dimensions, from which large pieces of highly transparent spar have been obtained abundantly for optical uses. Large rhombohedral crystals up to two or three feet in diameter have been obtained.

Clear calcite of the Iceland-spar type has recently been exploited at Grey Cliff in Montana, U.S.A., where it occurs as extensive veins, four to seven feet thick, in gneiss. The calcite of these veins is free from admixture with foreign matter, but it is mostly unsuitable for optical purposes, on account of its cloudiness.

Lithographic stone is a limestone or dolomitic limestone of extremely fine and uniform texture. Stones having the requisite uniformity and fineness of texture for lithographic use are rare ; and the best material for this purpose is the celebrated Solenhofen limestone, a compact limestone of Jurassic age occurring in the Solenhofen district of Bavaria, where it has long been quarried for use as lithographic stone.

Dolomite (named after the French geologist Dolomieu).

General.—Trigonal. Common form the rhombohedron, often showing curved faces. Cleavage, rhombohedral and perfect. Hardness, about $3\frac{1}{2}$. Specific gravity about 2·85.

Optical.—Usually white or yellowish in well developed crystals, which are less common than those of calcite and seldom transparent. Lustre vitreous or pearly, but dull when massive-granular as in many magnesian limestones. Refractive index shows a wide range, as in calcite, $\omega = 1{\cdot}682$. Birefringence extremely high, $\omega - \epsilon = 0{\cdot}179$, though as in calcite this maximum value is not seen in cleavage plates. Optical sign negative. Microfragments rhomboidal, with symmetrical extinction.

Chemical and blowpipe.—Carbonate of calcium and magnesium ($CaCO_3 . MgCO_3$). Infusible. Yellowish-red flame coloration with hydrochloric acid. Closely related to dolomite, and intermediate in composition between it and siderite, is the mineral *ankerite*, in which the magnesium is partly replaced by iron, the formula being $CaCO_3 . (Mg, Fe)CO_3$. Ankerite is distinguished from dolomite by its higher density, which is about 3, and by containing much iron, which causes it to blacken in a closed tube or in the blowpipe flame.

Both dolomite and ankerite are distinguished from calcite by the fact that they do not effervesce freely with cold hydrochloric acid; and they are not stained by a solution of aluminium chloride (about 1 in 15) to which hæmatoxylin has been added. In such a solution calcite readily takes up the stain.

Occurrence and origin.—Dolomite and ankerite are abundant as vein minerals. It is, however, in the form of magnesian limestone beds and crystalline dolomites that dolomite occurs most abundantly. Ordinary calcitic limestones become changed into dolomitic limestones or dolomites by the action of solutions of magnesium salts. This process is called dolomitization. Where this has taken place long subsequent to deposition, the resulting dolomite rock is porous, except where thermally metamorphosed. Porosity is the result of the contraction of the mass, the molecular volume of dolomite being smaller than that of calcite.

The thermal metamorphism of dolomites makes them white and highly crystalline, and often converts them back in part to calcitic marble in consequence of the development of secondary magnesium silicates such as olivine and phlogopite mica. This process is the opposite of dolomitization, and is known by petrologists as de-dolomitization. Sedimentary and infiltration dolomites are common among the Carboniferous, Permian, and other strata. Thermally metamorphosed and crystalline dolomites are more especially abundant in the early Palæozoic and pre-Cambrian rocks.

Uses.—Dolomite rocks are often used as building stones; and many of the marbles used for statuary purposes are more or less dolomitic. Dolomite is also calcined (shrunk) and used for furnace linings, as in the basic Bessemer process for the manufacture of steel. For this purpose the shrunk dolomite is crushed, mixed with tar and then made into bricks which, when the tar has been burned off, are ready for use as a lining for the converter. Dolomite is further useful for the manufacture of Epsom salts and carbon dioxide. Lithographic stone sometimes consists of dolomitic limestone.

Hydromagnesite is a hydrated basic carbonate of magnesium, the formula of which is generally given as $3MgCO_3 . Mg(OH)_2 . 3H_2O$. It is found as a rule as white chalk-like masses, not much unlike some forms of magnesite in appearance, but rather soft and easily powdered. It occurs in some places as encrustations, and occasionally assumes a globular form. When crystalline it consists of small monoclinic prisms. Its low specific gravity (about 2·1) and the fact that it gives off water copiously when heated in a test tube, afford a ready means of distinction from anhydrous magnesite.

Large deposits of hydromagnesite occur near Atlin and at other localities in British Columbia. The magnitude of the Atlin deposits may be judged from the fact that they are about three feet thick and cover a large area. They are estimated by the Geological Survey of Canada to contain about 180,000 tons of the mineral. Samples dried at 105° C. contain about 18 per cent. of water. The Atlin magnesite is supposed to have been formed by swamp waters which have been derived from underground sources. Other deposits of hydromagnesite are found in the Lilloet district, and it is thought that their origin is connected with the occurrence of the later Tertiary volcanic rocks (basalts, etc.), which are very abundant in the district.

Among other occurrences of hydromagnesite, perhaps the most noteworthy are those of the Reinosa district of the Province of Santander in Spain, where hydromagnesite has been mined for some years. The hydromagnesite of the Reinosa district occurs superficially as irregular pockets in Triassic dolomites, of which it is regarded as an alteration product. It contains an appreciable percentage of lime and is much less pure than the Canadian material, presumably owing to admixture with dolomite.

Magnesite (Gr. *Magnesia*, a locality in Thessaly ; magnesite is known also as giobertite, a name given to it by French authors after Giobert, a chemist who analysed the mineral).

General.—Trigonal, but seldom shows crystalline form. The crystalline variety shows a perfect rhombohedral cleavage. Often nodular (fig. 214) with a very compact or cryptocrystalline texture, and a porcellanous appearance on freshly fractured surfaces. Hardness, $3\frac{1}{2}$, when pure. Specific gravity when pure about 2·95 for the compact variety and 3·05 for the non-ferriferous crystalline variety. The breunnerite variety has an average specific gravity of about 3·15.

Optical.—Usually white. Lustre, vitreous to dull. Refractive index shows a wide range, $\omega=1{\cdot}717$. Birefringence extremely high, $\omega-\epsilon=0{\cdot}202$. Optical sign, negative. Microfragments of crystalline material are rhomboidal in shape with symmetrical extinction. Nodular varieties show a compact-aggregate condition between crossed nicols.

Chemical and blowpipe.—Carbonate of magnesium ($MgCO_3$) when pure. The compact variety usually contains disseminated silica which is sometimes in the condition of quartz. The crystalline variety is liable to mechanical admixture with dolomite and isomorphous admixture with chalybite. In the latter case we get the variety breunnerite, which as mined in Austria contains about 4 per cent. of iron oxide in the condition of ferrous carbonate, and blackens on reduction in the blowpipe flame. Infusible. Does not effervesce freely with cold dilute hydrochloric acid, but does so on warming. Pure crystalline magnesite and breunnerite are distinguished from dolomite and ankerite respectively by their higher specific gravities. The compact or cryptocrystalline variety of magnesite generally contains little or no lime; but as already indicated the crystalline variety may contain a considerable amount of lime owing to admixture with dolomite.

FIG. 214.—Nodular magnesite. (× ½).

Varieties.—There are three varieties of commercial anhydrous magnesite, viz.:

1. Compact or cryptocrystalline magnesite, showing no cleavage, and occurring as veins in serpentine or as nodules in surface clays.

2. Spathic or coarsely crystalline magnesite showing cleavage and containing less than 5 per cent. of ferrous carbonate in isomorphous admixture.
3. Spathic breunnerite differing from spathic magnesite in the restricted sense of No. 2, by containing more than 5 per cent. of isomorphously admixed ferrous carbonate. For refractory purposes breunnerite should not contain more than 6 or 7 per cent. of ferrous carbonate.

Uses.—Magnesite is the most valuable of all basic refractory materials, and is the source of the dead-burnt magnesia used largely in the basic lining of steel and copper furnaces. For this purpose it should be sintered at a temperature of about 1500° C. (see Refractories, p. 409).

The purer varieties of magnesite, especially the compact variety, serve as a source of caustic magnesia, which is calcined at a temperature of 900° C. or so, and which is used extensively in combination with magnesium chloride as a cement material (Sorel or oxychloride cement) for flooring purposes. For use in this way it is mixed with asbestos or sawdust. Another use for magnesium oxychloride cement is as a fire-resisting paint.

Magnesite is preferred to limestone for the manufacture of carbon dioxide, owing to its lower dissociation temperature. It can also be used for making magnesium chloride and Epsom salts ; and it is used largely in the manufacture of magnesium bisulphite which is required in the pulp- and paper-making trades.

Occurrence and distribution.—Magnesite is widely distributed, but the world's supplies have been drawn chiefly from Greece, Austria and Hungary, Russia, the United States, Canada, and India.

The Grecian deposits are of the compact or cryptocrystalline variety, occurring as veins and irregular masses in serpentine, from which they have presumably been derived through the action of surface waters carrying carbon dioxide in solution. Nearly the whole of the Greek output has been obtained from mines and quarries in the northern part of the island of Euboea. The magnesite veins vary in width, and one vein has been traced over a length of 500 feet. Grecian magnesite of the best quality is fairly pure, and on that account suitable for the manufacture of caustic magnesia. Much of it, however, contains scattered pieces of serpentine, and this is used in the manufacture of dead-burnt magnesia for refractory purposes.

At various localities among the Austrian Alps in Styria and Lower Austria and farther east in northern Hungary there are important deposits of magnesite of the breunnerite variety, from which in the past the world's main supplies of magnesia sinter for refractory purposes have been drawn. The breunnerite occurs in beds associated with shales and dolomites of Carboniferous age and is supposed to have been formed as a replacement product by the action of magnesium-bearing solutions on the dolomite. The Sattlerkogels, a hill lying less than a mile north-west of Veitsch in Styria, is built up largely of magnesite, which is quarried in terraces and can be worked very economically. There is a large industry at Veitsch, where dead-burnt magnesia for use as a metallurgical refractory is produced for export.

Breunnerite deposits of a character closely similar to those of Veitsch are reported to occur at Mt. Boltsheja, between Satka and Berdjaush, some miles west of Zlatoust in the eastern part of the Ufa Province, southern Urals, Russia, and is sintered at Satka for use as a refractory in connection with the Russian steel industry.

In the United States cryptocrystalline magnesite occurs at various localities in California, notably in Tulare, Santa Clara, and San Benito Counties, chiefly as veins and lenticles in serpentine, and have yielded large supplies in recent years. Other important deposits in the United States are the spathic deposits of fairly pure magnesite, near Valley and Chewelah, Stevens Co., in the State of Washington, from which also large supplies have been obtained to meet American requirements in recent years. These Washington State crystalline magnesites vary in colour. There are white, grey, black, and red varieties, and they were quarried as marbles prior to their recent extensive use as a source of refractory magnesia.

In Canada, spathic magnesite is found associated with dolomite and serpentine, forming large lenticular masses in the metamorphosed pre-Cambrian rocks of the Grenville district, Argenteuil Co., Quebec. It is white and crystalline and not obviously different in superficial appearance from crystalline limestone or dolomite. Some of the magnesite contains a considerable admixture of dolomite, but bands of nearly pure magnesite are found. As mined on a large scale, however, the magnesite contains an appreciable percentage of lime. The origin of the magnesite of the Grenville district is attributed to the replacement of dolomite by magnesite through the action of solutions rich in magnesia.

In southern India, magnesite has been mined chiefly in the so-called "Chalk Hills" near Salem, where it occurs abundantly among the altered peridotites and serpentines of that area. The "Chalk Hills" magnesite is of excellent quality, and well suited for the production of lightly-calcined or caustic magnesia, though it has been used also for refractory purposes. Less important deposits are found in the Hassan and Mysore districts of Mysore State.

Magnesite of the white compact variety occurring as veins in serpentine is found near Kaapmuiden in the Transvaal. The veins have been deposited by surface waters bearing carbon dioxide which have decomposed the serpentine. The Kaapmuiden magnesite is sent to Johannesburg where it is used in the manufacture of carbon dioxide. The residues are dead-burnt to some extent and used as refractory magnesia.

Deposits of the white crystalline variety of magnesite are quarried for refractory uses near Snarum in the Modum district of southern Norway. The magnesite occurs as veins averaging 13 feet thick in a mass of serpentine which is associated with schists and quartzites. It contains scattered pieces of serpentine, but is remarkably free from lime and is stated to yield refractory bricks of first rate quality.

Among other deposits of magnesite of note mention may be made of those of the island of Margarita near the north coast of Venezuela, Fifield in New South Wales, Castiglioncello in Italy, the Chalkidike peninsula in Macedonia, Eski-Shehir in Asia Minor, and those of Manchuria.

Strontianite (from Strontian in Argyllshire, where it was first found).

General.—Orthorhombic, but usually found in a coarsely fibrous or massive condition. Cleavage, prismatic and fairly good. Fracture uneven. Hardness, about 3½. Specific gravity, about 3·7.

Optical.—Usually white or colourless, but sometimes yellow or green. Lustre, vitreous. Refractive index shows a wide range, $\alpha = 1{\cdot}52$. Birefringence extremely high, $\gamma - \alpha = 0{\cdot}152$. Optical sign, negative. Microfragments prismatic, and show straight extinction.

Chemical and blowpipe.—Carbonate of strontium ($SrCO_3$). Infusible. Flame coloration crimson, especially when moistened with hydrochloric acid. Dissolves with effervescence in hydrochloric acid, and the solution gives a white precipitate of strontium sulphate with dilute sulphuric acid.

Occurrence and uses.—Strontianite occurs in the form of veins in calcareous clay near Münster and Hamm in Westphalia, Germany. The mineral occurs at other localities, but not in sufficient quantity to make quarrying or mining profitable. Strontianite has been used as a source of strontium hydrate, which is applied extensively in the refining of beet sugar ; and also as a source of strontium nitrate, used for making red fire in pyrotechny ; but the use of strontianite for these purposes is insignificant compared with that of the sulphate (celestite) which occurs more abundantly (see p. 418).

Witherite (named after Dr. Withering, who discovered it).

General.—Orthorhombic; but usually found in granular or fibrous masses. Crystals pseudo-hexagonal (figs. 215, 216) simulating hexagonal bipyramids, due to repeated twinning. Prismatic cleavage imperfect. Fracture, uneven. Hardness, about 3½. Specific gravity, about 4·3.

Optical.—White or greyish white. Lustre, vitreous. Refractive index shows a wide range; $\gamma=1{\cdot}67$. Birefringence extremely high,

$$\gamma-\alpha=0{\cdot}15.$$

Microfragments prismatic in part and showing straight extinction.

Chemical and blowpipe.—Carbonate of barium ($BaCO_3$). Fusibility, 2; fusing with extreme ease, and yielding the yellowish-green flame coloration due to barium. Dissolves with effervescence in hydrochloric acid, and the solution thus obtained gives a white precipitate of barium sulphate with dilute sulphuric acid.

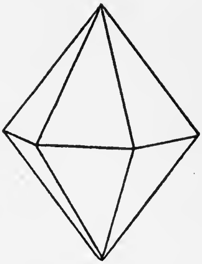

FIG. 215.—Witherite.

Occurrence and distribution.—Witherite occurs as a vein mineral associated with galena, notably in the veins of lead ore that traverse the Carboniferous limestone in various parts of the British Isles. It has been produced partly as a by-product in lead-mining. The chief producers have been the Fallowfield mine, near Hexham, and the Settlingstones mine, both in Northumberland.

FIG. 216.—Witherite, Fallowfield, Northumberland. (×½). B.M.

Uses.—Witherite is used as a rat poison; it is also used for making barium dioxide from which hydrogen peroxide and oxygen are manufactured; and for making barium nitrate to obtain green fire in pyrotechny. It has also been used to a small extent in glass-, pottery-, and brick-making.

Trona (derivation of name doubtful, but possibly of Arabic origin).

General.—Monoclinic. Occurs as loosely compacted and friable masses of crystals, sometimes showing well-developed crystals of prismatic habit (fig. 217). Cleavage, perfect and pinakoidal. Hardness, about 2½. Specific gravity, about 2·1.

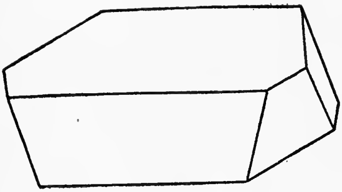

Fig. 217.—Trona.

Optical.—Colourless, white, or greyish. Lustre, vitreous. Refractive index low, the mean value being 1·507. The maximum refractive index is greater than that of cedar oil, and the minimum less, as can be seen by mounting crushed fragments in this medium. Birefringence high. Yields platy microfragments.

Chemical and blowpipe.—Hydrated acid sodium carbonate, with a composition corresponding to the formula $Na_2CO_3 . NaHCO_3 . 2H_2O$. Fusibility, 1·5. Flame-coloration intense yellow. Yields water in closed tube. Gives a strong alkaline reaction with moistened litmus paper. Dissolves with effervescence in dilute hydrochloric acid. Soluble in water.

Occurrence and distribution.—Trona is found as an efflorescence on the surface soil in many arid regions, and is very injurious to plant life. It is frequently associated with other salts, notably sodium sulphate and sodium chloride. The accumulation of these highly soluble salts in the soil is due to the fact that the rainfall is insufficient to wash the soil adequately and to carry off the salts in the surface drainage.

Deposits of trona occur in Egypt, notably in the Wadi Natrun in the Libyan desert. The trona occurs partly in solution, but partly also as a deposit around the margins and on the floors of the lakes. The smaller lakes dry up almost entirely in the summer, and the larger lakes diminish considerably, with the result that the trona is deposited as a crust. This crust is not of uniform quality; and though as a rule it consists largely of trona, it contains in some places large amounts of sodium sulphate and sodium chloride.

Trona is also abundant in various parts of East Africa, notably at Lake Magadi in the Rift-valley region. This lake is about 18 miles long and 2 or 3 miles wide; and it is in large part covered with a solid white or pinkish crust of trona. The rocks of the vicinity are volcanic, The region as a whole is noteworthy for the abundance of alkali volcanic rocks containing silicates rich in soda, such as nepheline and soda felspars. These minerals are readily decomposed by weathering agencies, and doubtless much of the trona in Lake Magadi has arisen from the action of atmospheric waters on these soda-rich silicates. The water that feeds Lake Magadi rises in the form of hot springs; but though a little of this may be exuded from the magma below, most of it probably represents water that has previously been at the surface, and that, circulating between the surface and the hot rocks below, leaches sodium out of the rocks in its course.

Other trona deposits occur in central India, as in the Lonar Lake; they are also found in America and various other places.

CEMENT MATERIALS.

The chief materials used in the manufacture of cements for building purposes are limestones and clays. These are usually ground and mixed to get a suitable product that can be calcined to yield Portland cement. A typical raw mixture has approximately the following composition:

	Per cent.
Calcium carbonate	75
Silica	15
Alumina	5
Ferric oxide	2

When calcined at a temperature near that of fusion, such a mixture yields Portland cement. In Portland cement as made in England, not more than 3 per cent. of magnesia is allowed; consequently the limestone used should not contain much dolomite. Limestones used in the manufacture of Portland cement should contain not less than 72 per cent. of calcium carbonate, and not more than three or four per cent. of magnesium carbonate. If a fairly pure limestone is used it matters little what the chemical nature of the argillaceous impurity is, but it should be in a finely divided condition. If much argillaceous impurity is present, and the calcium carbonate percentage is down as low as about 75, it then becomes a matter of importance that the ratio of SiO_2 to $Al_2O_3 + Fe_2O_3$ should be about that required in a cement mixture. This ratio should range in value from 2 to $3\frac{1}{2}$.

In England, the limestones and mudstones of the Jurassic and Cretaceous strata furnish an abundance of the materials required in cement manufacture; and some strata, notably those of the Lias, provide natural cement rock, *i.e.* a rock having approximately the composition required in a cement mixture.

The estuarine mud of the river Thames also furnishes a good supply of argillaceous material for use in conjunction with chalk in the manufacture of Portland cement. Fairly pure white chalk contains as much as 98 per cent. of calcium carbonate. The estuarine mud of the Thames contains about 60 per cent. of silica, 11 alumina, 8 ferric oxide, 5 calcium carbonate, together with small percentages of magnesium carbonate, calcium sulphate, and organic matter.

In the United States, dolomitic limestones are used largely in the manufacture of " natural cement," which is not so strong as Portland cement, though it is found very useful for building purposes. Such a magnesian cement rock contains typically 50 per cent. of calcium carbonate, 25 of magnesium carbonate, 16 per cent. of silica, 2 of ferric oxide and 4 of alumina.

Magnesite is of some interest as a cement mineral, since the material known as magnesium oxychloride or Sorel cement is made by mixing magnesia with magnesium chloride, and has the property of setting to produce a firm solid mass. A mixture of zinc oxide and zinc chloride possesses the same property, which was discovered by Sorel after whom these cements are sometimes named. Zinc oxychloride cement is used as a stopping by dentists. Magnesium oxychloride cement is used as a binding agent in making emery and carborundum discs, and various artificial stones. In the latter connection its resilient properties makes it valuable for flooring purposes and other uses in building construction.

In connection with cement, the extensive use of gypsum in the manufacture of " plaster of Paris " should be mentioned. Certain cements, *e.g.*, Keene's, Martin's, and Parian cements consist almost entirely of " plaster of Paris " (see p. 421).

CHLORIDES.

Halite (common salt, rock-salt, or sodium chloride).

General.—Cubic (fig. 218). Occurs most commonly in the massive form as beds of rock-salt. Perfect cubic cleavage, *i.e.* along three planes at right angles to each other. Hardness, about 2½. Specific gravity, about 2·2.

Optical.—Colourless or white when pure; rock-salt is usually yellowish or reddish owing to ferruginous impurity. Lustre, vitreous. Refractive index low (about 1·54). Isotropic.

Chemical and blowpipe.—Chloride of sodium. Fusibility, 1. Flame coloration intense yellow. Mixed with copper oxide gives an azure-blue flame-coloration due to copper chloride, indicating the presence of chlorine. Soluble in water, and has a characteristic taste.

Uses.—In addition to its familiar uses for food preservation and various domestic purposes, salt is used largely in the chemical and metallurgical trades. Clear flawless crystals of halite are used to a small extent in the manufacture of special lenses.

Occurrence and distribution.—Sodium chloride is very widely and abundantly distributed. It is, as is well known, a constituent of sea water, in which it has slowly accumulated during past geological ages from material derived from the waste of the land and carried in solution by rivers.

FIG. 218.—Halite, showing cubic form. (× ½). B.M.

Sea water has a specific gravity of about 1·025 ; it contains on the average about 3·5 per cent. of saline matter in solution, and of this the greater part (about 2·7 per cent.) is sodium chloride. The remainder consists chiefly of sulphates of calcium, magnesium, and potassium, together with small amounts of calcium carbonate, magnesium chloride and magnesium bromide.

In some countries salt is obtained by solar evaporation. The sediment is first allowed to settle ; the water is afterwards evaporated down until the carbonate of lime has deposited and the salt has begun to separate out. The liquid is then drawn off and evaporation continued until most of the salt has crystallized out. The evaporation requires to be arrested before the sulphate of sodium, chloride of magnesium and other deleterious ingredients begin to crystallize.

In some cold countries the practice is adopted of allowing the sea water to freeze. The ice consists of fairly pure water, and the salts remain behind concentrated in the unfrozen liquor, from which the sodium chloride can be obtained by artificial evaporation.

Considering the abundance of sodium chloride in ocean waters, it is not surprising to find that the mineral halite occurs abundantly among rocks in the form of beds of massive rock-salt in all parts of the world, and at various stratigraphical horizons. Though rock-salt occurs in sedimentary rocks of various geological ages, it occurs in Europe chiefly in beds of Permian and Triassic age. Arid conditions of climate existed in western Europe during Permo-Triassic times, and salt beds were deposited in inland seas, the waters of which were dried up under desert conditions in much the same way as lakes are known to be drying up in arid regions at the present day. It is from such beds of rock-salt, and the brines derived from them, that the main supplies of commercial salt are obtained.

Salt beds are generally interbedded with gypsum-bearing marls and mudstones. In this respect the Triassic salt-bearing strata of Cheshire, in England, are typical. In the vicinity of Northwich there are two thick beds of rock-salt, the upper one about 75 feet thick, the lower one about 115 feet thick, separated by 30 feet of salt-bearing red marl, the whole being surmounted by some 120 feet of clays and marls, some beds of which are gypsiferous. These beds occupy a roughly oval area which is about 1½ miles long and ¾ mile wide. Elsewhere in Cheshire and in other parts of the British Isles, as in Worcestershire and Antrim, rock-salt occurs abundantly in strata of Triassic age.

The famous salt deposits of Stassfurt in Germany, which are more noted for their potash salts (see p. 402) than for their rock-salt, are of Permian age. At Wieliczka, in Poland, there are immense deposits of rock-salt of exceptionally good quality of Tertiary age. The salt-bearing strata in this region cover an area of about 10,000 square miles and have a thickness of about 1200 feet. The salt occurs partly in the form of beds about 100 feet thick, and partly in the form of irregular masses of even greater thickness.

Bischofite is a hydrated magnesium chloride ($MgCl_2 . 6H_2O$), of hardness about 1½ and specific gravity 1·65, occurring along with more complex chlorides in the Stassfurt and other potash salt deposits. It is worthy of mention as an economic mineral on account of the fact that magnesium chloride is obtained as a by-product in the Stassfurt potash industry, and for many years Germany had a monopoly of this product. Bischofite occurs as thin layers in the carnallite beds, and the magnesium chloride is recovered from the mother liquors after separating potassium chloride from solutions of carnallite.

Magnesium chloride occurs abundantly in some natural brines, such as those of the Salt Lake of Utah, U.S.A. The bitterns of India are also stated to contain large quantities.

Magnesium chloride is used chiefly in the manufacture of magnesium oxychloride cement. It is used also in the production of metallic magnesium by electrolysis, and as a thread lubricant in the textile trades.

For other chlorides see carnallite (p. 401), and sylvite (p. 403).

CLAYS.

The term clay is applied in a general sense to various materials consisting essentially of hydrated silicate of aluminium. Clays can be moulded in a wet state, and yield a hard mass when baked, for which reason they are used in the manufacture of pottery, stoneware, bricks and tiles.

Clays are mostly of exogenetic origin. They arise from the action of atmospheric weathering on felspars and other silicates. The amorphous hydrated silicates of aluminium resulting from this action constitute the plastic basis of all ordinary rock clays; they are carried in streams and rivers and deposited to form beds of clay and mud. Kaolin or China clay is an exception to this mode of origin. It has probably been formed primarily by the action of igneous emanations on granite masses, and is thus of endogenetic origin.

Clays are very variable in appearance and composition, and have received numerous names. From an economic standpoint, the chief varieties of clay can be grouped under the following heads according to their uses:

1. Kaolin or China clay.
2. Ball clays.
3. Brick and tile clays.
4. Fireclays.
5. Fuller's earth.
6. Halloysite and other clays.

(1) **Kaolin** (Chinese *kau-ling*, or high ridge, from the locality where the Chinese originally obtained their porcelain clay. Hence the alternative name China clay).

Kaolin or China clay is a white or pale-tinted clay used extensively in the pottery trade for the manufacture of China or porcelain ware. It differs from ordinary rock clays in having comparatively little plasticity. This is due to the fact that it consists essentially of kaolinite, which is crystalline, whereas ordinary rock clay is amorphous; and it is to the presence of colloidal clayey matter that ordinary clay owes its plasticity.

Kaolinite is a definite crystalline mineral, occurring in the form of six-sided plates which as a rule are very small (fig. 219). These crystalline plates are monoclinic in symmetry. Kaolinite is a hydrated silicate of aluminium with a composition corresponding to the formula $Al_2O_3 . 2SiO_2 . 2H_2O$. Material showing good crystalline form is, however, of comparatively rare occurrence; it is found occasionally as an exogenetic mineral infilling small pockets and crevices in rocks but is of no commercial value in this condition. The kaolinite of China clay does not show definite crystalline form. It consists of extremely small and irregular crystalline plates and fibrous looking aggregates (fig. 220). Kaolinite has a refractive index about 1·56.

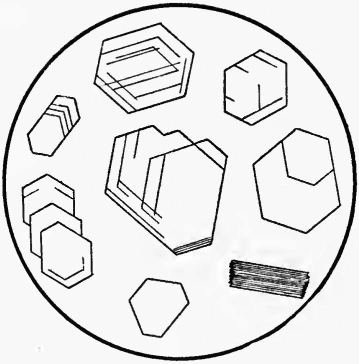

FIG. 219.—Kaolinite (× 200).

China-clay rock contains, in addition to kaolinite, a considerable amount of other mineral matter, chiefly quartz, mica, and felspar. When freed from these as far as possible by washing, it approximates very closely in its composition to kaolinite. The free silica and other impurities are sometimes so finely divided that it is not possible to wash the kaolin free from them, and for that reason refined kaolin sometimes contains a considerable excess of silica over the amount required to form kaolinite. A small percentage of alkalies is also usually present in refined China clay, owing to the presence of mica. The following analyses will serve to illustrate the difference in composition between pure kaolinite and a typical specimen of refined Cornish kaolin :

	Kaolinite.	Kaolin.
SiO_2	46·3	48·3
Al_2O_3	39·8	37·6
Fe_2O_3	—	0·5
CaO	—	0·1
K_2O Na_2O	—	1·5
H_2O	13·9	12·5

Kaolin occurs in granite regions. Its mode of occurrence is such as to indicate that it has not been formed by atmospheric weathering as formerly supposed, but rather by the action of vapours escaping from a deep seated acid magma, and decomposing the alkali felspars of the already consolidated granites.

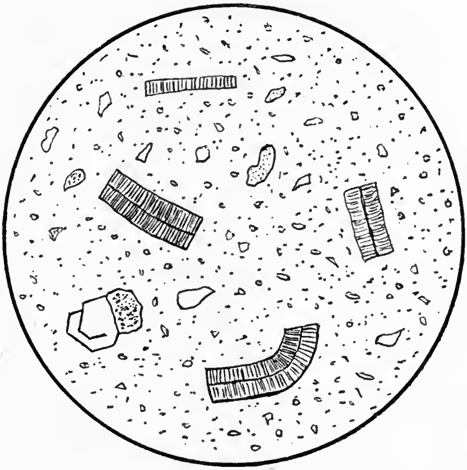

FIG. 220.—Kaolin (× 125).

The most important occurrences are those of Devonshire and Cornwall, where kaolin occurs in association with tourmaline, topaz, and cassiterite. The kaolin is worked in large quarries. The crude rock is subjected to the action of a stream of water, which carries off the finer kaolinic matter as a milky liquid. This is allowed to settle in a series of tanks so as to separate kaolin of the finest grade from the coarser particles.

In addition to its use in the manufacture of pottery and porcelain, kaolin is used as filler for cloth and paper.

(2) **Ball Clay or Potter's Clay.**—Under the name ball clay or potter's clay, it is convenient to include all fine-textured and highly plastic detrital clays that yield white or pale-tinted pottery when fired. Ball clay is often sufficiently free from coarse grit and sand to permit of its use alone in the manufacture of fine pottery or stoneware; and it can be used in conjunction with kaolin to impart plasticity to the latter. When much sandy or gritty impurity is present, this can be eliminated by levigation and the use of settling tanks; and in this way various grades of clay are obtained. Ball clay is usually greyish or dark coloured. It generally contains more silica than does refined China clay, and its silicate of alumina is largely in the amorphous condition.

Pipe clay is a white siliceous ball clay that is used in the manufacture of tobacco pipes, and in various other ways. It is usually among comparatively young strata that ball clays are found, as for example in the Tertiary beds of Dorset, Devon and Cornwall and numerous other localities. Less frequently they occur as residual clays filling pockets in limestone from which they have been derived by weathering.

(3) **Brick** and **Tile Clays** include the coarser kinds of detrital clay containing a considerable amount of sandy and ferruginous matter. For making coarse bricks the clay may contain much gravel and other very coarse material; but for the better qualities of bricks and tiles the silica should be in a comparatively fine sandy or silty condition.

(4) **Fireclay** is an amorphous and plastic detrital clay in which the percentages of iron oxide, lime, magnesia, and alkalies are low enough to make the clay highly refractory, so that it will resist fusion at a temperature of 1500° or more. Such clay is used in the manufacture of firebricks, and for various other purposes where refractoriness is necessary. Fireclays are generally greyish in colour. They are found in strata of various ages from the Carboniferous onward; but they occur chiefly in association with coal beds of Carboniferous age. They usually underlie the coal seams, and occur abundantly in the Carboniferous coal measures of England, notably in the Stourbridge district.

(5) **Fuller's Earth.**—This is a greyish or greenish detrital clay that has the property of absorbing greasy matter. It has a somewhat soapy texture, and owes its name to the fact that it was formerly used in fulling cloth; but it is now also used as a clearing agent in refining oils, and as an ingredient of soap. It is less plastic than ordinary rock clay of the ball-clay or brick-clay type. Its chemical composition is variable. A typical fuller's earth of good quality from Nutfield in Surrey contained 58·66 per cent. of silica, 17·33 of alumina, 7·21 of ferric oxide, 3·26 of magnesia, 3·17 of lime, 1·63 of potash and soda, and 8·74 of water. A

clay can, however, depart very considerably from this composition and still have the properties of a fuller's earth.

Fuller's earth of the best quality occurs in the Lower Greensand (Cretaceous) of Nutfield and neighbouring localities in Surrey, where it forms a bed from 8 to 12 feet thick; and in the Inferior Oolite (Jurassic) near Bath, in Somersetshire. In the U.S.A., it is quarried near Quincy, in Florida, and also near Benton, in Arkansas. Material of somewhat poorer quality is widely distributed.

(6) **Halloysite and other clays.**—Halloysite is a whitish or pale-tinted amorphous clay found as an encrustation or infilling in rock crevices in which it has been deposited from solution. It has a composition resembling that of kaolinite $(Al_2O_3 . 2SiO_2 . 2H_2O)$. Halloysite swells when placed in water and falls to powder. It has a hardness about $1\frac{1}{2}$, a specific gravity about 2·1, and is infusible. It is decomposed by sulphuric acid, and can be used for making aluminium sulphate or alum. Usually, however, alum clays are pyritic clays in which, as a result of either roasting or atmospheric action, the decomposition products of the pyrites attack the clay and convert it into aluminium sulphate.

Another variety of amorphous hydrated silicate of aluminium is *allophane*. It contains a much larger percentage of water than does halloysite, and has a composition corresponding approximately to the formula $Al_2O_3 . SiO_2 . 5H_2O$. Its specific gravity is therefore lower and is about 1·9. Allophane resembles halloysite in its origin and mode of occurrence.

Bentonite is an amorphous (colloidal) clay found in the Cretaceous beds of Wyoming, U.S.A. It is cream-coloured, absorbs water to a large extent and swells much when wetted. It is closely similar to some varieties of fuller's earth in chemical composition. It is used as a filler in paper manufacture, and as an adulterant in soap.

Other clays that are worthy of note, especially as differing from halloysite in their origin and mode of occurrence, are *lithomarge* and *bole*. It is convenient to restrict these terms to the amorphous weathering residues of basalts and similar rocks. As a consequence of their mode of origin they are less simple in their composition than halloysite. Lithomarge usually contains a considerable amount of iron oxide and magnesia. Bole is a red and highly ferruginous variety of lithomarge; it is used in a rough way as a pigment and may be regarded as a red ochre.

COALS.

Coals are the more or less completely carbonized remains of woody and other vegetable matter, occurring in the form of bedded deposits. The chief varieties of coal proper are brown coal (including lignite), sub-bituminous coal, bituminous coal, sub-anthracitic coal, and anthracite. The varieties free from an excess of shaly matter range in specific gravity from 1·2 to 1·7.

Brown Coal (including lignite) is typically dull, and, as its name implies, generally brown in colour. It yields more volatile matter than fixed carbon, and burns with a long smoky flame. When freshly mined it contains a large amount of moisture, frequently 20 to 30 per cent., or even more. Much of this water it loses on standing exposed to the air, and in consequence of this it often cracks, and falls to pieces when handled, after being air-dried. The variety of brown coal in which a large proportion of woody matter is present, preserving its original structure, is known as lignite. *Jet* is a compact black lignite, used for ornamental purposes (see p. 302). The following figures show the usual range in proximate composition for brown coals, calculated free from ash and sulphur :

Fixed carbon - - - -	30 to 40 per cent.
Volatile matter - - - -	40 to 55 ,,
Moisture - - - - -	10 to 30 ,,

Sub-Bituminous Coal is usually dull or only feebly lustrous, and brownish black to black. It is intermediate in character between brown coal and bituminous coal. It contains less water than brown coal and generally retains its compactness after being air-dried. The fixed carbon is in excess of the volatile matter, and consequently these coals burn with a more moderate flame and have better fuel properties than brown coal. The following figures show the usual range in proximate composition for sub-bituminous coals, calculated free from ash and sulphur :

Fixed carbon - - - -	45 to 55 per cent.
Volatile matter - - - -	35 to 45 ,,
Moisture - - - - -	5 to 10 ,,

Bituminous Coal is typically lustrous black, though the different layers frequently differ considerably in this respect. The dominant variety contains a considerable excess of fixed carbon over volatile matter. *Cannel coal*, however, a dull black variety of coal, which occurs as lenticular masses in the coal measures associated with ordinary bituminous coal, differs from the latter in containing from 60 to 65 per cent. of volatile matter and 30 to 35 per cent. of fixed carbon ; *i.e.* in cannel coal the ratio of fixed carbon to volatile matter is about 1 : 2, whereas in ordinary bituminous coal this ratio is about 2 : 1. Though cannel coal is usually treated as a coal, it is really more closely related to torbanite and " kerosene shale " than to the coals proper (see p. 392). It has been largely used in the manufacture of illuminating gas, and was formerly distilled to obtain oil. It has recently again become interesting as a possible source of commercial supplies of oil.

Ordinary bituminous coals are of two types, viz., (1) caking coals, and (2) non-caking coals. Both varieties burn freely with a good flame and give off much smoke. The caking variety becomes pasty when burning, and yields a residue of coke. It is much used for household fuel and for the production of illuminating gas. The non-caking variety is commonly called steam coal; in composition it merges into the better-class steam coals, viz., the sub-anthracitic variety. The following figures show the usual range in proximate composition for ordinary bituminous coals, calculated free from ash and sulphur :

Fixed carbon - - - -	55 to 75 per cent.
Volatile matter - - - -	20 to 40 ,,
Moisture - - - - -	2 to 5 ,,

Sub-Anthracitic Coal comprises those black coals which are most highly prized for steam-raising purposes. The material commonly referred to as steam coal includes some of the non-caking bituminous variety, but the best kind of steam coal is typical sub-anthracitic coal, or semi-anthracite, as it is sometimes called. Sub-anthracitic coal is intermediate in character between non-caking bituminous coal and anthracite. It contains enough volatile matter to flame slightly on ignition, but it is practically non-smoky. The following figures show the usual range in proximate composition for sub-anthracitic coal, calculated free from ash and sulphur :

Fixed carbon - - - -	75 to 85 per cent.
Volatile matter - - - -	10 to 20 ,,
Moisture - - - - -	1 to 2 ,,

Anthracite.—True anthracite is a lustrous black, compact and brittle coal that burns practically without flame. It contains a very small percentage of volatile matter and therefore does not ignite readily, but when ignited it gives out intense heat and is one of the most efficient fuels. The following figures show the usual range in proximate composition for anthracite, calculated free from ash and sulphur :

Fixed carbon - - - -	85 to 95 per cent.
Volatile matter - - - -	4 to 14 ,,
Moisture - - - - -	1 to 2 ,,

Origin of coal.—The variable nature of these different coaly materials indicates that plant products of various kinds have contributed to the formation of coal beds. Of these different plant products doubtless the chief were the wood, leaves, spores and seeds of the higher plants, together with much resinous and gummy matter; but thallophytes must also have contributed. These different materials have been variously affected by the compacting processes and dynamic changes from which the beds have suffered during the long ages that have elapsed since deposition; and it is to this varying response to alteration, by materials differing somewhat in their original characters, that we must attribute the fact that in the coal measures of the Carboniferous we get such different types as bituminous coal, cannel coal, sub-anthracitic coal, and anthracite. The ordinary bituminous and anthracitic varieties of coal probably consist for the most part of carbonized woody matter. It is considered highly probable that cannel coal consists chiefly of spore remains; and the variability in the percentage of volatile matter present in bituminous coals is doubtless due to variations in the amount of spore material and resinous substances.

Coal has been formed at many different geological periods, and probably under many widely different physical conditions, such as are represented at the present day by peat and forest growth, fresh-water deposits, and marine swamps. In the older Palæozoic strata there is occasionally found anthracitic material which not improbably represents the remains of algæ. It was, however, in the later Palæozoic strata that plant remains, chiefly in the form of arboreal lycopods (club-mosses), equisetaceæ (horse-tails), and the peculiar fern-like pteridosperms, accumulated in richest profusion, to form the immensely valuable coal seams that have played such an important part in the world's economic development.

Though coal occurs extensively in the Carboniferous strata of Europe and North America, the so-called Permo-Carboniferous of Australia, the Gondwana of India, and the Karroo strata of Africa, it is by no means confined to these older strata. It occurs to a smaller extent in Jurassic rocks. It is found very abundantly in the Cretaceous strata, notably in western North America; and it is found in Tertiary rocks in Europe, India, North America, and elsewhere.

Except where they have been seriously influenced by earth movements or by igneous intrusions, the Jurassic and younger coals have been much less effectively carbonized than those of the Carboniferous, and are on that account usually of less value as fuels. It is, indeed, a fact of great interest that coals, like rocks in general, manifest in a general way clear evidence of progressive lithological change with increase in geological age.

The youngest masses of vegetable matter that can be regarded as coals in the making, are peat bogs, moorland turf accumulations, and certain swamp deposits. An advance on this condition is represented by the brown coals and lignites of the Tertiary strata. Still further progress is represented by the dominantly sub-bituminous type of coal found in Cretaceous rocks; whilst in the Carboniferous, Gondwana, and Karroo rocks, the dominant types are bituminous, sub-anthracitic, and anthracitic coals. It should be noted, however, that where the brown coals and sub-bituminous coals have been altered by earth movements and intrusions they have been converted in some cases into bituminous and even into anthracitic types, as for instance in western Canada.

It is interesting to compare the ultimate compositions of the above mentioned chief types of coal. It will be seen from the following ultimate analyses of typical peat and coals that there is an increase in the percentage of carbon as we pass from peat through brown, sub-bituminous, bituminous, and sub-anthracitic coals to anthracite.

	Carbon.	Hydrogen.	Oxygen.
Peat - - - - -	61	7	32
Brown coal - - -	70	6	24
Sub-bituminous coal - -	76	6	18
Bituminous coal - -	83	6	11
Sub-anthracitic coal - -	88	5	7
Anthracite - - -	93	4	3

In a general way the increase in the percentage of fixed carbon, already noted in the proximate analyses of these dominant types of coal, harmonizes with this increase in the total carbon percentage. Together with this progressive increase in carbon percentage there is a slight diminution in the percentage of hydrogen, and a marked diminution in the oxygen percentage.

Distribution of coal.—Commercially important coals are obtained mostly from strata of Carboniferous age, in which they occur interbedded with sandstones, shales, and iron ores. Infilling the numerous joint cracks of these Carboniferous coals in England, and forming miniature infiltration veins (fig. 221), there is an abundance of ankerite (carbonate of lime, magnesium, and iron); associated with this ankerite are smaller amounts of calcite, iron-pyrites, barite, galena, and zinc-blende. Another mineral occurring in this way as an infiltration product in the joint cracks of coal, is crystalline kaolinite. Carbonates and iron-pyrites in nodular form sometimes occur in considerable amount more intimately mixed with the coal in the bedding planes.

The world's annual output of coal is about 1300 million tons. Of this total, nearly 85 per cent. is produced by the United States, the United Kingdom, and Germany. The remaining 15 per cent. is contributed almost wholly by Austria, France, Russia, Belgium, Japan, Canada, India, China, and New South Wales. By far the greater part of this output is of the type usually described as bituminous coal.

The most important sources of anthracite of good quality are South Wales in the United Kingdom, and Pennsylvania in the United States; but valuable as true anthracites are, they constitute only a small portion of the total output of coal; though doubtless a considerable portion of the so-called bituminous coal produced is of the short-flaming steam-coal type that is perhaps best described as sub-anthracitic coal (semi-anthracite of many authors).

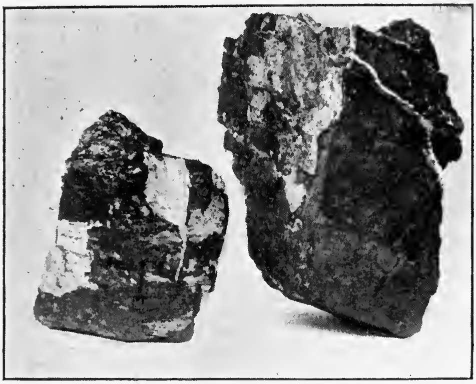

FIG. 221.—Veins and films of ankerite in English coal. (× ½).

Although, however, on account of their superior fuel values, the bituminous, sub-anthracitic, and anthracite coals of Carboniferous age contribute chiefly to the output, the sub-bituminous and brown coals, of Mesozoic and Tertiary ages respectively, are worthy of note. Their output in certain countries is an important factor in commerce, and they constitute a very important part of the world's coal reserves.

Immense reserves of Cretaceous sub-bituminous coal and Tertiary brown coal occur in western North America, notably in the Rocky Mountain region of Canada and the plains to the east. In the region of the Rockies they have been in part converted into bituminous and anthracitic types by the earth movements that have been responsible for the mountain uplifts. The estimated reserves in Alberta alone amount to over a billion tons (1,072,627,400,000). Somewhat similar deposits of Cretaceous sub-bituminous coal and Tertiary brown coal occur in Southern Nigeria, West Africa.

Brown coals of Tertiary age are mined extensively in Germany, notably near Cologne, and in other parts of Europe.

Immense deposits of brown coal of Tertiary age occur also in Victoria, Australia. At one locality (Morwell) a thickness of 700 feet of coal was traversed in boring through a total thickness of 1010 feet of strata. It is estimated that Victoria has not less than 30,000,000,000 tons of this brown coal.

DIATOMITE.

Diatomite or diatomaceous earth is known under various other names, including kieselguhr and tripolite. It is often incorrectly termed "infusorial" earth. Diatomite comprises those siliceous earths that consist essentially of the frustules of diatoms. Diatoms are unicellular plant organisms of microscopic size; they have a skeleton of opaline silica. They should not be confused with radiolaria, which are siliceous protozoa and which are of little or no economic importance. Radiolarian earths lack the absorptive capacity which gives diatomaceous earths their economic value.

Diatoms are abundant in certain parts of the ocean, and some deposits of tripolite are of marine origin; but the more valuable white diatomites are of fresh-water origin (fig. 222). Diatomite varies very much in colour and texture, the frustules of the diatoms in some cases being in a pulverized condition.

When free or practically free from iron oxide and organic impurity, diatomite may be of a pure-white appearance. This variety is much more valuable than the slightly ferruginous variety, It is used in sugar refining and various chemical industries for filtration purposes and as a decolorizing agent. Two or three per cent. of iron oxide is sufficient to impart a perceptible yellow colour to diatomite, and to unfit it for use in this way. Moreover, for this purpose it is necessary that diatomite should have a high absorptive capacity. Another use for diatomite of good quality is as an absorbent for nitro-glycerine in the manufacture of dynamite, though for this purpose wood pulp can be used as a substitute. Diatomite is used to some extent in the manufacture of fire-proof materials and as a sound deadener. Refractory bricks that will float on water can be made from diatomite. These bricks are useful for heat-insulation purposes (see p. 409).

Diatomite is of widespread occurrence. It is frequently found in the form of beds of Tertiary age associated with clays. Important deposits from which large supplies have been obtained occur at Oberhohe, near Ebstorf in Prussia. Raw material of good quality from this locality contains 87·8 per cent. of silica, 0·7 per cent. of ferric oxide and 8·4 per cent. of water. After calcination the silica percentage is raised to 98·2 and the ferric oxide to 0·82.

Tripolite from the extensive deposits near Bilin in Bohemia contains 74·2 per cent. of silica, and 6·8 per cent. of iron oxide and alumina in the raw material, these percentages being raised to 90·8 and 8·3 respectively by ignition.

FIG. 222.—Diatomite; highly magnified.

Diatomite is frequently found associated with peat and peaty clay in Scotland, Ireland, Canada, and elsewhere, especially in localities where there occur basalts and other volcanic rocks from which the surface waters have been able to obtain a plentiful supply of silica.

White diatomite of good quality has been worked in the Island of Skye in north-west Scotland, where it is found in beds 40 feet thick. The Skye diatomite deposits occur in depressions in the basalt, on the sites of old lakes or tarns; and like the Aberdeen and other Scotch deposits, they are usually covered by a layer of peat or moss. A sample of diatomite from the deposit at Cuithir (Quire) in Skye gave on analysis 88·7 per cent. of silica, 0·7 of ferric oxide, 4·1 of organic matter, and 6·4 per cent. of water. On calcination it gave a product containing 99·2 per cent. of silica, and 0·75 per cent. of ferric oxide.

Yellowish and rather ferruginous diatomite occurs abundantly along the course of the River Bann in north-east Ireland, between Toome Bridge and Coleraine, where it is found in beds from one to five feet thick.

Important deposits of diatomite of good quality occur associated with basalts at Lillicur and other localities in Victoria, Australia. Certain hollows in the basalts have been found to contain as much as 60,000 tons of diatomite of snowy-white appearance and practically free from iron oxide. These deposits have in recent years yielded large supplies of diatomite of first-rate quality.

FERTILIZERS.

The minerals of chief importance as fertilizers are potash minerals (see p. 400), apatite and phosphorite (see p. 396), and nitrates (see p. 385).

Gypsum is used as a soil-dressing under the name of "land-plaster," and is considered to be especially effective in application to soils containing sodium carbonate, such as occur frequently in arid regions.

Limestones are used extensively, sometimes in the form of carbonates, but more often after calcination, owing to the fact that lime and calcium carbonate have the effect of liberating other mineral-food constituents in the soil. They also neutralize the acidity of sour soils, and improve the tilth of "heavy" clayey soils.

Ammonium sulphate is manufactured extensively as a by-product in the destructive distillation of coal and oil-shale, and constitutes one of the most valuable of fertilizers.

Calcium cyanamide and ammonium sulphate are obtained by the electrical furnace treatment of limestone and coal, especially in localities such as Norway, where water power is cheap and abundant. Ammonium sulphate can also be obtained by decomposing aluminium nitride, which can be made by treating bauxite in an electrical furnace.

FELSPARS.

The felspars are of considerable importance as economic minerals. Their chemical and physical characters have been already described, with special reference to the gem varieties (p. 293).

Felspar of the orthoclase and microcline varieties (potash felspar) is extremely abundant in the pegmatite veins associated with many granitic intrusions. These pegmatites usually consist of a mixture of quartz and felspar, and in some places potash felspar is the dominant constituent. In some localities mica of commercial value is found in the veins and the felspar is then obtained as a by-product of mica-mining.

Most of the felspar of commerce is used in pottery manufacture. The rock known as "Cornish stone" is an altered granite and consists essentially of partly kaolinized potash felspar. It is used largely in the English pottery trade. In the United States ordinary felspar is used. Felspar finds other uses in glass-making, in the artificial-stone trade, as a binding agent in the manufacture of corundum wheels used for abrasive purposes. Orthoclase and albite of exceptional purity and whiteness are used in making artificial teeth. Felspar is an important ingredient in some building and ornamental stones, notably granites, some of the finest of which owe their beauty to felspar crystals (see p. 337).

Orthoclase and microcline contain from 10 to 15 per cent. of potash, and for that reason rocks rich in potash felspar, notably those of the syenite type, are sometimes used in a crushed condition as fertilizers. Potash felspar is very insoluble, however, and the potash contained in it is therefore not readily available to plants, though it is better than no potash fertilizer at all. In a finely-ground condition it constitutes a valuable reserve of potash, which becomes slowly available as a consequence of decomposition due to weathering. For some years past many experiments have been made in the attempt to discover a method that can be applied commercially to the manufacture of soluble potash salts from felspar; and sooner or later this widely distributed mineral will doubtless become of economic value as a source of the soluble potash fertilizers that are so valuable in agriculture.

Potash felspar has been obtained chiefly from the pegmatites of the United States, Canada, Norway and Sweden, and Italy. A large part of the potash felspar found in granite-pegmatites is of the microcline variety. The potash felspar is sometimes fairly pure, but more commonly it is mixed with other minerals, notably quartz, mica, albite (soda felspar), and sometimes ferriferous minerals, which are unwelcome because injurious for some purposes. In some instances rare minerals are present, such as uranium minerals (see p. 430), gadolinite (see p. 435) and beryl (see p. 411).

In the United States, the chief producing States are Maine, New York, North Carolina, Pennsylvania, and Connecticut. The felspar obtained from the pegmatites of Maine and Connecticut frequently contains a considerable amount of quartz which is so intimately mixed with the felspar that it cannot be separated. In felspar used for ceramic purposes however, an appreciable quantity of quartz is permissible, so long as the quality is fairly constant and the amount does not become excessive; though many of the users prefer to have the felspar and quartz separately.

In Canada there are extensive deposits of pegmatite cutting the pre-Cambrian rocks both in Ontario and Quebec, though they have been mined chiefly in Frontenac Co., Ontario, at a locality on the Kingston and Pembroke railway, about 20 miles north of Kingston. The pegmatites at this locality consist almost entirely of quartz and felspar, and the texture is so coarse that these minerals can be mined separately or can readily be separated by hand-picking.

Felspar pegmatites are abundantly developed in the region to the north of the St. Lawrence in Quebec. At Manicouagan Bay, in this region, there are pegmatite veins up to 200 feet thick, and in some places they consist of almost pure potash felspar. In the Buckingham district of Quebec, north of the Ottawa River, felspar has been obtained as a by-product of mica-mining.

The mica pegmatites mined in many parts of India (see p. 382) are rich in potash felspar, which is regarded as a waste product, and which would doubtless yield large supplies of good quality if there were sufficient demand.

Norwegian supplies come from various parts of the south coastal region, as from Sætersdalen and other localities in the vicinity of the Christiania fjord, and near Arendal. Large supplies are obtained also in Sweden.

FLUORIDES.

The two mineral fluorides of economic importance are fluorite and cryolite. For an account of cryolite, see p. 154.

Fluorite (also commonly named fluorspar and fluor. The name has reference to the ready fusibility of the mineral and its use as a flux. L. *fluor*, a flowing).

As already mentioned (p. 296), the different coloured varieties of fluorite are occasionally used as gemstones and ornamental stones. The chief use of fluorite, however, is as a flux for metallurgical purposes, notably in the production of iron, steel, lead, and aluminium. It is also used in the manufacture of opalescent glass, as a glaze in pottery manufacture, and in the construction of special lenses for optical work (apochromatic objectives, etc.). For making these special lenses the comparatively rare colourless and transparent variety is required.

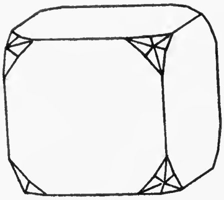

FIG. 223.—Fluorite.

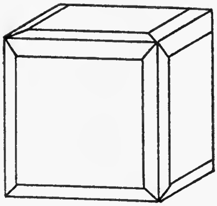

FIG. 224.—Fluorite.

General.—Cubic. Crystallizes usually in the form of cubes, and frequently as interpenetrant twins (figs. 223 to 225, and fig. 55). Perfect octahedral cleavage an important characteristic. Hardness, 4. Specific gravity, about 3·2.

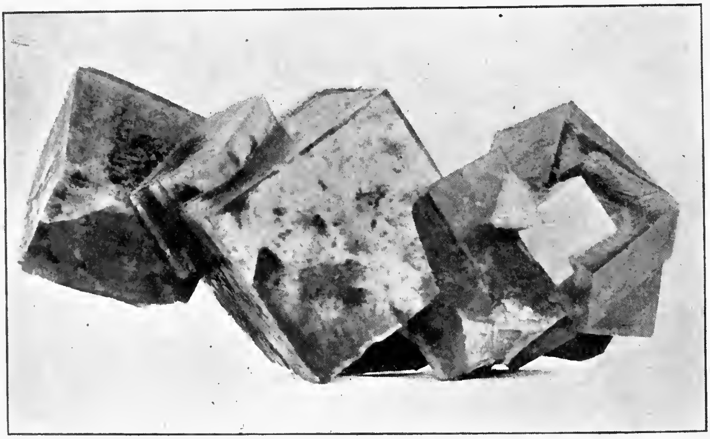

FIG. 225.—Fluorite, Weardale, Co. Durham. ($\times \frac{1}{2}$). B.M.

Optical.—Colour variable, but frequently violet. Lustre, vitreous. Refractive index very low, $\mu = 1{\cdot}43$. Isotropic. Microfragments frequently of triangular shape, owing to octahedral cleavage (fig. 226).

Chemical and blowpipe.—Fluoride of calcium (CaF_2). Fusibility, 3, fusing with readiness to a white enamel. Red flame-coloration due to calcium. Gives off hydrofluoric acid, which etches glass, when the powdered mineral is heated with sulphuric acid.

Occurrence and distribution.—Fluorite occurs in veins traversing limestone and other rocks, and is frequently associated with galena, zinc-blende, and barite. Fluorite for fluxing purposes is produced largely in England, the United States, France, and Germany.

In England the chief producing areas are Durham and Derbyshire. In Durham the supply comes from Weardale, where fluorite is formed abundantly in fissure veins traversing Carboniferous limestone and sandstone. In these veins it is associated with the minerals galena and chalybite. Some of the Weardale veins attain a considerable thickness, ranging up to 20 ft. or more, and consist of pure fluorite. In Derbyshire the fluorite occurs in fissure veins, gash veins, and pockets in Carboniferous limestone, associated with galena, calcite, and barite.

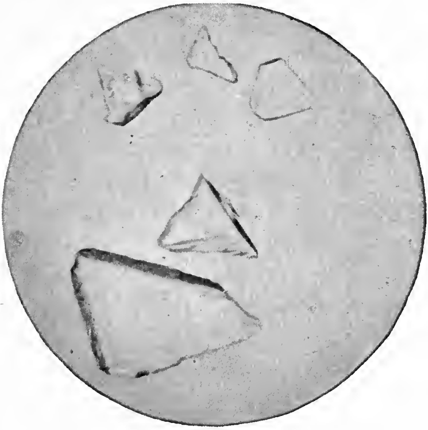

FIG. 226.—Fluorite grains from a Cornish sand. (× 20).

Much English fluorite has been exported to the United States, but in the latter country there is now a large output of the mineral, chiefly in the States of Kentucky and Illinois, where, as in England, it occurs abundantly in fissure veins traversing Lower Carboniferous limestone and sandstone. In the Illinois veins fluorite is associated with calcite, galena, and zinc-blende. In Mineral County, Colorado, it occurs in veins that traverse fragmental rhyolites (tuffs and breccias) of Tertiary age.

FLUXES.

Fluxes are the materials used in metallurgy for the purpose of inducing fluidity during a smelting operation. A flux in ore smelting acts in various ways. It permits the particles of reduced metal to aggregate together ; it protects the metal from oxidation ; and it combines with various impurities to form a fluid slag, from which the reduced metal can be separated. The selection of a flux depends upon the nature of the ore. Fluxes are classified as acid (*e.g.* silica), neutral (*e.g.* fluorite), and basic (*e.g.* limestone, dolomite, clay, and shale).

Limestone (see p. 340) is used extensively in iron smelting. Silica (see p. 410), used preferably in the form of a clean quartz sand, forms a fluid slag of silicates in the presence of various earthy impurities. Fluorite (see p. 371) is useful in the presence of sulphates of calcium, lead, or barium, and large quantities are consumed in the basic Bessemer process of steel manufacture.

In smelting the hæmatite ores of Cumberland in England, the ferruginous bauxite of Co. Antrim is used as a flux.

In the metallurgy of aluminium, cryolite is used as a flux.

In the pyritic smelting of gold ores by means of a blast furnace, pyrite (see p. 424) acts as a flux, and is often added to pyritic gold ores that contain too little of this ingredient in their natural state.

For laboratory purposes, more expensive materials can be used. Of these sodium carbonate is a very effective flux in the presence of silica, and acts also as a de-sulphurizer. Borax fluxes well with basic oxides, forming metallic borates. Litharge is used extensively in gold assaying to form fusible silicate, and to act as an oxidizing agent.

In connection with fluxes, mention should be made of the use of salt (see p. 355), borax (see p. 335), and fluorite for the production of glazes in pottery manufacture.

GRAPHITE.

Graphite (Gr. *grapho*, I write) owes its name to the fact that it is made into writing pencils. It has the same chemical composition as diamond, and consists of practically pure carbon. Though similar in chemical composition, however, graphite and diamond are strikingly different in their physical properties.

General.—Trigonal. Perfect basal cleavage. Frequently found in platy or flaky condition showing the cleavage; but fibrous and compact varieties also occur (fig. 227), and in some cases radiating spherical aggregates (fig. 228). Hardness, 1. Specific gravity, about 2·1. Marks paper readily.

Optical.—Black. Streak, shining black. Lustre, metallic. Microfragments opaque. Cleavage flakes usually show triangular striations.

Chemical and blowpipe.—Carbon; but often contains ashy impurity. Ceylon graphite may contain as much as 99 per cent. of carbon; but graphite can contain a considerable amount of ash and still be of commercial value. Infusible. No smell of sulphur dioxide in open tube if pyrite is absent. No flame-coloration. Burns away very slowly on ignition. Insoluble in acids.

Uses.—In addition to its familiar uses as a stove polish and for the manufacture of pencils, graphite serves as a lubricant and in various other ways. Its chief use, however, is as a refractory material in admixture with fireclay for the manufacture of crucibles, etc. For this purpose graphite should be as far as possible free from iron oxides and alkalies.

As a rule, the highly crystalline (flaky, scaly, or fibrous) varieties of graphite are required for the manufacture of crucibles and lubricants, whereas for pencils, paint, stove polish, and foundry facings, earthy impurities are permissible, and indeed for these purposes the amorphous variety is preferred.

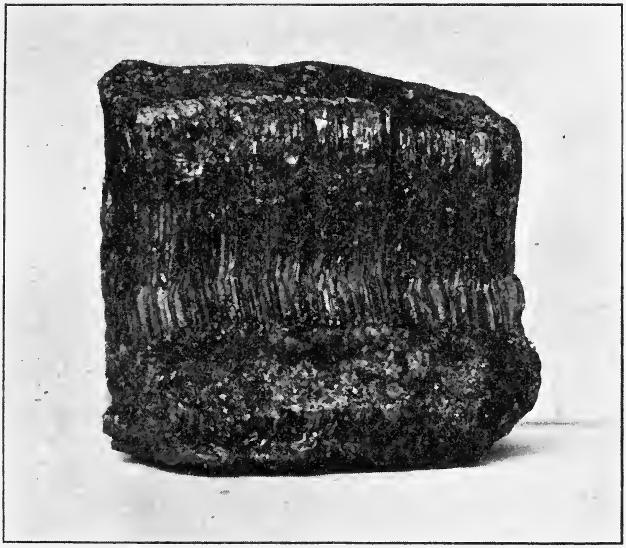

FIG. 227.—Fibrous graphite, Ceylon. (× $\frac{2}{3}$).

Occurrence and distribution.—The chief producers of graphite are Ceylon and Austria. Considerable amounts are also obtained in Bavaria, Italy, and Madagascar. The United States, Mexico, Korea, and Canada also contribute to the output. It should be noted, however, that artificial graphite has been manufactured for some years in considerable quantities from anthracite by electric furnace treatment at Niagara Falls.

It is in the gneisses, schists, and crystalline limestones of pre-Cambrian age that graphite of the flaky variety mostly occurs. In these rocks the graphite often occurs disseminated in the form of small flakes; but in some localities it is found segregated in lenticles of considerable size along the foliation planes of the gneisses. In still other cases the graphite occurs in the form of true veins that cut across the foliation planes of the gneiss. It is from veins and lenticles that the graphite of best quality is obtained; but disseminated flaky occurrences are often worked. Even when there is not more than 5 or 10 per cent. of graphite in a rock, if it exists in a flaky condition and the rock is uniformly rich throughout a large mass, it becomes possible to crush the rock and concentrate the graphite at a profit.

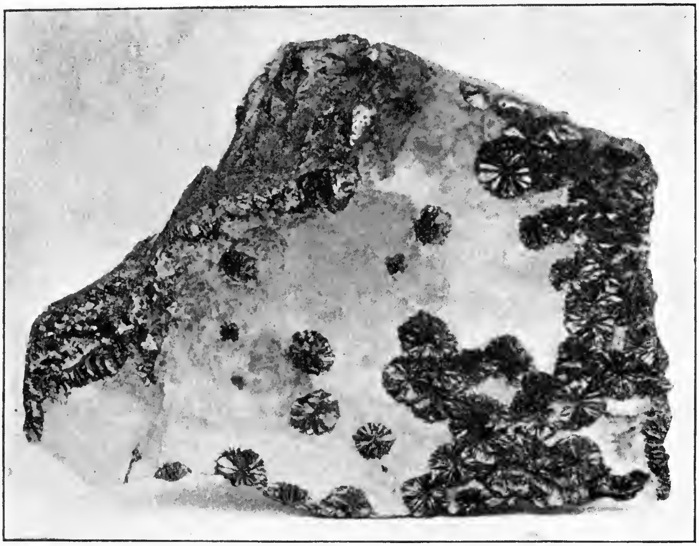

FIG. 228.—Radiating aggregates of graphite in quartz. (× ⅔).

In Ceylon, graphite is mined chiefly in the Western, North Western, and Southern Provinces, notably in the districts of Kurunegala, Kegalla, and Ruanwella. The containing rocks are gneisses and granulites, in which the graphite occurs sometimes in veins and sometimes in lenticular masses. The graphite is mostly of the flaky type; but the fibrous variety occurs frequently, and where the veins have been crushed by earth movements, compact graphite is found. The chief associated minerals are quartz, felspar, pyrite, phlogopite, and apatite. Molybdenite and pitchblende also occur, but hitherto no large quantity of these minerals has been found.

Ceylon graphite is roughly hand-picked in dressing sheds, and sent in barrels to Colombo for further refinement. Here it is more carefully cleaned and graded by screening; and the poorer qualities are concentrated by washing or winnowing. The mining of graphite in Ceylon has been carried on in a very primitive fashion. This is doubtless due in large measure to the sporadic distribution of the lenticles from which the graphite is chiefly obtained; but a more systematic procedure in mining would probably result in a larger output and a less frequent abandonment of mines.

In Travancore, India, where graphite occurs and has been mined under conditions somewhat similar to those of Ceylon, the mineral occurs in association with pyrite, pyrrhotite, molybdenite, apatite, and monazite.

Other Indian localities for graphite are Bihar and Orissa, and Merwara in Rajputana.

Low-grade graphite rocks occur extensively in Bohemia, Moravia, and Styria. They have been worked extensively in the region between Schwarzbach and Krumau in Bohemia, where they consist of graphitic gneisses and schists containing a considerable amount of pyrite, the weathering of which gives the rocks a rusty appearance. Graphite also occurs abundantly at Rottenmanner Tauern in Styria, where it occurs in the form of beds intercalated among phyllites and schists that have been metamorphosed by contact with an intrusive mass of gneissose granite. Fossil evidence indicates that the beds are of Upper Carboniferous age, and they are regarded as metamorphosed coal seams. The graphite is of the "amorphous," *i.e.* non-flaky type. Deposits that are supposed to have had a similar origin occur in the gneisses of Altstadt and Goldenstein in Moravia.

The occurrences of graphite near Pinerolo and Bagnasco in northern Italy are closely similar to those of Styria.

Near Passau, in Bavaria, flaky graphite occurs disseminated in the gneisses and schists. Occasional lenticular masses also occur in these rocks; but on the whole the deposits are of a low-grade character, though they have yielded a large output of graphite.

Graphite has been mined near Ronda in Granada, Spain, and at various other localities. Spanish graphite has been exported to England for pencil making, and to Holland for use as a stove polish.

Madagascar has grown in importance during recent years as a producer of graphite. The mineral is found at numerous localities in the eastern part of the island, between Tananarive and Fianarantsoa. It occurs in gneisses and schists, and is of the flaky or crystalline variety. It has hitherto been obtained at and near the surface in large quantities and has therefore been produced at a comparatively cheap rate.

In the United States, a deposit of some importance is that near Ticonderoga, Essex County, New York, where graphite occurs in quartzites associated with gneisses. The quartzites contains about 10 per cent. of graphite, which is separated from the rock by crushing and concentration, though much of the graphite is lost in the operation.

In Canada, near Buckingham, Quebec, and in various other localities among the pre-Cambrian rocks of Quebec and Ontario, graphite occurs in veins that traverse gneisses and crystalline limestone. It occurs also disseminated as small flakes in the gneiss and limestone, and in lenticular masses in the latter rock. It is only the disseminated type of occurrence that is worked, and the graphite is won by an elaborate system of milling and concentration. The deposits worked in Canada contain from 10 to 15 per cent. of graphite.

Large deposits of amorphous graphite of good quality are mined at Santa Maria in central Sonora, Mexico. The graphite at this locality occurs in a series of metamorphosed sedimentary strata, and has arisen from the metamorphism of coal seams by granite intrusions. The Mexican graphite is of excellent quality, the carbon ranging up to 95 per cent. It is largely used in pencil making, for which purpose it is eminently suitable.

Large deposits are mined also in Korea (Chosen), where flake graphite of the Ceylon type occurs, though most of the graphite hitherto mined has been of the amorphous type. Korean graphite has been worked extensively in recent years; it has been shipped chiefly from Japanese ports, and has been able to compete successfully with supplies from other sources in the European and American markets.

An occurrence of some importance formerly is that at Batugol in Irkutsk, Siberia, where graphite occurs in veins traversing a granitoid rock which is intrusive in limestone. The limestone has been metamorphosed by the intrusion, and it also contains masses of graphite.

Another occurrence of importance formerly is that of Borrowdale, in Cumberland, England, where graphite associated with quartz occurs in vein-like deposits and irregular masses in the Borrowdale volcanic series.

Origin of graphite.—Most graphite owes its origin to thermodynamical metamorphism of carbonaceous matter of organic origin. The "amorphous" occurrences that have resulted from the metamorphism of coal seams and carbonaceous shales, the disseminated flaky occurrences in gneisses, schists, quartzites, and crystalline limestones, and probably also the lenticular masses that are flattened along the foliation-strike of the gneisses and granulites in which they occur, all owe their origin to this cause. The carbon of which they are composed existed in the rocks as carbonaceous matter of plant or animal origin prior to metamorphism, and became converted into graphite at considerable depths.

The origin of the rarer vein-graphites in association with granitic and other intrusions is less easy to explain. It must be admitted in this case that the graphite has been deposited by the hydrothermal agencies that have deposited the quartz, pyrite and other minerals with which the graphite is associated in the veins. Some authorities attribute the origin of the vein graphite to the decomposition of compounds of cyanogen and iron in the presence of water and carbon monoxide, and regard these compounds as being primarily of magmatic origin; but this view seems unnecessarily complicated.

The fact that vein graphite occurs as a rule only in areas where the genetically-connected intrusives traverse graphitic rocks, suggests strongly that the intrusive magma has probably dissolved the graphite from the invaded rocks, holding it back in the mother liquor during crystallization and ultimately depositing it from this liquor along with the ordinary pegmatitic products. This view of the origin of vein graphite harmonizes well with the fact of the rarity of graphite as a pegmatite mineral. At any rate, even if it be admitted that graphite has been deposited as a primary magmatic constituent, its formation in a highly-crystalline form in veins is much more likely to have taken place by deposition from solution than by the action of gaseous emanations of carbon monoxide and cyanogen compounds.

LITHIUM MINERALS.

The chief source of lithium compounds is the mineral *amblygonite*, a fluo-phosphate of lithium and aluminium. Other minerals from which lithium compounds have been obtained are *spodumene* ($LiAl(SiO_3)_2$), *lepidolite* (lithium mica), *triphylite* ($Li(Fe,Mn)PO_4$), and *lithiophilite* ($Li(Mn,Fe)PO_4$), but amblygonite is preferred, as it can be treated more cheaply than other lithium minerals. For a description of the properties of spodumene, see p. 315. Lepidolite occurs in the form of lilac-coloured scaly aggregates associated with spodumene and amblygonite in pegmatite veins. Triphylite and lithiophilite also are pegmatite minerals, occurring in the form of resinous nodular masses associated with cassiterite and columbite.

Lithium carbonate is used as a medicine and in making lithia mineral-water. Lithium hydrate is used in making electrical storage batteries, and the bromide is used to a small extent in photographic work.

Amblygonite (Gr. *amblys*, blunt or obtuse, and *gonia*, an angle; so named on account of the blunt cleavage angle).

General.—Triclinic, but seldom found in good crystals. Basal cleavage perfect. Fracture uneven. Hardness, 6. Specific gravity, about 3·05.

Optical.—Colour usually white or pale green. Lustre, vitreous to pearly. Refractive index low, $\alpha = 1{\cdot}57$. Birefringence moderately high, $\gamma - \alpha = 0{\cdot}018$. Optical sign, negative. Yields platy micro-fragments.

Chemical and blowpipe.—Fluo-phosphate of lithium and aluminium $Li(AlF)PO_4$, the lithium being partly replaceable by sodium. Fusibility, 2. Flame-coloration, red, due to lithium, when not much sodium is present. Pale bluish-green flame, after moistening with sulphuric acid, due to phosphate. Decomposed by sulphuric acid.

Occurrence and distribution.—Amblygonite occurs in pegmatite veins connected with granite intrusions. It is usually associated with lepidolite and spodumene. The chief supplies are obtained from pegmatite deposits near Keystone in the Black Hills, South Dakota, U.S.A., where it occurs in nodular masses some of which are very large and weigh nearly half a ton. It is also found associated with lepidolite and pink tourmaline near Pala, San Diego Co., California, where the lepidolite was formerly worked as a source of lithia. It is found associated with cassiterite in the tin mine of San Finx near Santiago in Galicia, Spain. It also occurs in pegmatites at Montebras in the department of Creuse, France, where it was formerly worked. Amblygonite is found in some abundance in a pegmatite vein at Ubini, Western Australia. A sample from this locality was found to contain 9·3 per cent. of lithia. Lepidolite occurs freely at Ubini and various other localities in Western Australia. Lepidolite has been worked for lithia at Zinnwald in the Erzgebirge, Saxony.

MAGNESITE (see p. 346).

MICAS.

The mica group comprises several silicates of aluminium containing alkalies, iron oxide, or magnesia, and small amounts of other constituents. They are monoclinic in symmetry, but pseudo-hexagonal in habit, occurring usually in the form of six-sided plates. They are all characterized by a perfect basal cleavage. It is to this cleavage, in consequence of which they split readily into thin plates, together with their transparency and insulating properties, that the micas owe their commercial importance. Mica plates are flexible, elastic, and tough, and no artificial product has yet been made which possesses all the qualities of mica in such a degree as to enable it to compete with this mineral for use as an insulating medium and in various other ways.

The micas are used as insulating plates in electrical apparatus, and for furnace doors; also for the dial plates of compasses. For these uses the mica plates are trimmed and sorted according to size, the large plates being the more valuable. The cuttings obtained during the trimming of the larger plates, together with other small pieces obtained in the course of mining, constitute what is called "scrap" mica. This is in part cemented by means of shellac to form the composite plates known as "micanite." Much of the scrap mica is ground to powder, which is of a flaky character, and in this condition it is used in the manufacture of certain wall papers, to which it imparts an attractive glistening or frosted appearance. Mica powder is also used as an ingredient of certain lubricants and in various other ways.

Mica plates are often buckled or cracked, and sometimes contain numerous inclusions. These flaws detract from the value of the mica, which, to be saleable, should be fresh and unweathered and fairly free from flaws.

The micas of commerce are almost entirely muscovite (potash mica) and phlogopite (magnesia mica). Muscovite is obtained chiefly in India and the United States. Phlogopite includes the varieties commonly known as "silver" and "amber" mica, and is mined chiefly in Canada. Some of the dark amber micas should probably be included under biotite. Typical biotite (ferromagnesian mica) is black, and very little of it is used in comparison with the amount of phlogopite used, the lighter-coloured varieties being much preferred. In addition to these varieties of mica, lepidolite (lithium mica, see p. 379) is of some commercial interest; it was formerly used as a source of lithia but it seems to be no longer in request for this purpose, for which amblygonite (see p. 380) is more useful.

Muscovite (formerly called "muscovy glass" from its occurrence in Russia, where it was at one time used extensively as window glass. Also called "potash mica" and "common mica").

General.—Monoclinic. Usually found in six-sided plates. Basal cleavage perfect (fig. 229). Hardness, about 2½. Specific gravity, about 2·8.

Optical.—Usually colourless, but sometimes green, and occasionally of a pale-ruby tint. Usually transparent. Lustre, vitreous or pearly. Refractive index, low, $\gamma = 1{\cdot}597$. Birefringence high, $\gamma - \alpha = 0{\cdot}038$; but the effect due to this maximum birefringence is seen only in sections normal to the cleavage, and the effect seen on cleavage plates is comparatively low. Optical sign, negative. Cleavage plates show good centric biaxial figures with a fairly wide angle.

Chemical and blowpipe.—A silicate of aluminium and potassium ($K_2O \,.\, 2H_2O \,.\, 3Al_2O_3 \,.\, 6SiO_2$). Fusibility, about 5. Yields a little water in a closed tube. Not decomposed by ordinary acids.

Occurrence and distribution.—The chief producers of muscovite are India and the United States; but it is also mined in Brazil, Canada, Tanganyika Territory, and Russia, and to a smaller extent in various other countries.

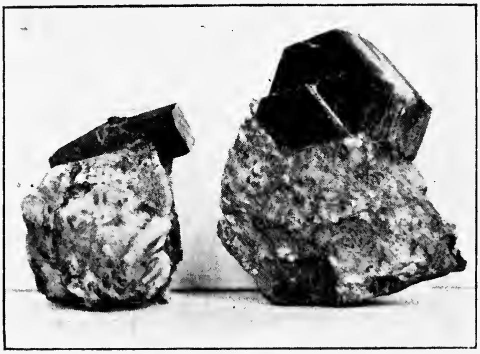

FIG. 229.—Muscovite, Norway. (× ¼). B.M.

Muscovite is a mineral of very widespread occurrence. It occurs abundantly in granites and schists, but as a rule in small plates only and these are of no commercial value. The muscovite of commerce occurs in the form of large tabular crystals or "books" in pegmatite, embedded in a matrix of quartz and felspar. These pegmatites occur as veins traversing granites, gneisses, and schists, and the muscovite crystals contained in them are sometimes of very large size. Plates measuring as much as 10 feet across have been found in India, and plates 2 feet square are of frequent occurrence in some mines.

In India, the chief mica mines are in the Gaya, Hazaribagh and Monghyr districts of Bengal, and the Nellore district of the Madras Presidency. The mica occurs in pegmatites that traverse pre-Cambrian schists (fig. 230). The minerals associated with mica in the Indian pegmatites include apatite, uraninite, samarskite, torbernite, tourmaline, lepidolite, and beryl.

Muscovite is the variety of mica obtained in the United States, where it occurs in pegmatite veins under conditions closely resembling those in India. It is mined in North and South Carolina, New York, and various other States.

Other producing countries of note are Tanganyika Territory, where muscovite occurs abundantly in pegmatites traversing biotite-gneiss in the Uluguru mountains; Brazil, where it occurs in kaolinized pegmatites traversing schists in the States of Goyaz, Bahia, and Minas Geraes; and Canada, where it is found in pegmatites that traverse diorite-gneiss, chiefly in the Saguenay District of Quebec.

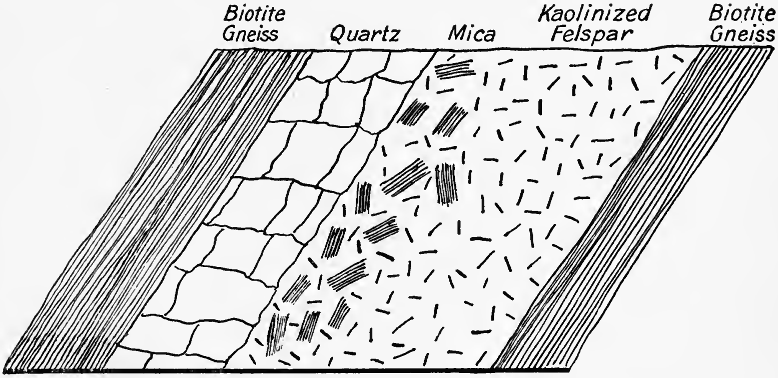

FIG. 230.—Section showing nature of mica-pegmatite veins in south-east Wainád, Madras Presidency (after Sir Thomas Holland).

Phlogopite (Gr. *phlogopos*, fire-like; named from the fine brownish-red colour of certain specimens. Also known as magnesia mica, and includes the varieties commonly known as "silver" mica and "amber" mica).

General.—Monoclinic, usually found in six-sided platy forms. Basal cleavage perfect. Hardness, about 2½. Specific gravity, about 2·85.

Optical.—Colourless, yellow, greenish or reddish brown. Some varieties of phlogopite are quite colourless and transparent. Plates are often opaque to normally incident rays, owing to the abundance of gas films in the cleavage rifts, or to intersecting linear inclusions. When gas films are present in abundance, and solid inclusions absent, the plates exhibit the property of pseudo-pleochroism, and are transparent to rays of oblique incidence. Plates which owe their translucency to linear inclusions, exhibit the phenomenon of "asterism," which is best seen by looking at the sun through a fairly thick plate, though it is seen well enough by looking at a candle light through a thin plate. These translucent and uncoloured phlogopites usually show a silvery sheen and are known as "silver" mica. When an appreciable amount of iron is present, as in many phlogopites, the colour is brownish or reddish brown, and this variety is known as "amber" mica. "Amber" mica usually shows fine pleochroism when plates are rotated in an obliquely incident beam of light, and it is the material best suited for showing a biaxial absorption-figure when a fairly thick plate is held close to the eye and examined against the sky.

The refractive index is low, $\gamma = 1{\cdot}60$. Birefringence high in sections across cleavage plates; $\gamma - \alpha = 0{\cdot}040$. Basal cleavage plates, however, show feeble birefringence. Colourless phlogopite is distinguished optically from muscovite by the fact that it is approximately uniaxial. The "amber" micas often show a fairly wide axial angle, but much smaller than muscovite. Optical sign, negative.

Chemical and blowpipe.—Silicate of magnesium, aluminium and potassium, with some water ($K_2O \,.\, 2H_2O \,.\, 6MgO \,.\, Al_2O_3 \,.\, 6SiO_2$). Fusibility, 5. Yields a little water in closed tube. Decomposed by hot concentrated sulphuric acid.

Occurrence and distribution.—Phlogopite is perhaps the most characteristic product of thermal metamorphism in dolomites, and is one of the commonest constituents of white crystalline limestones, though it usually occurs in these rocks in the form of disseminated small crystals of no commercial value. The most notable occurrences of commercial phlogopite are those of Canada, the chief being those north of Ottawa in Quebec, and those south of Perth in Ontario. Reference has already been made to the occurrence of apatite associated with phlogopite in vein-like bodies in this area of pre-Cambrian gneiss (see p. 273). The veins sometimes lie along the strike of the foliation planes of the gneiss and sometimes cut across this strike. The chief constituents of the vein-stuff are pyroxene and calcite, the mica and apatite being embedded in these. The phlogopite is sometimes found in large pockets, and crystals of large dimensions occur. Near Sydenham crystals 9 feet in diameter have been found. The rock enclosing the veins in some places consists almost entirely of pyroxene.

Brown phlogopite has been mined to some extent in pegmatites that traverse the ancient metamorphic rocks of Ceylon; fine specimens have been obtained in the Mineran oya near Balangoda from pegmatites; and material of good quality has been mined at Haldummulla in Uva.

MONAZITE (see p. 426).

MOULDING SAND.

Sands used for moulding purposes in the metallurgical trades should be of a refractory character, and of fairly uniform grain except for the comparatively small amount of clayey matter necessary to bind the sand grains together. The best moulding sand contains from 80 to 90 per cent. of sand; the remainder should consist chiefly of plastic refractory clay, with little or no silt. Such a sand yields a refractory, porous, and firm mould, which retains its shape, and which, moreover, has the important property of permitting the escape of gases formed when the molten metal is poured into it.

Alkalies and lime, either in the felspathic or any other condition, are undesirable, and if present in appreciable quantity the sand is not sufficiently refractory.

Sands possessing the requisite qualities for use as moulding sands are not of common occurrence. In judging of their suitability for this purpose, a mechanical and mineral analysis is of more value than an elaborate chemical analysis; for whilst it may be desirable to establish the absence or insignificantly small percentage of certain chemical constituents, it is far more important to see that the sand has the requisite physical characters, and much information as to its chemical nature can be got from a study of its mineral composition.

In England, moulding sands are obtained from the Bunter (Triassic) and Thanet (Lower Eocene) beds, in both of which formations loamy sands of the moulding-sand type are found.

NITRATES.

Compared with chlorides and sulphates, nitrates are very scarce. Sea water contains practically no nitrates; hence there are no nitrate beds among the deposits that are formed by the drying up of inland seas or salt lakes. Nitrates occur only as surface deposits of recent age, such as efflorescences in the soil, and beds near the surface, that have been formed in dry countries, either through nitric acid derived directly from the air, or through the bacterial alteration of organic nitrogenous matter in the presence of lime and alkalies. True saltpetre or potassium nitrate of natural occurrence is found only in very small amounts as an efflorescence in soils, and is of comparatively small commercial importance. Chile saltpetre or sodium nitrate, on the other hand, occurs in comparatively large deposits, and is of considerable economic significance.

Nitratine (soda nitre or Chile saltpetre).

General.—Trigonal. Cleavage rhombohedral and perfect. Hardness, about $1\frac{1}{2}$. Specific gravity, about 2·2.

Optical.—Usually white or greyish. Lustre, vitreous. Refractive index shows a wide range, but is low; $\omega = 1{\cdot}58$, $\epsilon = 1{\cdot}33$. Birefringence, extremely high, $\omega - \epsilon = 0{\cdot}25$. Optical sign, negative.

Chemical and blowpipe.—Sodium nitrate ($NaNO_3$). Fusibility, 1. Strong yellow flame-coloration. Deliquescent. Yields a reddish vapour $(NO)_2$ when heated in a closed tube with potassium bisulphate. Soluble in water. Cool to the taste.

Uses.—Nitratine is used extensively by agriculturists as a fertilizer. It is used also in the manufacture of nitric acid.

Occurrence and distribution.—Nitratine occurs abundantly in northern Chile in the region of the Atacama desert between Tarapaca and Taltal. The nitric acid required for the formation of the soda nitre is supposed to have been derived directly from the atmosphere, whilst the sodium has been derived from the sodic felspars, which occur abundantly in the underlying rocks. The region is almost rainless, but heavy night-fogs are frequent. It would appear that in this region of Chile, presumably owing to peculiar atmospheric conditions, an abnormal amount of nitric acid is produced. Hence sodium nitrate is formed in place of the sodium carbonate (trona) which characterizes the superficial saline deposits of other arid regions (see p. 352).

The nitratine is quarried from a bed 1 to 6 feet thick, which is covered by beds of gypsum, clay, sand, and gravel. The crude salt, which is known as *caliche*, is porous and granular in texture, and white, yellow or brown in colour. It consists of a mixture of nitratine, sodium chloride, and sodium sulphate, with a small amount of various other salts, including iodates and borates. The amount of nitratine in the caliche varies from 20 to 60 per cent.

Iodine is an important by-product in the preparation of soda nitre from the caliche, and the world's supply of iodine is obtained chiefly from this source. The amount of iodine present is small, and corresponds to only about 0·1 per cent. of sodium iodate. Its presence in the caliche is perhaps attributable to sea-weed dust blown inland from the coast. A small amount of potassium perchlorate (about 0·2 per cent.) is also present in the caliche.

Nitre = Saltpetre is found only as an efflorescence of needle-shaped orthorhombic crystals in surface deposits. Refractive index low; $\alpha = 1{\cdot}33$.

Birefringence extremely high; $\gamma - \alpha = 0{\cdot}172$. It dissolves readily in water and yields a good potash flame reaction (violet colour). It is found as a surface efflorescence in India, Egypt, South Africa, and some other countries. It is formed most abundantly in hot weather after the rains. Naturally-formed nitre constitutes but a small proportion of the total nitre used. The material is now manufactured largely from Chile saltpetre (nitratine). It is used in the manufacture of explosives.

One of the most important occurrences is that in the Behar region of the Gangetic plain in India, where it has been obtained for many years by allowing animal excretions and vegetable refuse to decompose in the surface soil under the action of nitrifying bacteria. The nitre occurs mixed with sodium chloride. The mixed salts are first washed out of the soil, fractionally crystallized to separate the nitre and sodium chloride, after which the nitre is refined and exported through Calcutta.

At and around Prieska in Cape Province, South Africa, there are deposits of nitre which have been formed by the decomposition of the excretions of rock rabbits (coneys) and other animals. Large pieces of fairly pure nitre are sometimes found there, and also in other parts of South Africa, notably Rhodesia. The Boers formerly used nitre from such deposits for the manufacture of gunpowder, and the material is still used to a small extent to supply nitre for local requirements.

PETROLEUM AND ALLIED PRODUCTS.

Petroleum, mineral oil, or rock oil as it is sometimes called, occurs associated with asphalt, and ozokerite; and as these materials have a common origin, it is convenient to deal with them together under the head of petroleum and allied products. There can be little doubt that these materials, like coal and oil-shale, have arisen from the slow decay or alteration of organic matter entombed in sedimentary rocks. The commercially important deposits of petroleum are invariably found in sedimentary rocks. No case is known of these substances occurring in large quantity in igneous or thermally metamorphosed rocks; and this fact constitutes very strong evidence that petroleum owes its primary origin not to deep-seated causes connected with igneous activity, but to superficial causes connected with sedimentation and the entombment of organic matter in the sediments. Whether the organic matter was of plant or animal origin, or both, is less certain, and opinions differ as to the relative importance of plant and animal remains as contributing factors in the origin of petroleum; but the view formerly held by certain chemists that petroleum was of igneous origin, is one that has no foundation in the facts of geology.

In the study of rock genetics, however, it is important to distinguish between igneous action, and ordinary dynamic or thermodynamic action; and there can be little doubt that dynamic or thermodynamic agents have played a part in the formation of petroleum reservoirs in sedimentary rocks. As will be seen from the details of distribution given below, these reservoirs are confined almost entirely to Devonian-Carboniferous and Cretaceous-Tertiary strata. In Chapter VII., we have seen that the late Carboniferous and the Tertiary were periods of active tangential compression in the earth's crust; and one is tempted to infer that the petroleum reservoirs in the Upper Palæozoic strata of the Appalachian region and those of the Tertiary strata in western America and Alpine Eurasia, owe their existence to the operation of dynamic or thermodynamic agents on rocks containing organic remains (oil-shales, etc.), the oil being driven from its place of origin and collecting as a liquid in porous strata.

Petroleum (L. *petra*, a rock, and *oleum*, oil). Petroleum is a mixture of liquid hydrocarbons. As found in nature it varies considerably according to the relative proportion of these various hydrocarbons. Crude petroleums range from about 0·78 to about 1 in specific gravity, though more commonly from 0·85 to 0·95. The lighter varieties are known as " white oil," and they do not usually occur in great abundance. Such a light low-boiling oil has been struck at Calgary in Alberta, Canada, and various other localities; it evaporated without leaving a residue and could be used as a motor spirit without refinement. More frequently crude or natural petroleum requires considerable refinement to separate the lighter oils from the heavy asphaltic product commonly associated with it. When exposed for any length of time to the action of the air, petroleum becomes oxidized, inspissated, and dark-coloured, and yields asphalt. It is to the presence of heavy asphaltic matter that many crude petroleums owe their blackness and relatively high specific gravity.

Crude petroleum is refined, and separated into its different products, by a process of distillation. These products are as follows:

	Temperature of Distillation.
Petroleum spirit (including benzine, petrol, and gasoline)	<150° C.
Kerosene (illuminating oils)	150° C. to 300° C.
Lubricating oils	>300° C.

Other products obtained from petroleum are gas oil or " solar " oil, vaseline, and paraffin. " Solar " oil or gas oil is a product that distils intermediately between kerosene and lubricating oil, and is so named on account of its use in the enrichment of illuminating gas.

In a general way petroleum may be regarded as of two distinct types, viz. asphaltic and paraffinic. Asphaltic petroleums are those which on distillation give a dark residue of asphaltic matter that is readily attacked by acids and solvents. Paraffinic petroleums are those from which, on reducing the temperature sufficiently, there separates out a light-coloured solid paraffin. Paraffin, unlike asphalt, is not susceptible to the action of acids, and is less readily affected by ordinary solvents.

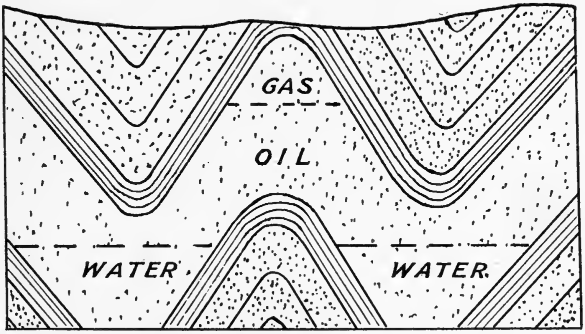

Fig. 231.—Oil and gas in an anticlinal fold.

As already stated, commercial supplies of petroleum are invariably obtained from sedimentary rocks, and the structure of the strata is of considerable importance in connection with oil occurrences. Oil occurs under a great variety of structural conditions ; but the type of structure most favourable for the occurrence and accumulation of oil is that of the anticline, in strata where thick beds of porous sand are covered by impervious argillaceous beds, as shown in fig. 231. Under these conditions the oil is usually found as a reservoir at and near the apex of the anticline in the sandy beds. Water is generally present with oil in such strata ; under these conditions the oil and associated gas, being lighter than water, float on the latter and rise to the highest part of the porous strata, *i.e.* the apex of the anticline. Hence, in exploiting oil occurrences under these conditions, the problem is to drill in such a position as to strike the oil-bearing porous bed at the apex of the fold. When the structure is simple, geological observations are of great value in locating such drilling sites ; but the structure may be so complicated that the choice of sites for drilling is necessarily to a large extent a matter of hazard.

Occurrence and distribution.—Of the world's total production of petroleum, the United States of America furnishes nearly two-thirds. Russia, Mexico, Roumania, the Sunda Islands, Galicia, and India together contribute about a third. The amounts contributed by Peru, Japan, Germany, Persia, Egypt, Trinidad, Canada, and other countries are comparatively very small, and make up together only about 3 per cent of the world's output.

United States.—Of the United States production, over 85 per cent. is contributed by the States of California, Oklahoma, Illinois, Texas, and Louisiana. The remainder of the production is contributed chiefly by Virginia, New York, Pennsylvania, Ohio, Wyoming, Kansas, and Indiana. Petroleum exhibits much variety in its nature and modes of occurrence in the United States, and is found in strata of widely different ages.

In California, which is by far the most productive State, the oil occurs chiefly in a thick series (20,000 ft. or so) of Tertiary sands and shales. The strata are folded, and the oil is of the heavy asphaltic type.

In Oklahoma and Kansas, the oil is obtained from folded sands and shales of Carboniferous age, and the oil is largely of the paraffinic type, though asphaltic and mixed types of oil also occur.

In Illinois, paraffinic types of oil are obtained from gently folded sandstones of Carboniferous age.

In the coastal area of Texas and Louisiana, Cretaceous and Tertiary strata are bent into dome-shaped folds in which asphaltic petroleum is associated with sands, clays, limestone, gypsum, and rock-salt.

In the Appalàchian region, including the States of New York, Pennsylvania, eastern Ohio, and western Virginia, the oil-bearing strata are of Palæozoic age and formerly yielded most of the United States output. The strata are folded and range in age from Ordovician to Carboniferous. The oil is of the paraffinic type, and the oil-bearing rock is chiefly sandstone.

In Indiana, oil of the paraffinic type is obtained from anticlinal folds in the Trenton limestone, which is of Ordovician age.

In Wyoming the oil-bearing strata, which are usually sandstones, range in age from Carboniferous to Tertiary and are generally folded. The oil is partly of the paraffinic and partly of the asphaltic type.

Russia.—In Russia the chief oil-fields are in the Caucasus region, and the most productive localities are those of Baku and Grosny, where the oil occurs in folded Tertiary strata. Other productive localities in this region are those of Maikop and the Taman peninsula.

Mexico.—Oil occurs abundantly in the Cretaceous shales and Tertiary sandstones along the coastal area of the Gulf of Mexico. The more notable localities are those of Tampico, Tuxpan, and Vera Cruz.

ROUMANIA.—Folded Tertiary strata with an abundance of oil occur in the Bushtenari, Campina, and other districts to the south of the Carpathians.

GALICIA.—On the flanks of the Carpathian mountains in Galicia there are folded shales and sandstones of Cretaceous and Tertiary age, from which oil is obtained in the Boryslaw and other districts of eastern Galicia. Boryslaw is an important locality for ozokerite (see below).

SUNDA ISLANDS.—In Java, Sumatra, Borneo, and other of these islands the oil is found in folded Tertiary strata, in which there are numerous well-developed anticlines.

INDIA.—The oil output of India is obtained chiefly from Burma, where oil of very good quality and of the paraffinic type is found in folded strata of Tertiary age. The chief oil-fields are those of Yenangyaung and Yenangyat.

Petroleum has been produced in considerable quantities in recent years at Khaur in the Punjab, where it occurs in folded Tertiary strata.

TRINIDAD AND BARBADOS.—In these islands oil of the asphaltic type occurs in folded Tertiary strata. Notable localities are those of Guayaguayare at the south-east corner, and Guapo near the south-west corner of Trinidad. For an account of the asphaltic and manjak deposits, see pp. 394, 395.

OTHER OIL-FIELDS.—Among other oil-fields mention may be made of that of Peru, in Tertiary rocks along the coastal belt, where there are important producing wells at Negritos, Lobitos, and Zorritos. The Peruvian oil-belt extends northwards into Ecuador. In this northern region of South America, including Colombia and Venezuela, there has been active prospecting for oil in recent years.

Petroleum is produced at Jemsa and Hurgada on the Suez Gulf coast of Egypt where there are petroliferous strata of Tertiary age.

Persia has rich oil-fields. The most productive wells have been those of Maiden-i-Naftun in the Bakhtiari country. The petroliferous rocks of this area are limestones associated with gypsum shales and sandstones in folded strata of Lower Miocene age.

Ozokerite = Ozocerite (Gr. *ozo*, to smell, and *keros*, wax) is a wax-like substance with a specific gravity about 0·9. It is a hydrocarbon containing about 85 per cent. of carbon and about 15 per cent. of hydrogen. Its colour is usually white or brownish. It has been obtained chiefly from Galicia, notably at Boryslaw, and in the Stanislawow region, where it is found in strata of Miocene age. It occurs in the form of veins, of varying thickness up to a maximum of about a metre, traversing beds of sand, loam, and clay. The crude material obtained from the veins is usually very impure and contains on the average not more than about 6 per cent. of ozokerite.

Ozokerite deposits are found near Soldier's Summit and Colton, in Utah, U.S.A., in veins traversing sandstone and shale. The veins are fracture zones and range from a few inches up to 12 feet in thickness. Lenticular masses weighing up to 175 lb. have been found in these veins, though the deposits as a whole appear to contain under 3 per cent. of ozokerite.

Ozokerite is a natural solid paraffin. Unlike asphalt it is not a product of the oxidation and inspissation of petroleum. As already pointed out, petroleum often carries paraffin in solution ; and ozokerite doubtless owes its formation to the deposition of paraffin from paraffinic petroleum, by a process of refrigeration comparable with that adopted for the artificial separation of paraffin from petroleum containing this substance.

Ozokerite is used in the manufacture of ceresin, a substance resembling bees wax. It is also used in the manufacture of candles, boot polish, and various other minor products.

Oil-Shales.—Oil-shales are carbonaceous shales that yield oil when subjected to destructive distillation. They are brown, dark grey, or brownish black in colour, and burn readily with a smoky flame. The oil does not exist as such in oil-shale, but is produced by the decomposition of solid carbonaceous material. The nature of this material is variable ; but it is supposed in all cases to have been derived from spores or other kinds of vegetable matter that have been incorporated in the shale during deposition. The name " kerogen " has been proposed, in the case of the Scotch shales, for the oil-yielding ingredient of the shales. In the Tasmanian oil-shales the oil-producing substance is a brown waxy material called " tasmanite."

In addition to oils, ammonium sulphate and solid paraffin are obtained from oil-shales, and many shales could not be worked at a profit if these valuable by-products were not obtained. Typical oil-shales, like those of the Lothians in Scotland, yield from 20 to 40 gallons of oil per ton of shale, and from 10 to 25 lb. of ammonium sulphate.

Associated with these typical shales there occurs a richer material, such as is known in Scotland by the name of " torbanite," and in New South Wales by the name " kerosene shale." These are not shales proper, and have the same appearance and texture as cannel coal. They yield from 60 to 120 gallons of oil per ton.

Occurrence and distribution.—Oil-shales have a wide distribution and occur abundantly in many parts of the world, though they have not been worked in many countries. The growing demand for oil, however, and the prospective insufficiency of the world's petroleum supplies to keep pace with this demand, is likely to lead to the extensive development of oil-shale deposits in the future. The chief places where oil shales have been worked up to the present are Scotland, France, and New South Wales, but large deposits of a promising character are receiving attention in other countries, notably in the United States, Canada, and Tasmania.

SCOTLAND.—Scotland is one of the few places where oil-shales have been worked successfully in spite of the comparatively poor yield of oil. The shales occur in beds from one to eight feet thick in the Calciferous Sandstone series of the Lower Carboniferous, and have been mined chiefly in the counties of Edinburgh and Linlithgow. The shale yields up to 30 gallons of oil and up to 60 lb. of ammonium sulphate per ton of shale, though the average yield in any given case is well below these figures. Paraffin and other by-products are obtained.

ENGLAND.—Large deposits of oil-shale occur in the Kimmeridge Clay of Dorsetshire, and at other places along the strike of the Jurassic strata in England, as for example in Norfolk. The oil obtained from these shales, however, contains an abnormally high percentage of sulphur, the percentage being from 5 to 8, as compared with about 1 per cent. in oil-shales of the normal type. The separation of this sulphur has not hitherto proved feasible on a commercial scale; but if this difficulty can be surmounted, the Jurassic shales of England will become an important source of oil.

FRANCE.—Permian oil-shales have been worked for a long time and on a fairly large scale in various parts of France, notably at Autun in the department of Saône-et-Loire, and at Buxières in Allier. The seams are several feet thick and are associated with coal. These French shales are on the average poorer than those of Scotland.

AUSTRALIA.—The so-called "kerosene shale" of New South Wales is mined at Wolgan and various other localities. It is closely similar to cannel coal in character and is very rich in volatile matter. It occurs in the "Permo-Carboniferous" coal measures in the form of flattened lenticular patches of variable extent, ranging from an inch up to 4½ feet in thickness. At their edges the lenticles of shale merge into bituminous coal, or into carbonaceous shale. In some cases the "kerosene shale" is more intimately associated with the coal and lies above or below the coal seams. The "kerosene shale" is much richer than ordinary

Scotch oil-shale, and yields from 60 to 120 gallons of oil per ton of shale. Oil-shales occur in some abundance in Queensland.

Canada.—In various parts of Canada, notably in the Albert and Westmorland counties of New Brunswick, there are extensive deposits of oil-shale. The Albert shales are of Lower Carboniferous age; they are stated to yield from 27 to 56 gallons of oil and 30 to 110 lb. of ammonium sulphate per ton of shale.

Tasmania.—In the area between Latrobe and Railton in northern Tasmania there is an extensive deposit of shale which is impregnated with small disc-shaped particles of a brown waxy material known as "tasmanite." This shale is rich in oil-yielding volatile matter. It occurs in the form of a bed 7 feet thick in strata of "Permo-Carboniferous" age. Near by and on the same horizon are coal seams which were deposited contemporaneously with the oil-shale.

Asphalt (Gr. *asphaltos*, asphalt or bitumen; the name is probably of Phoenician origin). Asphalt is a black viscous or solid substance frequently found in association with petroleum, and arising from the latter by a process of oxidation and inspissation. It is readily inflammable, burns with a smoky flame, and gives off a tarry odour. It is often found as an impregnation of sandstones and limestones. It is frequently found oozing from the outcrops of petroliferous strata; and in certain places, as in Trinidad, it occurs in huge quantities at the surface as a lake formation.

Notable among the asphaltic rocks of Europe are those of Val de Travers near Neuchâtel in Switzerland, and Seyssel in France. Here the asphalt occurs as an impregnation of Cretaceous limestone, and the material has been extensively quarried for paving purposes.

In the United States the chief areas for asphaltic rocks (including sands and limestones) are Kentucky, Oklahoma, and California. The residual asphalts obtained by refining crude petroleum in California and other areas are also extensively used as paving materials.

The deposits of chief importance in the paving industry, however, are the fairly pure natural asphalts of the Trinidad pitch lake, and those of Bermudez on the neighbouring coast of Venezuela. Less important deposits of the same type occur in Cuba, Mexico, and California.

The pitch lake of Trinidad, which is the most noteworthy of these deposits, occupies an area of not less than about 100 acres, in the south western part of the island, near La Brea. The rocks in this area consist of shales and sandstones that have been thrown into a series of gentle folds the axes of which run east and west. It is at the western end of one of these anticlines that the pitch lake occurs. The lake is hollowed out of a bed of oil-bearing sand which is overlain by a bed of clay. The asphalt is the inspissated and oxidized product of oil that has oozed out at the outcrop of the oil-bearing sand.

Closely akin in nature and mode of origin to the asphalts proper, but less important commercially, are the solid brittle bitumens that are found in the form of vein deposits traversing sedimentary beds. These are known under various names; but the most important of them are *manjak* and *gilsonite*, both of which have a specific gravity about 1·1. They melt readily at a moderate temperature without decomposition, and are used for making black varnishes, for which purpose they are very effective, as they yield a strong and elastic film when deposited on surfaces from solvents.

Manjak occurs in Barbados in veins from ¼ inch up to 30 feet thick, traversing beds of Tertiary sandstone and shale. It also occurs in Trinidad, but the Trinidad variety is of a quality inferior to that of Barbados. In addition to its use as a varnish-making material, manjak is used for insulating electric wires.

Except that it is less friable and shows a conchoidal fracture, gilsonite is closely similar to manjak in its properties. Gilsonite occurs in Utah and Colorado, in veins traversing Tertiary sands and shales. It yields a brown powder when crushed. Like manjak it is used for making black varnish, and it is also used to some extent in admixture with asphaltic limestones as a paving material.

PHOSPHATES.

In addition to the phosphates already referred to in connection with ore minerals and gemstones, there remain to be considered several phosphates, including apatite and phosphorite, monazite, amblygonite, autunite and torbernite, that have other uses. Of these only apatite and phosphorite are used for the sake of their phosphorus, and they will be dealt with in this section. Monazite will be dealt with as a thorium and cerium mineral (see pp. 166, 426); amblygonite is a lithium mineral (see p. 379); autunite and torbernite are uranium minerals of value as sources of radium (see p. 433).

Apatite (tri-basic calcium phosphate, with some fluorine or chlorine). This mineral has already been described under gemstones on p. 271, where its mode of occurrence in veins and pockets in the granites and gneisses of Quebec has also been mentioned. Apatite has been produced for many years, as a by-product in mica-mining, from these Canadian deposits; and prior to the discovery of the richer and more cheaply worked deposits of phosphorite, the Canadian apatite veins were of considerable significance as a source of superphosphate, but were rendered comparatively unimportant by the exploitation of phosphorites in the United States and north Africa ; they are worked chiefly for the phlogopite mica that they contain. Canadian apatite is used in Canada, partly in the manufacture of phosphorus and partly in making superphosphate.

Vein-deposits of apatite have also been mined for some years near Kragerö in southern Norway.

Phosphorite or Rock-Phosphate (figs. 232, 233).—Under these names are described the massive types of tri-basic calcium phosphate which bear the same relation to apatite that limestone does to calcite. In some deposits, as in the Cretaceous and Tertiary beds of England, France, Belgium, Germany, and Russia, phosphorite occurs in the form of nodules in sands and clays ; and these nodular phosphorites have been worked at many localities as a source of superphosphate. Of far greater importance are the products that form extensive beds of phosphorite in sedimentary deposits as replacements of limestones, especially those of the United States (chiefly Florida and Tennessee) and North Africa (Algeria, Tunis, and Egypt). Immense quantities of this rock-phosphate are produced annually and converted into superphosphates of lime, for use as a fertilizer by agriculturists. Phosphorite frequently contains a large amount of impurity in the form of calcium carbonate, iron oxide, and alumina. It is chiefly as a diluent that calcium carbonate is objectionable ; but iron oxide and alumina are quite obnoxious in the manufacture of superphosphate if present in considerable amount,

FIG. 232.—Phosphatized coral, showing the structure of the coral. (× ½).

owing to the deliquescence and stickiness they impart to the superphosphate. A large amount of high-class rock-phosphate, containing from about 60 to 75 per cent. of tri-basic calcium phosphate, and not more than 3 per cent. of iron oxide and alumina, is available; and for that reason it is customary for manufacturers of superphosphate to stipulate a high standard of purity in the material they purchase. Calcium carbonate is frequently present, but should not exceed 10 per cent.

Phosphorite deposits occur in many parts of the United States, which country contributes by far the greatest amount to the world's total output. The most important deposits are those of Florida, where the phosphate beds are of two types, namely (1) *hard-rock* phosphate, and (2) *land-pebble* phosphate.

The hard-rock type is usually a whitish and close-grained rock and is of Oligocene age. It occurs in huge irregular masses embedded in a matrix of sand, clay, and soft phosphate, the whole being underlain by a bed of limestone. It is mined chiefly for export, with a guaranteed percentage of 77 of tri-basic calcium phosphate.

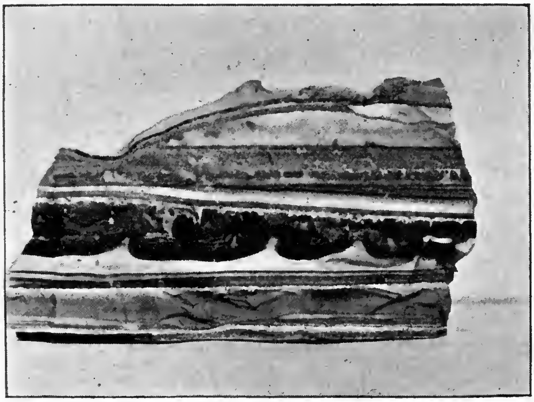

FIG. 233.—Banded phosphate.

The land-pebble deposits are of Pliocene age. They consist of phosphatic pebbles, embedded in a matrix of sand and clay like that of the hard-rock deposits, and their formation is probably due to the denudation and re-distribution of the older hard-rock deposits. These land-pebble deposits are more easily worked than the hard-rock variety, and the material obtained from them is dressed to yield a product containing from 60 to 75 per cent. of tri-basic calcium phosphate.

Deposits of phosphorite of importance occur to the north-east of

Georgetown in Idaho; and though these deposits have not figured in phosphate production to a large extent in the past, their good quality and great extent makes them worthy of note. The Idaho phosphorite is oolitic in texture, and occurs as beds in a limestone formation that is probably of Permian age. One bed is from 5 to 7 feet thick, and in this bed alone it is estimated that there is not less than 2,633,000,000 tons of exploitable phosphate. Phosphate samples from this bed show 70 per cent. of tri-basic calcium phosphate, and only very small amounts of iron oxide and alumina.

Next in importance to the phosphorite deposits of the United States are those of northern Africa, where important supplies are obtained in Algeria, Tunis, and Egypt.

In Algeria, phosphorite is worked chiefly in the department of Constantine, where at Dyr there is a bed of phosphate about 9 feet thick. This bed occurs between Upper Cretaceous marls and Eocene limestone. The phosphate obtained from it carries from 55 to 70 per cent. of tri-basic calcium phosphate.

In Tunis, the important phosphate beds occur at the base of the Eocene, under geological conditions closely resembling those of Algeria. In the Tunis deposits, however, the phosphate beds are more numerous. At Gassa, a locality where there are extensive workings, there are four beds of phosphate, the uppermost of which is about 10 feet thick and has yielded on the average about 60 per cent. of tri-basic calcium phosphate.

In Egypt, phosphorite beds occur at various localities in the desert areas, in sedimentary strata of Upper Cretaceous age. The chief deposits are those in the Safâga district, near the Red Sea coast. The beds in which they occur form part of a mass of Cretaceous and Tertiary sediments occupying a basin-shaped depression in the older rocks. There are three phosphate beds, from 4·2 to 6·5 feet thick, interlaminated with grey clays and chert beds, and the middle bed, which is 4·2 feet thick, carries from 50 to 75 per cent. of tri-basic calcium phosphate.

Of considerable interest in connection with the origin of phosphorite beds is the occurrence of guano deposits on coral islands, and the way in which the coral rock is altered to phosphorite by the action of phosphatic solutions derived from the overlying guano. Where, as on the Peruvian coast, the guano occurs in a region of no rainfall, it preserves its organic character; but where, as in the Indian Ocean and many parts of the Pacific, there are plentiful tropical rains, the phosphatic matter is washed out of the guano, and, percolating through the underlying coral limestone, metasomatizes it into phosphorite. Excellent examples of this extensive phosphatization of limestone in recent times by solutions derived from guano deposits are provided by the Island of Assumption and other islands in the Seychelles, and by various islands in the Pacific, notably Ocean Island and Nauru.

PIGMENT MINERALS.

The insoluble powders of various colours that are used for making paints include many artificial compounds, but in some cases they consist of minerals in a crushed condition. The following is a list of the more important minerals used as pigmentary materials :

Asbestos (see p. 327) is used to a small extent as an ingredient of fireproof paints.

Azurite (see p. 177) was formerly used as a pigment under the name of *mountain blue.*

Barite (barytes, see p. 415) is used as an adulterant of white lead, but it is not merely an adulterant, as it possesses in itself some value as a pigment. Barite used in this way requires to be perfectly white and free from iron oxide. The material freshly mined seldom possesses the requisite degree of purity, and has to be refined by treatment with sulphuric acid after being finely ground. Barium sulphate is an ingredient of the white pigment known as *lithopone,* which is a precipitated mixture of zinc sulphide and barium sulphate.

Celadonite (" terre verte," see p. 411) is used to a small extent as a green pigment.

Chalk (calcium carbonate of organic origin and in a somewhat porous condition) is the pigment used in common whiting or whitewash.

Cinnabar (see p. 232) is not much used in its natural condition for making vermilion, owing to its defective consistency and colour. Vermilion pigment is as a rule made artificially from mercury and sulphur, though the artificial pigment has the same chemical composition as natural cinnabar.

Graphite (see p. 374) is the essential constituent of the " black lead " used for stove polishing. It is also used as a protective paint for iron and steel.

Gypsum (see p. 419) is used as a white pigment in a crushed condition under the name of *terra alba* or mineral white.

Hæmatite (see p. 194) in certain compact and good-coloured varieties is used in making *red ochre* ; but the variety of red ochre known as

Indian red, which has the same chemical composition as hæmatite, is made by roasting pyrite (see p. 424) or copperas (see p. 421).

Crystalline hæmatite of the fine scaly variety known as micaceous hæmatite, is used to some extent as an ingredient of paint; the scales lie flat, and presumably by their imbrication with one another, afford a good protection to readily oxidizable surfaces such as those of iron and steel. A deposit of this scaly hæmatite occurs and has been worked near Bovey Tracey, in Devonshire.

Kaolin (China clay, see p. 357) is used as a filler. It is also used in mixture with zinc oxide in the manufacture of *Chinese white*.

Lapis-lazuli (see p. 303) was formerly used as a source of ultramarine, but this pigment is now made artificially.

Limonite (see p. 195) is the essential ingredient of *yellow ochre*, which usually contains a considerable amount of argillaceous matter. If gritty impurity is present this has to be removed by washing. Yellow ochre usually occurs in the form of sedimentary beds, as in the Keuper (Triassic) strata at Wick near Bristol; but it is sometimes found as a weathering residue of limestone. It turns red when dehydrated by heating strongly.

The presence of manganese oxide in an ochre darkens the colour, and yields the light brown *sienna* or dark brown *umber* according to the amount present.

Malachite (see p. 176) is used to a small extent as a green pigment.

Orpiment (see p. 161) is used as a yellow pigment, and is supposed to owe its name to a contraction of the Latin name *auripigmentum* (gold pigment).

Talc (steatite, see p. 413) is used as a paper filler and to some extent also in the manufacture of paint.

PLUMBAGO (see p. 374).

POTASH MINERALS.

Potash is an essential ingredient in the mineral food of plants, and for that reason potash minerals are of great economic importance as fertilizers. Among other uses of potash minerals, the use of alunite in the manufacture of alum, and nitre in the manufacture of gunpowder should be noted.

Potassium is a widely and abundantly distributed element. It is an essential constituent of the potash felspars, which enter largely into the composition of granite, and the syenites and pegmatites frequently associated with granite. Potash felspar usually contains from 10 to 15 per cent. of potash. Granite is the commonest igneous rock, and occurs in the form of immense intrusive masses in all parts of the world. One might expect, therefore, that potash fertilizers would be abundant and cheap. In fact, however, potassium salts of the kind desired as fertilizers are not abundant. This is because they are required in a readily soluble form, and the potash felspars are not readily soluble.

Ground potash felspar has been used to some extent as a fertilizer, and it is easy to believe that land requiring potash would profit greatly and durably by the application of finely powdered potash felspar. In practice, however, agriculturists prefer the more soluble potassium compounds from which the plants can derive an immediate and plentiful supply of potash. Many attempts have been made to manufacture soluble potash compounds from felspar, and although it is not unlikely that this manufacture will ultimately prove an economic success, it has not hitherto been able to compete with the production of naturally-occurring soluble potassium minerals.

Another silicate in which there is a considerable percentage of potash is leucite (see p. 406). This mineral contains a higher percentage of potash than felspar, and is more readily decomposed ; it is therefore a more effective fertilizer than powdered felspar. It is used to some extent as a source of potash, but it has to be obtained by electromagnetic separation from crushed phonolite. This is a rather expensive process, though it appears to have been a commercial success as carried on at Civita Castellana, in Italy.

More suitable than either of these minerals, however, as a potash fertilizer, is the mineral alunite, a hydrated sulphate of aluminium and potassium. By ignition, alunite is decomposed into potassium sulphate and alumina, and the potassium sulphate in the mixture thus obtained is readily soluble.

The minerals of economic importance at the present time as sources of soluble potassium compounds are carnallite, kainite, sylvite, alunite, leucite, and nitre. For remarks on nitre (saltpetre), see p. 386. Glauconite is of some interest as a potash mineral (see p. 412).

In recent years, and especially during the war when there was a shortage of potash, many efforts have been made to secure potash supplies from blast furnace dust, and these efforts have had some measure of success.

Carnallite (named after von Carnall).

General.—Orthorhombic, but rarely shows crystalline form, being found in a massive-granular condition. Fracture, conchoidal. Hardness, 1. Specific gravity, about 1·6. Deliquescent.

Optical.—Colour usually reddish due to ferruginous impurity, but white when pure. Lustre, vitreous to greasy. Refractive index low, $\alpha = 1{\cdot}466$. Birefringence high, $\gamma - \alpha = 0{\cdot}027$. Optical sign, positive.

Chemical and blowpipe.—Hydrated chloride of potassium and magnesium ($KCl \,.\, MgCl_2 \,.\, 6H_2O$), containing 26·8 per cent. of potassium chloride. Fusibility, about $1\frac{1}{2}$. Flame-coloration violet; azure-blue with copper oxide. Yields water in a closed tube. Soluble in water, and decomposed on heating the solution, from which the potassium chloride crystallizes out in part separately from the magnesium chloride.

Occurrence and distribution.—Carnallite occurs associated with kainite ($KCl \,.\, MgSO_4 \,.\, 3H_2O$), sylvite ($KCl$), and many other minerals in the famous Stassfurt salt deposits of Germany, about 25 miles south-west of Magdeburg. These potash salts were formerly regarded as a nuisance by the Stassfurt salt miners, who lumped them together as undesirable products under the name of *Abraumsalz*. As a result of the discovery by von Liebig of the importance of potassium as an ingredient in plant food, the potash salts of Stassfurt came to be regarded as valuable, and the supply of potash salts was for a long time practically a German monopoly. The working of potassium salt deposits at Kalusz in Galicia (Poland) and Alsace did not at first seriously affect this monopoly; but now that Alsace has been regained by the French the German monopoly is ended. Moreover, carnallite deposits have been found to occur extensively in Catalonia in Spain. Another important deposit of potash salts of the Stassfurt type has been found at Mt. Dellol in Abyssinia, and this has yielded considerable amounts of potassium chloride in recent years. There are somewhat similar deposits at the Mayo salt mine in the Salt Range of the Punjab, India, but it is not likely that these can be worked economically. To these considerations should be added the very active attempts that are being made in the United States of America to obtain supplies from the salt lakes of the west, from the sea weeds of the Pacific coast, and from the chemical treatment of felspars.

The Stassfurt salt-deposits have a floor of rock salt, above which occur in ascending order beds of *polyhalite*

$$(K_2SO_4 \,.\, MgSO_4 \,.\, 2CaSO_4 \,.\, 2H_2O),$$

kieserite ($MgSO_4 \,.\, H_2O$), carnallite partly altered to kainite, clay, anhydrite ($CaSO_4$), and gypsum ($CaSO_4 \,.\, 2H_2O$), the whole being overlain by mudstones, shales and sandstones.

Many other comparatively unimportant potassium minerals have been proved to occur in the Stassfurt and other salt deposits. Of these the more notable are picromerite ($K_2SO_4 . MgSO_4 . 6H_2O$), langbeinite ($K_2SO_4 . 2MgSO_4$), syngenite ($K_2SO_4 . CaSO_4 . HO$), misenite ($KHSO_4$), and aphthitalite [$(K,Na)_2SO_4$].

Carnallite is the most important of the Stassfurt potash minerals, and to it chiefly the Stassfurt deposits owe their commercial importance. The carnallite bed has been in part altered to kainite by reaction with magnesium sulphate. Like the rock-salt with which it is associated, carnallite has been deposited from solution during the drying up of a desert salt-lake in Permian times.

Kainite (Gr. *kainos*, recent).

General.—Monoclinic, but like carnallite usually found in a massive-granular condition. Hardness, about 2½. Specific gravity, about 2·1. Not deliquescent.

Optical.—Reddish, grey, or white. Lustre, vitreous to greasy. Refractive index about 1·50. Birefringence high, $\gamma - \alpha$ about 0·03. Optical sign, negative.

Chemical and blowpipe.—Hydrated potassium chloride and magnesium sulphate ($KCl . MgSO_4 . 3H_2O$), containing 30 per cent. of potassium chloride. Fusibility, about 2. Flame-coloration violet. Gives off water in closed tube. Soluble in water, but decomposed on heating the solution, potassium sulphate and magnesium sulphate separating out and leaving magnesium chloride in solution. The aqueous solution yields a heavy white precipitate of barium sulphate when treated with barium chloride.

Occurrence and distribution.—Kainite occurs associated with carnallite and is used extensively by agriculturists as a fertilizer on account of its potash. The kainite was not deposited originally with carnallite, but has arisen from the latter as a secondary product through interaction with magnesium sulphate.

Sylvite (from *Sal digestivus Sylvii*, the old chemical name for potassium chloride).

General.—Cubic (fig. 234). Perfect cubic cleavage. Hardness, 2. Specific gravity, 1·95.

Optical.—Colourless or white. Lustre vitreous. Refractive index, low (about 1·49). Microfragments show cubic shapes and are isotropic.

Chemical and blowpipe.—Potassium chloride (KCl). Fusibility, 1½. Yields no water in closed tube. Violet flame coloration due to potassium. Soluble in water. When to an aqueous solution in distilled water a little nitric acid and silver nitrate are added, a white precipitate of silver chloride is obtained.

Occurrence and distribution.—Sylvite occurs associated with carnallite and halite in the potash-salt deposits of Stassfurt in Germany and Catalonia in Spain. It is, moreover, the chief of the potassium minerals occurring in the deposits of Kalusz in Galicia, and the Salt Range of India. Sylvite has been obtained in considerable quantities in recent years at Mt. Dellol in Abyssinia (inland from Massowa and near the Eritrean border), where there are potash-salt deposits of the Stassfurt type. The name " sylvinite " is used by some to describe mixtures of sylvite with halite, the latter constituent predominating.

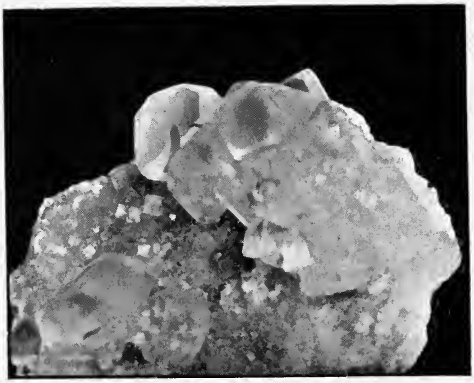

FIG. 234.—Sylvite, Stassfurt. ($\times \frac{1}{3}$). B.M.

The Alsace deposits consist of sylvinite, containing from 30 to 35 per cent. of potassium chloride. They are situated near Mulhause, in the south of the province ; and occur as beds in Oligocene strata, at a depth of from 650 to 1000 metres. There are two beds of sylvinite, the deeper and larger of which is about 4 metres thick. Overlying the sylvinite beds is a bed of rock-salt 240 metres thick. The Alsace deposits are estimated to contain 1,472,058,000 tons of sylvinite, equivalent to about 300,000,000 tons of potash (K_2O).

Alunite (name abbreviated from aluminilite. It has also been called alumstone, on account of its use in the manufacture of alum).

General.—Trigonal, but usually found massive with a microcrystalline texture. Basal cleavage. Fracture, uneven. Hardness, about 4. Specific gravity, about 2·7.

Optical.—Colour, white, grey, or pinkish. Lustre, vitreous. Refractive index low, $\omega = 1{\cdot}57$. Birefringence moderately high, $\epsilon - \omega = 0{\cdot}02$.

Optical sign, positive. Microfragments often show a centric uniaxial figure.

Chemical and blowpipe.—Hydrated sulphate of aluminium and potassium, with a composition corresponding to the formula

$$K_2O . 3Al_2O_3 . 4SO_3 . 6H_2O.$$

Infusible. Decrepitates in blowpipe flame, and gives potash flame coloration. Yields water in a closed tube when strongly heated, and the water given off has an acid reaction. Yields a blue colour in charcoal when moistened with cobalt nitrate. After heating in closed tube it is partially soluble in water; cubic crystals of alum crystallize out from this aqueous solution and can be identified microscopically.

Occurrence and distribution.—The chief occurrences of alunite are those at Bullah Delah, New South Wales, Australia; Tolfa near Rome, Italy; Benahadux in Almeria, Spain; and near Marysvale, Utah, U.S.A.

At Bullah Delah in N.S.W., about 35 miles from Port Stephen, a narrow range of hills that reaches an altitude of 900 feet consist almost entirely of alunite over a length of about a mile. The rocks of the Bullah Delah area are rhyolites, interbedded with Permo-Carboniferous strata, the whole being folded and invaded by dolerite dykes of Tertiary age. It is supposed that sulphurous vapours were emitted during the intrusion of the dolerites, and that these vapours acted on the rhyolites, decomposing the felspathic ingredients and forming alunite. In its purest form the Bullah Delah alunite is microcrystalline in texture, pink in colour, and contains about 9½ per cent. of potash. It has been worked for many years as a source of alum, to obtain which the alunite is first heated at the required temperature and then leached with water. If heated more intensely it is converted into a mixture of alumina and potassium sulphate, and in this condition, as already stated, it is useful as a potash fertilizer.

At Tolfa, near Rome, alunite occurs as veins in a mass of trachyte that overlies Tertiary sediments. The trachyte is very pyritic. There are two views as to the origin of alunite in the Tolfa trachytes. According to one of these views the alunite has been formed by the action of solfataric vapours on the trachyte. The other view is that the alunite has been formed by the decomposition of the felspars of the trachyte due to the action of the acid solutions arising from the decomposition of the pyrite by descending waters.

The alunite near Marysvale in Utah occurs in veins traversing andesites that are probably of Tertiary age. The main vein is in one place 20 feet thick, and the outcrop has been proved to extend over a distance of 3500 feet. At Rosita Hills in Colorado, alunite occurs associated with quartz in a granite-like rock that contains not more than about 2½ per cent. of potash.

Deposits of alunite occurring at Benahadux in Almeria, Spain, have been described under the name of "calafatite." There is, however, no justification for regarding the Benahadux material as a separate species. Its chemical composition is identical with that of ordinary alunite. It occurs in compact, chalk-like masses, the texture of which is the same as that of ordinary alunite. It occurs in the form of parallel beds 5 or 6 metres thick beneath Triassic limestone, and is easily and cheaply quarried. Deposits of chalk-like alunite occur at other localities, notably at Carrickalinga Head in South Australia.

Leucite (Gr. *leucos*, white).

General.—Pseudo-cubic, occurring in the form of icositetrahedra in alkali volcanic rocks. These depart slightly from cubic symmetry at ordinary temperatures, but they are truly cubic at a temperature of 714°, which fact indicates that they probably crystallized from the molten rock in a cubic condition. No good cleavage. Fracture, conchoidal. Hardness, about 5½. Specific gravity, about 2·5.

Optical.—Colour white or grey. Lustre, vitreous. Refractive index low ($\beta = 1{\cdot}508$). Birefringence very low, so slight as to make the mineral appear isotropic in many cases, especially in small crystals. Frequently shows a striped appearance between crossed nicols, due to repeated twinning.

Chemical and blowpipe.—Silicate of potassium and aluminium ($K_2O \,.\, Al_2O_3 \,.\, 4SiO_2$). Contains about 21 per cent. of potash when pure. Infusible. Flame-coloration violet. Decomposed by hydrochloric acid, but without gelatinization.

Occurrence and uses.—Leucite occurs abundantly at some localities as a constituent of volcanic rocks (phonolites and leucitites). Rocks of this type occur abundantly in Central Italy, near the coast, and have been worked as a source of leucite, notably at Civita Castellana. Here the rock worked is a leucite-phonolite, and the leucite is separated from the weakly magnetic matrix of the phonolite by using electromagnets. Leucite rocks occur also in some abundance at Leucite Hills, Wyoming, U.S.A., and at many other localities. These Wyoming rocks in some cases contain as much as 26 per cent. of leucite.

Leucite differs from potash felspar in containing a higher percentage of potash and a lower percentage of silica. It is more readily decomposed than felspar, and its potash is therefore more readily available to plants when it is used directly as a fertilizer. Soluble potash salts are readily prepared from leucite.

POTTERY AND GLASS-MAKING MATERIALS.

The plastic ingredients of pottery mixtures are kaolin and ball clay (see p. 357). To these are added various hardening materials, the chief of which are quartz and flint; and various fluxing materials, chiefly potash felspar, China stone (partly-decomposed potash-felspar), lime, magnesia, and gypsum. The readily fusible materials that are used to give a superficial glaze on pottery include borax, white lead, and common salt.

Glass is a silicate, and the silica used in its manufacture is quartz, in the form of sand (so-called silver sand) consisting of white or colourless grains, and practically free from minerals other than quartz. Such sands are found in a loose and readily-quarried condition in many of the Mesozoic and Tertiary detrital deposits. The best glass sands, such as those of Fontainebleau in France and Lippe in Germany, contain over 99·5 per cent. of silica. Sands of fairly good quality occur at Aylesbury and other localities in England. At Muckish Mountain in Donegal (Ireland) there is a very interesting deposit of sand that has been formed by the disintegration of a quartzite under weathering influences. Though not quite of the best texture, this sand is remarkably pure, and contains over 99·5 per cent. of silica.

For use in making the best qualities of glass, sands should contain little or no iron oxide. For making plate glass, not more than 0·2 per cent. of ferric oxide should be present. More than this, up to one per cent. or rather more, is permissible for making bottle glass. Magnesia is likewise an objectionable constituent.

In texture, the sand should be of medium grain and as uniform as possible. Angular rather than rounded grains are preferred. The grain-sizes in the best qualities range from 0·5 mm. to 0·2 mm. diam. Grains of the silt grade (0·1 mm. to 0·01 mm. diam.) are objectionable for most purposes, and should not exceed one per cent. or so. Grains of the mud grade (0·01 mm. and under) should be absent.

The materials used together with quartz in making glass include sodium sulphate, potassium carbonate (pearl ash), calcium carbonate (chalk), and barium carbonate. In making opalescent glass, fluorite and cryolite are used.

Numerous metallic compounds are used in colouring pottery and glass, notably those of iron, manganese, copper, chromium, cobalt, antimony, titanium, uranium, silver, gold, platinum, and iridium.

In connection with glass mention should be made of fused-silica ware which is made by fusing pure silica. For the best quality of transparent silica ware, clear quartz of the rock-crystal type is required (for quartz, see p. 310).

RADIUM MINERALS (see p. 430).

"RARE-EARTH" MINERALS.

The term "rare-earth" is used somewhat loosely and vaguely of certain oxides that were formerly regarded as of rare occurrence. In its strictest sense the term should be applied only to the cerium and yttrium earths and their near relatives. In practice, however, the term is seldom thus restricted, and is generally used in a broader sense to include zirconia and thoria. Even in this sense the term "rare-earth" must be considered inapt, for zircon is a ubiquitous mineral, and certainly cannot be regarded as rare; nor can monazite, from which the cerium and thorium of commerce are obtained, be regarded as a rare mineral.

The term "rare-earth" however, is used in a yet broader sense by many writers, and is usually made to include titanium dioxide, which is one of the really abundant constituents of the earth's crust.

In this book "rare-earth" minerals are dealt with separately under the heads of the elements chiefly concerned, as follows: cerium minerals, p. 166; yttrium minerals, p. 435; thorium minerals, p. 426; zirconium minerals, p. 436; titanium minerals, p. 247.

REFRACTORY MINERALS.

The minerals usually classed as refractories are those which, on account of their resistance to chemical and physical changes at high temperatures, are useful as furnace linings in metallurgical operations. They are generally classified as acid, neutral, and basic materials.

Acid refractories are those containing a high percentage of silica; they include sand, sandstone, flint, and fireclays. The amount of alkalies and iron oxide should be as small as possible. In Vancouver Island a quartzose variety of the mineral pyrophyllite (p. 412) is used for making fireclay, by mixing with ordinary clay and shale. Kaolin (China clay, see p. 357) is usually regarded as the most highly refractory variety of clay. Ganister and Dinas rock contain up to 97 or 98 per cent. of silica in the form of granular quartz. They are used to make highly refractory silica bricks, in the manufacture of which only a small amount of lime and clay are used as binding materials.

Basic refractories include limestone, dolomite (p. 344), and magnesite (p. 346). Dolomite is preferable to limestone, and was first used as a basic lining in smelting operations by Thomas and Gilchrist. Dolomite used for this purpose should contain over 20 per cent. of magnesia. Magnesite is more effective than dolomite; and furnaces lined with magnesia bricks are far more durable than those lined with bricks made from dolomite. For ordinary metallurgical requirements it is considered permissible and even desirable that the magnesite should contain 4 or 5 per cent. of iron oxide, and the magnesite of Austria and Hungary which has been used largely in the past for ordinary metallurgical purposes is of this variety. It yields a dead-burnt product of a brownish or brownish black colour, and is known as breunnerite. Purer dead-burnt magnesia in the form of slabs is stated to be highly effective when used for the roofs of small electrical furnaces.

The neutral refractories include graphite (p. 374), chromite (p. 167), and bauxite (p. 150). Graphite of the flaky or fibrous variety has to be mixed with fireclay before it can be made into bricks and crucibles, and when mixed with a suitable clay it yields crucibles of a highly refractory character. Chromite in its natural matrix of serpentine or talc is a highly refractory substance; but pure chromite can also be used by first crushing the mineral and mixing it with a little lime, which acts as a binder. Bauxite makes highly refractory bricks when not much iron and silica are present. When much silica is present the iron oxide should not exceed one or two per cent.; but when little or no silica is present a considerable percentage of iron oxide is permissible.

Zirconia, which occurs native as the mineral baddeleyite, is far more refractory than the minerals mentioned above, as may be judged from the fact that whereas silica softens at about 1800° C. and pure kaolin fuses at a temperature of about 1830° C., the fusion temperature of pure zirconia is stated to be about 3000° C. Zirconia is now used as a special refractory for the roofs of electrical furnaces in which exceptionally high temperatures are attained.

In connection with refractories mention should be made of diatomite bricks (see p. 367 for diatomite). These are very porous and not strong; but they are highly refractory and are used as backings for heat-insulation purposes, for which they are eminently suited on account of their low degree of thermal conductivity.

ROCK-SALT (See Chlorides, p. 354).

RUTILE (See Titanium, p. 247).

SELENIUM MINERALS.

The element selenium enters into the composition of a number of minerals, forming selenides. These are analogous to sulphides, as in the case of clausthalite (PbSe) which is the analogue of galena (PbS).

Selenium and selenides are found in nature associated with sulphur and sulphides. The element selenium is regarded as a deleterious ingredient in the pyrites used for the manufacture of sulphuric acid. Commercial supplies of the element are obtained as by-products in the manufacture of sulphuric acid, and in the smelting and electrolytic refining of copper.

Selenium is used in telephotography on account of the fact that its electrical conductivity varies with light intensity. It is also used as a colouring agent in the manufacture of red glass and enamels.

SILICA.

Silica assumes many forms, most of which are crystalline and as a rule consist of quartz, as for example rock-crystal (p. 310); sand grains in glass sands (p. 407), moulding sands (p. 385) and refractory sands (p. 408), silts and siltstones for polishing etc. (p. 326). Chalcedony (p. 277) and opal (p. 306), the latter of which is amorphous, have been dealt with under gemstones. Diatomite (p. 367) is a form of opaline silica of organic origin.

SILICATES.

In addition to the various silicates included under gem minerals and ore minerals, there are several which are most conveniently grouped under miscellaneous economic minerals. Some of these have been dealt with already under special headings, *e.g.* asbestos, clays, and micas.

Agalmatolite (Gr. *agalma*, image, and *lithos*, stone; so named from the fact that the stone is carved into figures).

The name agalmatolite is applied loosely to steatite (see p. 413), pyrophyllite (see p. 412), and pinite (see p. 412), all of which are sufficiently soft and compact to be carved. These three minerals can be distinguished by their hardnesses, which are 1, about 1½, and about 3 respectively.

Asbestos (see p. 327).

Beryl (see p. 274). Common beryl is used in small quantites to make beryllium compounds. Beryllium nitrate is used to a small extent in the manufacture of mantles for incandescent gas-lighting, for which purpose it acts as a strengthener of the fabric.

Common beryl occurs frequently, associated with mica and felspar, in coarse-grained granites and pegmatites. The demand is not large enough to make beryl-mining profitable for beryl alone, and the mineral is usually obtained as a by-product in the mining of felspar and mica.

Many of the mica-pegmatites of Canada and the United States carry beryl. At Grafton in New Hampshire, U.S.A., masses of the mineral exceeding a ton in weight have been found.

The mineral is found in many parts of France among the pegmatites associated with granite intrusions, notably those of the Central Plateau area. It occurs abundantly in pegmatites that have been quarried for felspar around Chanteloube to the north-east of Limoges in Haute-Vienne.

In Ireland, beryl is found in coarse-grained granites and pegmatites near Dungloe in Donegal; and at Glencullen, County Dublin, in the Leinster granite area.

Celadonite (Fr. *céladon*, sea-green; also known as *terre verte*). This mineral, like glauconite, with which it appears to be chemically identical, is essentially a hydrated silicate of iron and potassium, usually containing also a little magnesium. It occurs as a soft alteration product of basic volcanic rocks, associated with calcite, zeolites, and chalcedony. It frequently coats the amygdales of basalts, and in some instances replaces them completely.

Celadonite has been and still is used to a small extent as a green pigment. It occurs in some abundance among the Deccan Traps (basalts) of India, where the natives extract it for sale. The *terre verte* of Cyprus, which has also been worked as a pigmentary mineral, is celadonite.

Clays (see p. 357).

Felspars (see pp. 293, 401).

Gadolinite (see Yttrium minerals, p. 435).

Garnet (see pp. 296, 325).

Glauconite (Gr. *glaukos*, sea-green). This mineral is a hydrated silicate of iron and potassium. It resembles celadonite in composition, but has a different mode of occurrence. It varies from yellowish to dark green in colour. It forms as a replacement product of the body substance of foraminifera, and occurs abundantly in some sandstones, limestones, and clays, notably those of Cretaceous and Tertiary age. The Cretaceous greensands sometimes contain a large percentage of glauconite, so much so that they have been used to some extent as potassic fertilizers. Their value as fertilizers is indeed enhanced by the fact that glauconitic greensands usually contain also a considerable amount of phosphatic matter. Glauconite can usually be separated from sands in a fairly pure condition by means of the electromagnet.

Kaolin (see p. 357).

Leucite (see p. 406).

Meerschaum (Ger. *Meer*, sea, and *Schaum*, froth; also called sepiolite).

General.—No crystalline form; occurs in compact and dull earthy masses. Highly absorbent. Fracture, uneven. Hardness, about 2½. Specific gravity, about 1·2, but sometimes higher due to impurities.

Optical.—White, greyish white, or yellowish white. Lustre, dull. Refractive index low, about 1·54. Microfragments irregular in shape and show a compact texture between crossed nicols.

Chemical and blowpipe.—Hydrated silicate of magnesium

$$(2MgO \,.\, 3SiO_2 \,.\, 2H_2O).$$

Fusibility, about 5. Gives off water in closed tube. Decomposed by hydrochloric acid with gelatinization.

Occurrence and uses.—Meerschaum is mined at Eski-Shehir in the province of Brusa, Asia Minor. It is found as nodular lumps associated with magnesite in a surface bed of earthy or clayey matter, formed by the decomposition of serpentine. When freshly quarried the meerschaum is very wet and requires to be carefully cleaned from earthy matter and slowly dried before it is exported. When dry it has a porous texture, hence its name. In New Mexico it occurs as nodules and bedded masses in limestone. It is exported to Vienna and used chiefly in the manufacture of tobacco pipes, on account of its absorbent property and the rich colour it develops after having been used for some time. Before being made into pipes it is soaked in wax, after which it takes a good polish.

Pinite.—A hydrated silicate of aluminium and potassium. A compact and usually greyish alteration product of cordierite and various other silicates. It is included with steatite and pyrophyllite under the name agalmatolite (see p. 410).

Pyrophyllite (Gr. *pyros*, fire, and *phyllon*, a leaf. Compact varieties are included with *agalmatolite*, and under this name often confused with steatite).

General.—Occurs usually as compact or fibrous masses with a granular or cryptocrystalline texture. Rarely as orthorhombic folia with a pearly lustre like those of talc. Hardness, about 1½. Specific gravity, about 2·8.

Optical.—Colour usually yellow, but sometimes white, greyish, or greenish. Lustre usually dull, but sometimes pearly. Refractive index low, $\alpha = 1{\cdot}57$. Birefringence fairly high, $\gamma - \alpha = 0{\cdot}02$. Microfragments usually irregular, and show a compact structure between crossed nicols; but in fibrous specimens microfragments may be prismatic with straight extinction and positive elongation.

Chemical and blowpipe.—Hydrated silicate of aluminium

$$(Al_2O_3 \,.\, 4SiO_2 \,.\, H_2O).$$

Infusible, but often shows strong exfoliation. Gives off a little water in closed tube when heated strongly. Yields a blue colour, indicating the presence of aluminium, when, after ignition on charcoal, it is moistened with cobalt nitrate and reheated; and by this test it can be distinguished from talc (steatite). Not decomposed by ordinary acids.

Occurrence and uses.—Pyrophyllite occurs associated with metamorphic rocks. In the Deep River district of North Carolina, U.S.A., it occurs as large beds in foliated rocks. One bed is 500 feet thick and stretches over a distance of six miles. The mineral also occurs abundantly among the metamorphic rocks on the south side of Conception Bay in Newfoundland. At Kyuquot Sound, in Vancouver Island, there occur large deposits of a compact rock that consists of an intimate admixture of pyrophyllite and quartz.

Pyrophyllite has much the same uses as talc (steatite) with which it is often confused. It is made into slate pencils. It is used as tailor's chalk (French chalk), and as a paper filler, and is also carved into ornaments. The pyrophyllite-quartz rock of Vancouver Island referred to above is used as an abrasive powder in making metal polish and scouring soap; and is also of use as a refractory to make fireclay by admixture with other clays.

Talc. (Arabic *talq*; the massive form of the mineral is known as *soapstone*, *potstone*, or *steatite*; Gr. *steatos*, tallow).

General.—Possibly orthorhombic. Found in the form of scaly aggregates and compact masses. Perfect pinakoidal cleavage. Hardness, 1. Readily sectile. Specific gravity, about 2·7.

Optical.—Colour white, greenish, or greyish. Lustre, pearly. Refractive index low, $\gamma = 1{\cdot}59$. Birefringence high, $\gamma - \alpha = 0{\cdot}040$. Optical sign, negative. Cleavage plates show a good biaxial figure of small axial angle, the acute bisectrix being at right angles to the cleavage.

Chemical and blowpipe.—Hydrated silicate of magnesium ($3MgO \cdot 4SiO_2 \cdot H_2O$). Fusibility, about $5\frac{1}{2}$, fusing only on the edges with great difficulty. Yields a little water when strongly heated in a closed tube. When moistened with cobalt nitrate and heated strongly in blowpipe flame it yields a pale pink colour. Insoluble in ordinary acids.

Occurrence and distribution.—Steatite is found frequently as an alteration product of basic igneous rocks rich in magnesia, and is therefore often found associated with chlorite-schist and serpentine. These, however, are usually inferior varieties, being as a rule rich in iron and of a poor colour. The better class or white varieties of talc occur as alteration products of tremolite associated with magnesian limestone. The history of the rock in this case is that the limestone first became crystalline through thermodynamical metamorphism, as a result of which tremolite (a silicate of calcium and magnesium) was formed, and this afterwards became hydrated and altered to form talc.

The United States is the largest producer and user of talc. The more notable of the other producers are France, Italy, Austria, Spain, Bavaria, Norway, Canada, India, South Africa, and South Australia.

Talc is mined at numerous localities in the United States, the States of New York and Vermont being the leading producers. In the district south-east of Gouverneur in New York State, as at Talcville, talc is found associated with pre-Cambrian crystalline limestone, in which it has been formed by the alteration of tremolite. Deposits of a similar character occur in North Carolina, California, and other states. The coarser soapstone variety is also mined largely in the United States, notably in Virginia.

In Canada, important deposits of massive white talc are mined at Madoc in south-eastern Ontario, where they occur as alteration products of tremolite in dolomitic limestone of pre-Cambrian age, as they do in New York State.

Talc of good quality has long been mined in France in the department of Ariège near Luzech on the north side of the Pyrenees, where it occurs in Lower Palæozoic dolomites. The thermodynamic metamorphism of these dolomites by granite intrusions has produced tremolite which has been subsequently altered to talc.

Talc is widely distributed in India and is mined at many localities. Compact white talc of excellent quality is associated with crystalline dolomitic limestones in the Jubbulpore district of the Central Provinces. Material of somewhat similar character is mined at Muddavaram in the Karnul District, Madras. In the Minbu and other districts of Burma, steatite suitable for making pencils for use in writing on blackened paper has long been mined.

In South Africa, compact talc of good quality is obtained at Barberton in the Transvaal, and is used as a soap adulterant and in other ways. It is at this locality that the chromiferous serpentine known as " verdite " occurs (see p. 339).

In South Australia, white compact talc of good quality is found at Yaranyacka in the Eyre Peninsula, associated with crystalline limestone. The deposit is worked in a small way, the talc obtained being ground in Adelaide for export to Queensland and Fiji.

Uses.—Talc is used extensively in paper manufacture, especially in the United States, where it is considered better than China clay for this purpose. It is also used as a filler for finishing silk goods ; as a marker under the name of French chalk ; for making toilet powder ; and for the adulteration of many articles, notably soap. It is of some use as a refractory, and offers strong resistance to the action of acids. The tips of gas burners are made of it, and it has been used to some extent in porcelain manufacture. It is frequently carved into ornamental objects, and is further used in the form of slabs for electrical insulation.

STEATITE (see p. 413).

STRONTIUM MINERALS.

Celestite (strontium sulphate), see p. 418.

Strontianite (strontium carbonate), see p. 350.

SULPHATES.

Alum.—Potash alum, $K_2SO_4 . Al_2(SO_4)_3 . 24H_2O$, occurs naturally as the mineral *kalinite.* It is found as a sublimation product in volcanic rocks, but not in quantities sufficient to make these occurrences of economic value. The alum of commerce is manufactured from alunite (see p. 404) ; also from alum-shales ; and from clays such as kaolin and halloysite by treatment with sulphuric acid.

Alunite (see p. 404).

Barite (Gr. *barys,* heavy ; also called *barytes* and *heavy spar*).

General.—Orthorhombic. Frequently found in the form of clear tabular crystals (figs. 235 to 237), with basal plane well developed. More commonly found in the granular massive form. Perfect cleavages parallel to basal plane and prism faces, yielding rhomboidal plates. Hardness, about 3. Specific gravity, about 4·5.

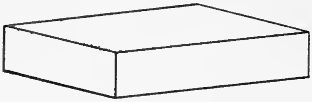

FIG. 235.—Barite.

FIG. 236.—Barite.

Optical.—Usually colourless or white, but frequently yellow, brown, and red, and crystals sometimes blue. Lustre vitreous, sometimes pearly. Refractive index high, $\gamma = 1{\cdot}647$. Birefringence low, $\gamma - \alpha = 0{\cdot}011$. Optical sign, positive; but cleavage fragments do not yield good interference figures, as the acute bisectrix is parallel to the basal plane. Microfragments are of two sorts; the lozenge-shaped basal plates have angles of about 78½° and 101½° and show symmetrical extinction; fragments in which the prism face predominates are rectangular in shape and show straight or parallel extinction. In the lozenge-shaped plates compensation takes place when the quartz wedge is inserted along the longer diagonal of the lozenge, and these plates show the emergence of the obtuse bisectrix. The rectangular cleavage plates show the excentric emergence of an optic axis.

FIG. 237.—Barite, Frizington, Cumberland. (× ¼). B.M.

Chemical and blowpipe.—Sulphate of barium ($BaSO_4$). Fusibility, 3½, but as a rule the crystal fragments decrepitate strongly. Flame-coloration, yellowish green. When fused with soda on charcoal the fused mass gives a black stain when moistened with water on a silver coin, indicating a sulphate. Insoluble in acids.

Occurrence and distribution.—Germany is the chief producer of barite, but large amounts are mined in the United States, England, France, and various other countries. Barite is very variable in its mode of occurrence. It occurs abundantly as a vein mineral in veins of lead-zinc ores, associated with galena and zinc-blende. It occurs also as a replacement product and cavity filling in limestone, forming lenticular masses. When such limestone masses are weathered they leave a residual clay in which the insoluble barite remains behind. Barite occurs also as a cement in certain sandstones. It is not infrequently found as stalactitic and nodular forms; and it is widely disseminated in association with galena and zinc-blende in the white ankerite joint-infillings that form such a familiar and conspicuous feature of English coal.

In Germany, the chief producing districts are the Harz and Thuringia, where barite occurs abundantly as a vein mineral associated with lead ore. In many of the lead-silver veins of the Clausthal mines in the Harz mountains barite and siderite are the predominant minerals.

Important deposits are found in many parts of the United States. In the State of Missouri, which is a large producer, barite occurs abundantly in veins of lead-zinc ore that traverse dolomitized Ordovician limestone, and in the surface residual clays resulting from the weathering of these deposits. Surface residual deposits containing lumps of barite are also abundant in Virginia. In Kentucky the barite is found in vein deposits associated with calcite and fluorite.

Barite is the predominant mineral in many of the veins of lead-zinc ore that traverse the Carboniferous Limestone and other Palæozoic strata in various parts of the British Isles. Shropshire, Cork, and Durham are the leading producers, but the mineral is mined also in several other counties, notably Westmorland, Yorkshire, Derbyshire, and Devonshire. In Shropshire there is a large production of barite from veins that traverse Ordovician sandstones; but elsewhere it is chiefly in the Carboniferous strata that the mineral occurs. The pure massive variety is found frequently in veins traversing the Carboniferous Limestone and the Coal Measures. A noteworthy occurrence of this type is that of the New Brancepeth Colliery near Durham, where there is a vein of pure barite reaching a thickness of about 16 feet, traversing the Coal Measures.

Uses.—The chief use of barite is as a paint-making material (see p. 399). It is also used as a filler, to give weight to rubber goods, paper, and asbestos cement, and to a less extent in the chemical trades. For most purposes whiteness, and therefore freedom from ferruginous impurity, is essential. In preparation for the market, the best grades are treated with sulphuric acid to remove iron oxide.

Celestite (L. *caelestis*, celestial; so named on account of the sky-blue colour of some specimens of the mineral).

General.—Orthorhombic (figs. 238, 239). The form and habit of the crystals resemble those of barite. Perfect basal cleavage, and less perfect prismatic cleavage. Hardness, about 3½. Specific gravity, 3·9.

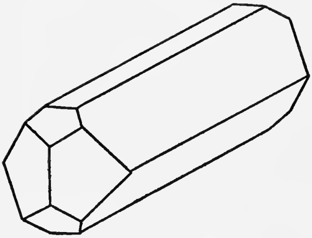

FIG. 238.—Celestite.

Optical.—Colourless or white, but sometimes pale blue. Lustre, vitreous. Refractive index high, $\gamma = 1{\cdot}631$. Birefringence weak, $\gamma - \alpha = 0{\cdot}009$. Optical sign, positive. Microfragments rhomboidal, with symmetrical extinction; or rectangular, with straight extinction.

Chemical and blowpipe.—Sulphate of strontium ($SrSO_4$). Fusibility, about 3½, with decrepitation, yielding a white globule without much difficulty. Flame-coloration, crimson. Gives no water in closed tube. Insoluble in ordinary acids. When fused with sodium carbonate yields sulphide reaction on a silver coin.

FIG. 239.—Tabular crystals of celestite, Yate, Gloucestershire. (× ½). B.M.

Occurrence and distribution.—Celestite is much more widely distributed than strontianite, and has been continuously quarried as a source of strontium compounds for many years. It occurs abundantly as veins, irregular masses, and geodes in the red Keuper marls (Triassic) of Gloucestershire and Somersetshire in England, from which it is obtained by means of shallow surface diggings. During recent years supplies have been obtained chiefly from the district around Yate in Gloucestershire. In these marls the celestite is associated with gypsum, and like the latter, has presumably been deposited from the water of a Triassic inland sea under arid climatic conditions.

Celestite is obtained also at Condorcet in France, where, in association with galena, zinc-blende, and gypsum, it forms veins traversing Mesozoic clays and limestones.

Other deposits of some note are those of the Upper Miocene calcareous clays of Sicily, as at Girgenti, where it is associated with sulphur and gypsum.

Uses.—Celestite is utilized for the manufacture of strontium hydrate, which is used in refining beet sugar. For this purpose it is better adapted than lime, which was formerly used. Celestite containing over 90 per cent. of strontium sulphate has been mined abundantly in England, and has been largely exported to Germany to be used in this way. Celestite is also utilized in the manufacture of strontium nitrate, which is used in pyrotechny to produce red fire.

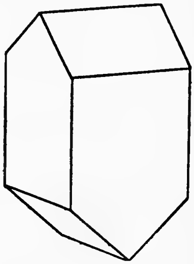
FIG. 240.—Epsomite.

Epsomite, or Epsom salt ($MgSO_4 . 7H_2O$) is orthorhombic (fig. 240). It occurs naturally at various localities and is deposited from spring waters, as at Epsom in Surrey, whence its name. The Epsom salt of commerce, however, is obtained from kieserite ($MgSO_4 . H_2O$) which occurs in extensive beds at Stassfurt (see p. 421), and from magnesite and dolomite.

Gypsum (L. *gypsum*, from Gr. *gypsos*, a name applied by the Greeks to both the mineral gypsum and the product obtained by igniting the mineral. The clear and well-crystallized variety with good cleavage is known as *selenite*. The massive granular variety is known as *alabaster*, and the fibrous variety *satin-spar*).

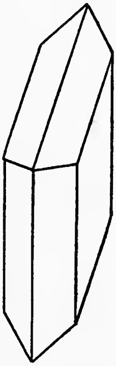
FIG. 241.—Gypsum.

General.—Monoclinic. Frequently found as good tabular crystals, the pinakoid parallel to the plane of symmetry being predominant (fig. 241). Often twinned. Also massive granular (alabaster) and finely fibrous (satin-spar). Cleavage good, parallel to the plane of symmetry. Hardness, 2. Specific gravity, 2·3.

Optical.—Usually colourless or whitish. Lustre vitreous or pearly when well crystallized, but often dull and earthy when compact. Refractive index low, $\gamma = 1{\cdot}53$. Birefringence low, $\gamma - \alpha = 0{\cdot}010$. Optical sign, positive. Optic axial plane parallel to good cleavage. Microfragments have mostly the form of rhomboidal plates, the angles of which are about 66° and 114°, and show extinction angles of about 13° and 37°. Compensation with quartz wedge along the short diagonal.

Chemical and blowpipe.—Hydrated sulphate of calcium ($CaSO_4 . 2H_2O$). Fusibility, about 2½, and whitens on fusion. Reddish-yellow flame coloration due to calcium. Gives off water in closed tube. Soluble in dilute hydrochloric acid and slightly soluble in water. Gypsum re-crystallizes from solution in the form of characteristic radiating groups of acicular crystals, which are readily identified under the microscope (fig. 242). Calcium sulphate occurs in solution in sea water, and crystallizes out before the sodium chloride when a drop is evaporated slowly on a microscope slide.

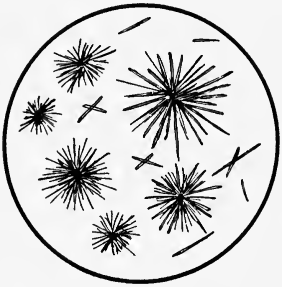

FIG. 242.—Radiating groups of calcium sulphate crystals.

Occurrence and distribution.—Gypsum is a widely distributed mineral, and is found in stratified rocks at all geological horizons. It occurs frequently in the form of colourless well-developed crystals and white concretionary masses in clays and shales. It occurs also as irregular masses in limestones where the latter have been acted on by sulphuric acid and sulphates arising from the decomposition of sulphides. It is particularly abundant in the form of thick beds in Permian and Triassic strata, frequently associated with rock-salt and marl beds ; and in this case it has usually been deposited from solution in lake waters, though in some instances it has arisen from the hydration of anhydrite, the anhydrous form of calcium sulphate, which also occurs in the form of beds among Permian and Triassic strata.

The chief producers of gypsum are the United States and France ; but large amounts are obtained also in Canada, Great Britain, India and other countries. In the United States it is mined at numerous localities and at various geological horizons, including Palæozoic, Mesozoic, and Tertiary strata. In Canada it is obtained chiefly from the eastern provinces, where it occurs abundantly in the Lower Carboniferous strata of Nova Scotia, New Brunswick, and Quebec. In France it has long been obtained from the Tertiary strata of the Paris basin. In India beds of gypsum are found among the pre-Cambrian strata of the Salt Range in Punjab.

In the British Isles, gypsum is found most abundantly in the Keuper

(Triassic) strata, associated with rock salt and marl beds. It is found in these strata in the form of beds, nodules, and lenticular masses. The beds are of variable thickness, but in many places they reach a thickness of 20 feet or more. The Keuper deposits are mined chiefly in Cumberland, Nottinghamshire, and Staffordshire. In Westmorland and Yorkshire Permian deposits are worked, and a considerable amount is obtained from the Purbeck (Jurassic) strata near Battle in Sussex.

Uses.—Gypsum is used in various ways. It has long been used by agriculturists and horticulturists as a fertilizer. More important is its use for plaster and cement making. When ignited at a temperature of about 350° C., gypsum loses water and becomes transformed into a white substance, the composition of which corresponds to the formula $2CaSO_4 . H_2O$. In this condition it is capable of absorbing water and setting, and is used extensively as a plaster under the name of "plaster of Paris," a name given to it because of the fact that it was originally produced by calcining the gypsum of Montmartre, near Paris.

Gypsum is used to some extent as a constituent of Portland cement, in which it exercises a retarding effect on the setting process. Certain cements consist almost entirely of plaster of Paris, *e.g.* Keene's, Martin's, and Parian cements. In the form of *terra alba* gypsum is used in the paint trade (see p. 399), and as a filler for paper and cotton. The massive granular variety of gypsum is used to a considerable extent, in the form of slabs, for internal decoration in buildings. Moreover, the satin-spar variety finds some use as an ornamental stone (see p. 314). In the brewing trade, salinity is imparted to alkaline waters by allowing the water to pass through a cistern containing fragments of gypsum. The selenite variety of gypsum is used for certain optical purposes, as in making gypsum plates (see p. 61).

Kieserite ($MgSO_4 . H_2O$) is monoclinic, whitish or yellowish in colour, and vitreous in lustre. Hardness, about 3½. Specific gravity, about 2·55. Fusibility, about 2½. It is soluble in water and gives a heavy precipitate with barium chloride. If to a dilute aqueous solution containing hydrochloric acid, ammonium hydrate is added, no precipitate is obtained; but by a further addition of sodium phosphate a precipitate of ammonium magnesium phosphate is obtained. Kieserite occurs in association with the potassium salts of Stassfurt and other localities (see p. 402), and is used in the manufacture of Epsom salt.

Melanterite or copperas ($FeSO_4 . 7H_2O$) occurs naturally as an efflorescence on decomposing pyrites, especially on marcasite; but the copperas of commerce is made by decomposing iron-pyrites in a stream of water, or by exposing it to the atmosphere. Copperas is used in the manufacture of ink, and as a mordant in dyeing operations.

Mirabilite or Glauber's salt ($Na_2SO_4 . 10H_2O$) occurs naturally as a surface efflorescence and in desert salt-pans. It sometimes crystallizes out from salt water in a very pure condition as a result of a lowering of the temperature. The mirabilite formed in the Great Salt Lake of Utah during winter time owes its deposition to this cause. Commercial supplies for use in glass-manufacture, paper-making, and medicine are for the most part manufactured from other sodium salts.

SULPHUR.

The minerals of importance as a source of sulphur are native sulphur and pyrite.

Uses.—Sulphur is used in a variety of ways, notably in the manufacture of paper. It is also used in the manufacture of matches, gunpowder, and rubber. Pyrite is used extensively in many countries for the manufacture of sulphuric acid.

Sulphur.—*General.*—Crystals orthorhombic, usually with the pyramid faces well developed (figs. 243, 244). Usually found massive as an impregnation in limestone. Occurs also as small crystals lining the cavities of volcanic rocks in which it has formed by sublimation. Cleavage imperfect. Fracture conchoidal. Hardness, about 2. Specific gravity, about 2.

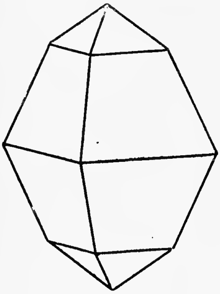
FIG. 243.—Sulphur.

Optical.—Colour, yellow. Streak, pale yellow. Lustre, resinous. Microfragments of irregular shape and transparent. Refractive index extremely high ($\gamma = 2{\cdot}24$). Birefringence extremely high ($\gamma - \alpha = 0{\cdot}29$). Optical sign, positive.

Chemical and blowpipe.—Native sulphur (S). Fusibility, 1. Fuses with ease and burns with a blue flame, emitting the pungent smell of sulphur dioxide. Insoluble in acids, but soluble in carbon disulphide.

Occurrence, distribution and origin of native sulphur.—Almost the whole of the world's supply of sulphur is obtained from Sicily, and from Louisiana and Texas in the United States, in both of which countries native sulphur occurs abundantly.

ITALY.—The sulphur deposits of Sicily are found chiefly along a line running between Catania on the east and Girgenti on the west, where they occur as impregnations in limestone beds of Upper Miocene (Pontian) age. These limestone beds are interbedded with black bituminous shales. There is an abundance of petroleum, asphalt, and natural gas in some of the workings. Barite, celestite, and gypsum are associated with the sulphur. Certain of the beds consist largely of gypsum; and at the base of the sulphur-bearing series there are beds of magnesian limestone and diatomaceous earth. The amount of sulphur in the impregnated limestone is very variable; in some places the sulphur is practically pure; in others the limestone carries little or no sulphur; and there are all intermediate grades. The rock as mined ranges from 8 to 40 per cent. of sulphur, and contains on the average about 25 per cent.

FIG. 244.—Sulphur, Girgenti, Sicily. (× ½). B.M.

The sulphur in the Sicilian deposits appears to have been derived from gypsum, by the reducing action of organic matter or hydrocarbons. The gypsum beds are clearly similar in origin to those known in other parts of the world, such as those of the Permian and Trias in Germany and England; and they were presumably formed by the drying up of lakes under arid conditions of climate. The gypsum was subsequently in part reduced to calcium sulphide, which by interaction with carbonated waters formed limestone and sulphur. Doubtless some of the limestone, especially the magnesium limestone, was deposited originally in the same way as the gypsum; but some of it must have arisen from the alteration of the gypsum.

UNITED STATES.—Extensive deposits of sulphur associated with limestone, similar in type to the Sicilian deposits, occur near the town of

Sulphur in Louisiana, and near Freeport in Texas. The sulphur-bearing limestone beds are several hundred feet thick and contain about 70 per cent. of sulphur. Below the sulphur beds are beds of gypsum, and above them are beds of clay, sand, and gravel totalling several hundred feet in thickness. To obtain the sulphur, holes about a foot in diameter are bored into the deposit, and the sulphur is melted by injecting superheated steam, after which it is pumped to the surface and cooled in large bins.

Elsewhere in the United States, and in Japan, as well as many other countries, sulphur occurs as a product of volcanic activity, partly as a product of sublimation in the form of small crystals in the cavities of the rocks, and partly as richer fumarole deposits where volcanic gases and vapours are escaping; but these types of deposit are of no economic importance, in comparison with the limestone type described above.

Pyrite (Gr. *pyr*, fire, in allusion to the fact that it emits sparks when struck. Known also as pyrites and iron-pyrites).

General.—Cubic. Often shows crystal form, the cube (with striated faces) and pyritohedron being the commoner forms (figs. 245, 246); less often octahedra are found. Commonly found massive. Fracture, conchoidal or uneven. Hardness, about 6½. Specific gravity, about 5.

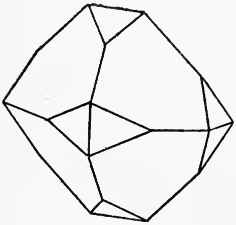

FIG. 245.—Pyrite.

Optical.—Colour, brassy yellow. Streak, greenish- or brownish-black. Lustre, metallic. Microfragments opaque, but in reflected light show the characteristic brassy yellow colour by which they may be distinguished from gold.

Chemical and blowpipe.—Iron disulphide (FeS_2), with about 53 per cent. of sulphur. Fusibility 3, and burns with a blue flame giving off sulphur dioxide. In a closed tube and in reducing flame on charcoal, becomes black and highly magnetic. Gives off sulphur in a closed tube. In open tube yields the pungent smell of sulphur dioxide. Not dissolved by hydrochloric acid, but decomposed by nitric acid with the separation of sulphur.

Occurrence and distribution of pyrite.—Pyrite occurs frequently in all varieties of rocks, chiefly in a disseminated condition, and is then of no value. It also occurs in masses of large size, forming lenses in schists, or contact ore-bodies, and it is these types of occurrence that are usually mined. Large bodies of pyrite frequently contain a small percentage of chalcopyrite, and are often worked for copper as well as for sulphur.

The chief producers of pyrite are Spain and Portugal, France, Norway, Germany, United States, Canada, Italy, Austria and Hungary; but considerable amounts are mined in many other countries.

Spain and Portugal.—One of the most important sources of pyrite is the region in the south of Spain and Portugal including Huelva province. The famous Rio Tinto deposit is of contact origin, and occurs as a huge lenticular mass at the junction of a porphyry with slates of Carboniferous age. In its upper portions, the pyrite carried an appreciable quantity of chalcopyrite, as well as galena and zinc-blende, and a vast amount of copper has been obtained from this deposit (see p. 180). The deeper portions of the deposit consist of almost pure pyrite. Lenticular deposits of pyrites occur in various other parts of this region, notably at Tharsis and San Domingo, under closely similar conditions.

Fig. 246.—Striated pyrite, Val di Brosso, Piedmont. (× ½). B.M.

France.—Important pyrite deposits occur at Sain-Bel (department of Rhône) in the Central Plateau region. The pyrite occurs as veins and lenticles in chlorite- and hornblende-schists, and is associated with quartz and barite.

Italy.—Notable among the Italian deposits are those of Gavorrano and other localities in the province of Grosseto, Tuscany, at the contact of a Tertiary intrusion of granite with Rhætic limestone and shale. The pyrite of the Gavorrano deposit is fairly pure, containing up to 48 per cent. of sulphur, and is free from arsenic.

Norway.—Pyrite deposits in schists associated with gabbro intrusions are mined in many parts of Norway, notably at Sulitjelma, Foldal, Orkla, and Röros; the ore mined carries from 1 to 3 per cent. of copper and 42 to 49 per cent. of sulphur.

United States.—Virginia, California, and New York are chiefly responsible for the output in the United States. In both Virginia and New York the pyrite is found as lenticular deposits in schists. A little chalcopyrite occurs in some of the Virginian mines. The New York pyrite occurs mixed with quartz and various silicates, and is a low-grade deposit.

Canada.—At the Helen mine in the Michipicoten range, near Lake Superior, lenticular deposits of pyrite occur in and near a body of hæmatite iron-ore. In Quebec, at the Eustis mine, large lenses of pyrite yield ore carrying from 40 to 45 per cent. of sulphur ; the ore contains a little chalcopyrite, but the amount of copper is usually less than 2 per cent. At Weedon, also in Quebec, pyrite containing 5 per cent. of copper is mined.

TALC (see p. 413).

THORIUM MINERALS.

The minerals of chief importance as a source of thoria are monazite, thorite, and thorianite. Thorianite contains from 70 to 90 per cent. of thoria (ThO_2) and thorite from 50 to 70 per cent. Either of these two minerals would probably be preferable to monazite as a source of thoria if they were available in quantities sufficient for commercial use ; but they are both scarce in comparison with monazite. Monazite is essentially a phosphate of the cerium metals, and usually contains only a small amount (3 to 10 per cent.) of thoria ; but on account of its comparative abundance it is the chief source of thoria, which is the principal ingredient of the mantles used in incandescent gas-lighting.

Monazite (Gr. *monazein*, to be solitary ; so named on account of its supposed rarity).

General.—Monoclinic. Seldom shows good crystal form. Usually found as irregular fragments or well-rounded sand grains (fig. 247). Basal parting. Fracture, uneven. Hardness, about 5½. Specific gravity, usually about 5·2, but somewhat variable.

Optical.—Colour in large fragments obtained from pegmatites is usually reddish or brownish. In the form of sand it is typically of a golden-yellow colour, but white and smoky-black varieties of monazite sand are sometimes found. Lustre, resinous. Refractive index high, $\alpha = 1{\cdot}796$. Birefringence high, $\gamma - \alpha = 0{\cdot}045$. Optical sign, positive. The acute bisectrix is almost normal to the basal parting, and the axial angle small.

Chemical and blowpipe.—A phosphate of the cerium metals

$$(Ce(La, Di)PO_4),$$

but contains variable amounts of other ingredients, notably thorium. The amount of thorium usually ranges from 3 to 10 per cent., but is sometimes greater, and in rare cases may reach 30 per cent. Some varieties contain uranium. Infusible. Flame-coloration bluish-green, due to phosphate, when moistened with sulphuric acid. Reacts readily for a phosphate with ammonium molybdate after fusion with sodium carbonate. Slowly but completely decomposed by strong sulphuric acid.

FIG. 247.—Monazite grains. (× 20).

Occurrence and distribution.—Monazite, as its name implies, was formerly regarded as a very rare mineral; but it is now known to be of fairly common occurrence. It is found in pegmatite veins at many localities, associated with quartz and felspar. In these veins it usually occurs as fairly large crystals and fragments of a brownish colour. It is also disseminated through gneisses in the form of small yellow grains, and under these conditions is less readily observed *in situ.* When these gneisses are disintegrated by weathering, however, the monazite grains are liberated, and become concentrated with other heavy minerals in stream and river beds, and along sea beaches. It is from these monazite sands that the monazite of commerce is chiefly obtained. The chief sources of monazite are Brazil and Travancore. During recent years, Travancore has taken the lead in production.

Monazite occurs abundantly in sands on the coast of Brazil, in the States of Bahia and Espirito Santo. On this coast there also occur bluffs of Cretaceous sedimentary strata containing monazite. These sedimentary strata suffer disintegration by marine denudation, and yield sand from which monazite concentrates are produced by tidal action on the coast. The monazite of the Brazilian Cretaceous sediments was derived from the gneisses, through which the monazite has been proved to be disseminated. The sands along the river courses of the interior are also monazitic. Brazilian monazite sand as marketed in Brazil is stated to contain about 92 per cent. of monazite and 6·2 to 6·4 per cent. of thoria.

Another important locality for monazite is the coast of Travancore in the south of India. Along this coast, between Muttum and Colachel, monazite occurs abundantly in a naturally-concentrated form, associated with ilmenite and zircon. An interesting parallel to the monazite-bearing Cretaceous sediments of Brazil is provided by the monazite-bearing Warkilli beds of Tertiary age on the Travancore coast. Monazite has been proved to occur disseminated through the garnetiferous biotite-gneisses of Travancore, and it occurs also in the pegmatites that traverse these gneisses. The monazite of the Travancore beach sands is much richer than that of Brazil, and contains from 9 to 10 per cent. of thoria.

In Ceylon, monazite is a constituent of certain of the gneisses, and is found also in the alluvial deposits. The beach sands of the west coast of Ceylon contain monazite; and in some places, notably near Bentota and near Kudremalai, there are beach concentrates, the monazite of which, like that of Travancore, contains about 10 per cent. of thoria.

Monazite has also been obtained from the gneisses and stream deposits of North Carolina, U.S.A. The mineral is known to be fairly widely distributed in Africa. It occurs also in considerable amounts in Australia and the Federated Malay States. Monazite indeed has a world-wide distribution in sands, in which it is usually associated with the heavy minerals ilmenite, garnet, zircon, and rutile. From these minerals it can readily be separated in a practically pure condition by using an electromagnet. Ilmenite and garnet are more magnetic than monazite and are readily lifted in a weak field, leaving monazite, zircon, and rutile behind. From this residue, monazite can be lifted in a stronger field. The amount of monazite present in a sand can be approximately estimated in this way. If the sand is not already concentrated, the heavy minerals can readily be concentrated by panning as described on p. 101. By this simple procedure the presence of monazite in a sand can be effectively demonstrated and its amount estimated even when it is present in very small quantities. The same methods are applied on a large scale to the exploitation of monazite deposits.

Thorite (including *orangite*).

General.—Tetragonal. Occurs rarely as crystals in the form of tetragonal prisms capped by pyramids, like those of zircon. Usually found as irregular and rounded fragments. Fracture, uneven. Hardness, about 4½. Specific gravity very variable, ranging from about 4·4 to 5·4, according to the state of hydration.

Optical.—Usually yellow or brown in colour. Lustre, somewhat resinous. Refractive index high. Although highly birefringent and optically positive when fresh, microfragments and sections of thorite usually show a cryptocrystalline texture, and are generally isotropic in part, presumably due to hydration. Anhydrous thorite is very unstable, and most thorites are found in an altered or hydrated condition.

Chemical and blowpipe.—Thorium silicate ($ThO_2 . SiO_2$) when fresh and pure, but usually contains water, the amount varying up to 10 per cent. or more. The thorium percentage varies from about 50 to 70. A little phosphate is usually present, and on this account the mineral is liable to be mistaken for monazite if too much reliance is placed on chemical tests. Small amounts of uranium, iron, lead and lime also present. Infusible. Decomposed by hydrochloric acid, yielding gelatinous silica.

Occurrence and distribution.—A brownish black variety of thorite was formerly obtained at various localities near Arendal, and in other areas in the south of Norway, where it occurs in pegmatites associated with intrusions of granite and syenite. It is also found as scattered grains in the syenites themselves.

Previous to the discovery of monazite in the coast sands of Brazil, Norwegian thorite was in considerable demand at high prices as a source of thoria; but the exploitation of the Brazilian deposits cheapened thorium compounds and made it unprofitable to continue the mining of Norwegian thorite.

Thorite occurs in some abundance in the gravels of the Sabaragamuwa province of Ceylon, where it is associated with monazite, zircon, thorianite, and various other minerals. A few parcels of the mineral have been obtained from these gravels; but hitherto no deposit has been found that can be considered comparable to deposits of monazite sand as a commercial source of thoria.

Thorianite.—*General.*—Cubic. Usually found in the form of cube-shaped crystals, more or less rounded, though the edges are quite sharp when crystals are fresh. Interpenetrant twins, like those of fluorite, are not uncommon. Fracture, uneven. Hardness, about 6. Specific gravity, about 9·5 when fresh.

Optical.—Colour, black or brownish black. Streak, dark brown. Lustre, submetallic or dull. Microfragments translucent, and differ as a rule in this respect from those of uraninite. Isotropic.

Chemical and blowpipe.—Chiefly thorium oxide, with some uranium oxide, a small amount of lead, and various other ingredients. Thoria percentage usually about 75, uranium oxide 15, and lead oxide $2\frac{1}{2}$, though some varieties contain about 30 per cent. of uranium oxide. Infusible. Yields good uranium reactions. Decomposed by hot sulphuric acid.

Occurrence and distribution.—Thorianite occurs in Ceylon, chiefly in the gravels of Sabaragamuwa province. It has been found as a constituent of pegmatite veins at various Ceylon localities, notably at Gampola and Hinidum Pattu; and it is reported to occur in a mica-spinel rock in Uva. It is probably from pegmatites that the thorianite of the Ceylon gravels has been derived. A small amount of thorianite has been obtained from the gravels for commercial use and has been eagerly bought at high prices, but no deposits have yet been found from which a steady supply could be obtained.

Thorianite of much the same composition as the Ceylon mineral has been found in small quantities in the form of small black cubes associated with monazite in Transbaikal, Siberia. It is reported to occur also in the Betroka district of south-eastern Madagascar as large crystals containing 93 per cent. of thoria.

TRONA (see p. 352).

URANIUM MINERALS.

Uranium compounds were formerly used to only a small extent, as a means of colouring glass. The discovery of radium gave a wider scope for the use of uranium minerals. Radium is one of the disintegration products of uranium, and is present in all uranium minerals. It is as a source of radium that these minerals are now chiefly sought for. The number of uranium minerals is fairly large. but only a few occur abundantly enough to make their mining as a source of radium practicable. The chief uranium minerals are uraninite (pitchblende), carnotite autunite, torbernite, and samarskite. (For thorianite see above.)

Uraninite = Pitchblende (the name pitchblende refers to the pitch-like lustre of the mineral).

General.—Cubic, but rarely shows any crystalline form, though it occurs both in the form of octahedra and cubes. Usually massive in concretionary or botryoidal form and often very impure. Fracture, uneven. Hardness, about 5½. Specific gravity from 9 to 9·7 when pure, but often much lower than this owing to admixture with impurity.

Optical.—Colour black. Lustre submetallic or dull. Streak black or brownish black. Microfragments usually opaque, but sometimes feebly translucent, in which case they are brownish and act isotropically between crossed nicols.

Chemical and blowpipe.—Oxide of uranium, of doubtful formula; but it consists essentially of uranyl uranate ($UO \cdot U_2O_3$), with some thorium and lead, and small amounts of other constituents, including radium. Infusible. Uranium bead reactions. Decomposed by hot sulphuric and nitric acids.

Occurrence and distribution.—The chief sources of uraninite are the occurrences in the Erzgebirge, in the border region of Bohemia and Saxony. The mineral also occurs in Cornwall, England; in Gilpin county, Colorado, U.S.A.; in India; and in Tanganyika Territory.

In the Erzgebirge, notably at Joachimstahl, uraninite occurs as a constituent of cobalt-silver veins, in a region of granitic intrusions. These veins contain various cobalt, nickel, bismuth, and silver minerals, the more notable constituents being smaltite, chloanthite, niccolite, bismuth, pyrite, chalcopyrite, and zinc-blende. The rich silver sulphides of these veins are regarded as products of secondary enrichment. The uraninite occurs as concretionary or botryoidal masses, intimately associated with pyrite and chalcopyrite.

In Cornwall, again, in a region of granitic intrusions, uraninite occurs as a vein mineral associated with ore minerals of copper, arsenic, lead, silver, nickel, and cobalt. These veins are younger than the main tin and copper veins of the district, since they cut across the latter; but they are supposed to have been deposited from solutions genetically connected with the granite intrusions.

At Quartz Hill, Gilpin Co., Colorado, uraninite occurs associated with metallic sulphides in veins that traverse intrusive granites. In these veins it is intimately associated with pyrite and chalcopyrite, and appears to have been deposited contemporaneously with these minerals.

It is thus noteworthy that the economically important deposits of uraninite are those intimately bound up with various metallic sulphides.

Other types of occurrence are known, as those of North Carolina, U.S.A., in which uraninite occurs as a constituent of granite-pegmatites, but these are not economically of much importance. Uraninite is obtained as a by-product of mica mining, but not in large amounts, in the Gaya district of Behar, India, and in the Uluguru mountains of Tanganyika Territory, at both of which localities it occurs in pegmatite veins embedded in muscovite. The uraninite of Tanganyika Territory is partly, and some instances wholly, altered to rutherfordine, a yellow uranium carbonate. In Ceylon, uraninite is sparingly associated with graphite.

Carnotite (named after A. Carnot).

General.—Orthorhombic. Occurs in the form of a yellow crystalline powder, occupying the interstices of friable sandstones in Colorado, and infilling cavities in an impure massive ilmenite near Olary in South Australia.

Optical.—Canary-yellow in colour. When highly magnified, especially in the case of the South Australian material, the powder is seen to consist of platy rhomboidal crystals which show symmetrical extinction and a centric biaxial figure. The angles of these plates are about 78° and 102°, and the plane of the optic axes bisects the obtuse angles. Optical sign, negative.

Chemical and blowpipe.—A hydrated vanadate of uranium and potassium, with sodium replacing potassium. Formula doubtful, but approximately $K_2O \cdot V_2O_4 \cdot 2U_2O_3 \cdot 3H_2O$. (A yellow powdery material indistinguishable to the eye from carnotite, but consisting of hydrated vanadate of uranium and calcium, has been described under the name of tyuyamunite, from its occurrence at Tyuya-Muyun in Ferghana, Russian Turkestan. Lime is sometimes present in carnotite, due presumably to admixture, isomorphously or otherwise, with tyuyamunite). Gives off water in a closed tube, and dissolves readily in nitric acid. Yields a good uranium microcosmic bead, and a potassium flame reaction.

Occurrence and distribution.—Carnotite occurs as a constituent of certain Mesozoic sandstones in various parts of Colorado, U.S.A., notably in the Paradox Valley, Montrose County. The material shipped carries from 2 to 3 per cent. of uranium oxide (U_3O_8), and 3 to 4 per cent. of vanadic oxide (V_2O_5). A small amount of richer material containing from 15 to 20 per cent. of uranium oxide is found in pockets in the sandstone.

Carnotite occurs near Olary in South Australia, in the form of a yellow crystalline powder in the cracks and cavities of a mass of impure ilmenite traversing a biotite-gneiss, in which there also occur intrusions of granite and diorite. The carnotite is associated in the ilmenite with vanadiferous rutile and biotite.

Another locality for carnotite is Mount Pisgah, near Mauch Chunk, Pennsylvania, where it occurs in a conglomerate of Pennsylvanian (Carboniferous) age. This conglomerate has in large part a quartzitic matrix; but in some parts the matrix is calcitic; and it is chiefly as a replacement of the calcitic portions by material dissolved in circulating surface waters that the carnotite has been deposited.

Autunite (from Autun in central France, where the mineral occurs; also known as lime-uranite).

General.—Orthorhombic, but approximates to the tetragonal in symmetry. Found in platy and scaly crystals resembling torbernite in form. Good basal cleavage. Hardness, about 2½. Specific gravity, about 3·1.

Optical.—Colour, pale yellow. Lustre, pearly. Refractive index, about 1·62. Microfragments are basal flakes, which show only a feeble birefringence between crossed nicols, and yield a biaxial figure with only a small axial angle.

Chemical and blowpipe.—Hydrated phosphate of calcium and uranium, $Ca(UO_2)_2(PO_4)_2 . 8H_2O$. Fusibility, about 3. Yields water in closed tube. Uranium bead reactions. Decomposed by hydrochloric acid and gives the characteristic radiating groups of gypsum when allowed to stand for some time after adding a little dilute sulphuric acid. The nitric acid solution gives a yellow precipitate with ammonium molybdate.

Occurrence and distribution.—Autunite occurs abundantly in the Guarda district of northern Portugal. Granite is the dominant rock of this district and is intrusive in Cambrian schists. Vein deposits carrying lead, tin, copper, and tungsten ores traverse the granite. Pegmatite veins carrying autunite traverse both the granite and schist. The vein-stuff is much decomposed near the surface where the autunite occurs, and contains much argillaceous matter. The crude material is considered of good quality if it contains 2 per cent. of uranium oxide.

Autunite has also been worked to some extent at Mount Painter in South Australia.

Torbernite (named after Torbern Bergman, a chemist; also known as copper-uranite).

General.—Tetragonal. Usually in the form of thin tabular crystals or mica-like plates resembling in form those of autunite. Good basal cleavage. Hardness, about 2½. Specific gravity, about 3·5.

Optical.—Colour, bright green, Lustre, pearly. Refractive index, about 1·16. Microfragments are basal flakes, which act isotropically between crossed nicols, but show a uniaxial figure in convergent polarized light.

Chemical and blowpipe.—Hydrated phosphate of copper and uranium $Cu(UO_2)_2(PO_4)_2 \cdot 8H_2O$. Fusibility, about 3, yielding a dark coloured globule and a green flame-coloration. Gives off water in a closed tube. Uranium bead reactions. Soluble in nitric acid, and the solution gives a yellow precipitate when treated with ammonium molybdate.

Occurrence and distribution.—Torbernite appears to be less abundantly distributed than autunite, but it is frequently associated with this mineral, and also with uraninite.

Samarskite (named after Samarski, a Russian).

General.—Orthorhombic, but usually massive. Fracture, conchoidal. Hardness, about 5½. Specific gravity, about 5·6.

Optical.—Colour, velvet-black or brownish black. Lustre, pitchy or submetallic. Streak, dark reddish-brown. Refractive index, high. Microfragments irregular in shape, translucent and reddish brown in colour, and usually isotropic.

Chemical and blowpipe.—A niobate and tantalate of yttrium, uranium, cerium, and iron, with from 12 to 20 per cent. of uranium oxide and a variable amount of lead. Fusibility, about 5. Good uranium bead with microcosmic salt. Decrepitates when heated in a closed tube. Decomposed by hydrochloric acid when finely powdered, and the solution yields a blue colour due to niobium when reduced with metallic tin.

Occurrence and distribution.—Samarskite occurs in pegmatite veins, as in the Ilmen mountains near Miask in the Urals, but not in sufficient abundance to be worth mining for its own sake. One of the few places where it has been obtained in large quantities is the Sankara mine in Nellore district, Madras, India, where it is found in mica-pegmatite veins. Masses weighing as much as 200 lb. have been obtained at this locality, as a by-product in mica mining, and sold as a radioactive mineral.

Other mica-pegmatites in which this mineral is found are those of Canada; and also those of Morogoro, in the Uluguru mountains of Tanganyika Territory. The samarskite of Morogoro has been found to contain an unusually high percentage of lead, equivalent to about 8 per cent. of lead oxide (PbO), and has been called "plumboniobite."

YTTRIUM MINERALS.

Yttrium is an important constituent of numerous minerals, the more notable and commoner of which are *gadolinite*, *fergusonite* (niobate and tantalate of yttrium, cerium, and uranium), *xenotime* (yttrium phosphate) and *samarskite*. Samarskite has just been dealt with as a uranium mineral (see previous page).

There appears to be now little or no demand for minerals in which yttrium is unaccompanied by other and more valuable constituents, such as thorium, uranium and radium. Of the above-mentioned yttrium minerals, only gadolinite has been produced in any considerable quantity for its yttrium alone, in connection with the manufacture of the Nernst incandescent lamp, which has been superseded in recent years by cheaper filament lamps of the tungsten and tantalum type.

Gadolinite (named after J. Gadolin, the Finnish chemist who discovered the rare-earth yttria in the mineral, and who by this discovery inaugurated the study of rare-earths).

General.—Monoclinic, but usually found in the form of rough lumps. No cleavage. Brittle, sometimes with a conchoidal fracture. Hardness, about 6½. Specific gravity variable, but about 4·3.

Optical.—Colour, black or greenish black when fresh. Opaque in the lump, but microfragments are transparent and green. Streak, greenish grey. Lustre, vitreous. Optical behaviour between crossed nicols variable; may be strongly birefringent and positive, or weakly birefringent, or even isotropic.

Chemical and blowpipe.—Silicate of yttrium, beryllium, and iron ($FeO \cdot 2BeO \cdot Y_2O_3 \cdot 2SiO_2$). Infusible or fusible with difficulty, but may swell and crack when heated in a blowpipe flame, and turns brown. Little or no water in closed tube. Decomposed by hydrochloric acid and yields a gelatinous residue.

Occurrence and distribution.—Gadolinite is a constituent of pegmatites occurring at Ytterby and near Fahlun in Sweden. It is to be obtained also from the felspar quarries of Sætersdalen and Hitterö and other localities in south-east Norway. The chief locality, however, is Barringer Hill near Bluffton in Llano Co., Texas, where most of the material used for commercial purposes has been obtained. At this locality gadolinite has been got in large masses, some of which have weighed nearly 2 cwt., associated with an abundance of fergusonite and other rare-earth minerals. The Barringer Hill gadolinite and fergusonite, both of which have been extracted for use as sources of yttria, occur in a vein of pegmatite traversing granite.

Gadolinite has also been obtained in considerable quantity at Cooglegong in Western Australia, where it occurs as black masses associated with fergusonite in pegmatite and surface gravels.

ZIRCONIUM MINERALS.

The chief zirconium minerals are baddeleyite (ZrO_2) and zircon ($ZrO_2 . SiO_2$). Zircon was formerly the chief source of zirconia, but the discovery of baddeleyite in large pieces and in considerable quantity in Brazil has naturally caused this mineral, which consists of fairly pure zirconia, to supersede zircon as a commercial source of zirconia.

Zirconia is one of the most highly refractory substances known. It is now being used for the manufacture of refractory bricks, muffles, and dishes, for which purposes it is stated to be much more efficient and in certain cases more economical than ordinary refractory materials (see p. 409). It is also used to a small extent in the manufacture of a certain variety of silica ware known by the name "siloxide"; and it has been found to be a useful ingredient of certain enamels when used in conjunction with cryolite. Zirconia was formerly used in the manufacture of mantles for incandescent gas-lighting, but for this purpose thoria is now used and is much more effective.

Zirconium finds some use in metallurgy as an alloy with iron and other metals. A small quantity of zirconium is said to improve the quality of brass.

Baddeleyite (named after J. Baddeley who found the mineral in Ceylon).

General.—Monoclinic, but generally found in the form of irregular masses. Good basal cleavage. Hardness, 6½. Specific gravity, about 5·7, but varies from 5·5 to 6.

Optical.—Colour, usually black or brownish black. Lustre, vitreous. Refractive index, high. Microfragments yellowish or brownish, and pleochroic (yellow to reddish brown). Optical sign, negative. Shows lamellar twinning.

Chemical and blowpipe.—Baddeleyite consists of zirconium dioxide (ZrO_2) when pure, but the mineral frequently contains iron oxide and silicate impurity. Fusibility, 6; almost infusible. When fused with sodium carbonate and the fused mass dissolved in dilute hydrochloric acid, the solution imparts an orange colour to turmeric paper, indicating the presence of zirconium.

Occurrence and distribution.—Baddeleyite was first found in Ceylon, where it occurs as crystals in the gem gravels, but it is very rare. It occurs in large quantities in Brazil, where it is found as an accessory constituent of a basic magnetite-pyroxene rock known as jacupirangite, from its occurrence at Jacupiranga in the State of São Paulo. It is associated in this rock with apatite, perovskite (calcium titanate), ilmenite, titanite, and zircon. It is found in the form of large water-worn pebbles and boulders in the gravels of the Caldas district in the States of São Paulo and Minas Geraes, and it is from these gravels that commercial supplies are obtained.

The baddeleyite of the Caldas gravels is ot variable quality. Some of it is in the condition of pebbles and vitreous fragments containing over 90 per cent. of zirconia (ZrO_2). An analysis of a sample of this material gave 94·1 per cent. of zirconia, 1 per cent. of titanium dioxide, 3·2 per cent. of ferric oxide, and 2·4 per cent. of silica. It is stated that material of this quality can be readily treated to yield a product containing 98 per cent. of zirconia. Much of the Caldas zirconia gravel, however, is far less pure, and contains a considerable amount of zircon, in consequence of which even the dressed material may contain not more than 80 per cent. of zirconia. In some places the zirconia gravel has a matrix of red earth or clay from which it can be separated readily after exposure to the weather.

Zircon.—An account of the properties of this mineral, and the occurrence of gem varieties, is given on p. 321. As already pointed out, common zircon is a mineral of widespread occurrence. It is found sparingly in all igneous rocks, and the detrital sediments derived from them. It is especially abundant in some coarse-grained pegmatites and nepheline-syenites.

One of the best-known deposits of this type is that at Zirconia in Henderson County, North Carolina, U.S.A., where there is a vein of kaolinized zircon-bearing pegmatite 100 feet wide, extending over a length of 1½ miles. The zircon crystals are up to two inches or so in length, and have been obtained in large quantities from this vein.

Zircon also occurs in some abundance associated with rutile near Gouldin in the Hanover county portion of the Virginia rutile area referred to on p. 248. In this district masses of zircon up to one or two pounds in weight occur associated with large masses of rutile, in pegmatite veins that traverse gneisses. Zircon-bearing pegmatites traversing biotite-gneisses occur also in Amelia County, Virginia.

It is noteworthy that zircon is often very abundant in the naturally-concentrated portions of stream and beach deposits. It occurs abundantly in the alluvial gem gravels of Ceylon; and in the monazite concentrates of Brazil and India. The non-magnetic portion of the monazite sand of the Travancore beaches in India, consists almost entirely of zircon; and the stream and beach deposits of many other localities contain the mineral in abundance.

CHAPTER XII

DETERMINATIVE TABLES

It is useful for determinative purposes to have a reference list in which minerals are arranged according to those of their characteristics that are most readily determined. In such a list it is convenient to make use of the fact of lustre to divide minerals into two broad groups, viz.:

(1) Minerals with a metallic or submetallic lustre.

(2) Minerals with a non-metallic type of lustre.

In the tables here given this broad two-fold division is adopted. Further subdivision can be made in various ways. The arrangement here adopted is in order of hardness (second column); and minerals having approximately the same hardness are arranged in order of specific gravity (third column). In the fourth column fusibility is given.

For minerals with a metallic or submetallic lustre the colour and streak of the mineral are fairly constant and characteristic, and for that reason columns are devoted to these in the list of minerals having a metallic lustre.

For minerals having a vitreous or other non-metallic lustre, colour is often variable, being due to a small amount of some non-essential constituent, and in such cases it is of little or no determinative value. These minerals, however, have usually some degree of transparency; hence the refractive index and birefringence, which are readily observable characters, can be made use of in determining these minerals, and are here given in the list of characteristics of minerals with a non-metallic lustre. A worker who makes use of these and other readily observed optical features in examining minerals having a non-metallic type of lustre will find them of great service, especially if he makes use of them as adjuncts to other determinative methods.

In the last column throughout the list are given a few of the more important chemical characteristics that are readily observed and useful in determinative work.

In doing rapid determinative work it is advisable to get a few important facts about the mineral under examination. Hardness, specific gravity, and fusibility are three important characters, and as a rule they can be determined approximately with readiness. Having determined the hardness, the list can be referred to in order to see what mineral with about that hardness has the specific gravity and other characters of the mineral in question.

A subsidiary list of economic minerals, arranged according to specific gravity, with hardnesses in the second column, is given on p. 472, and will be found useful in conjunction with the main tables. A third list in which minerals of metallic lustre are grouped according to colour is given on p. 474.

After a little experience, a student who works with care and judgment should be able, by means of determinative tables such as those here given, to fix the identity of the commoner useful minerals with a minimum of trouble.

DETERMINATIVE TABLES.

1.—MINERALS WITH METALLIC OR SUBMETALLIC LUSTRE.

Mineral.	H.	Sp. Gr.	Fus.	Colour.	Streak.	Other Characteristics.
MERCURY (Hg). See p. 232.	liq.	13·6	—	Tin-white.	—	Volatile, and leaves no residue. Yields metallic globules on walls of closed tube. Soluble in hot nitric acid. Associated with cinnabar.
GRAPHITE (C). See p. 374.	1	2·1	Infus.	Black.	Black.	Good basal cleavage. No sulphur dioxide in open tube. Resists attack by nitric acid.
MOLYBDENITE (MoS_2). See p. 220.	1	4·7	Infus.	Bluish black.	Dark greenish grey.	Good basal cleavage. Yields sulphur dioxide in open tube. Yellowish green flame-coloration. Decomposed by nitric acid, leaving a white residue which turns blue on reduction.
COVELLITE (CuS). Hexagonal.	1½	4·6	2½	Deep blue-black.	Bluish black.	Lustre submetallic. Good basal cleavage. Yields sulphur in closed tube. Readily reduced to copper on charcoal.
TETRADYMITE [$Bi_2(Te,S)_3$]. Trigonal.	1½	7·5	1½	Tin-white.	Dark grey.	Good basal cleavage. Bismuth reactions on charcoal. Gives a reddish violet solution with sulphuric acid. Associated with chalcopyrite and gold.
PYROLUSITE (MnO_2). See p. 213.	2	4·8	Infus.	Black.	Black.	Fracture splintery or uneven. No water in closed tube. Manganese beads. Evolves chlorine when heated in hydrochloric acid. Soils fingers.
LIVINGSTONITE ($HgS \cdot 2Sb_2S_3$)	2	4·8	1	Grey.	Reddish.	Gives off mercury when heated in closed tube with sodium carbonate. Volatilizes completely in blowpipe flame. Sublimate of Sb_2O_3 in open tube and on charcoal.
SYLVANITE ($AuAgTe_4$). See p. 186.	2	8	1	White.	Grey.	Good pinakoidal cleavage. Flame-coloration bluish green. Yields a reddish violet solution with sulphuric acid.
STIBNITE (Sb_2S_3). See p. 156.	2½	4·6	1	Lead-grey.	Greyish black.	Good pinakoidal cleavage. Flame-coloration pale green. Reddish brown sublimate in closed tube. Gives a white sublimate and evolves sulphur dioxide in open tube.

Mineral.	H.	Sp. Gr.	Fus.	Colour.	Streak.	Other Characteristics.
CHALCOCITE (Cu_2S). See p. 174.	2½	5·7	2½	Dark grey.	Dark grey.	Fracture uneven. Fuses to a non-magnetic globule. No sublimate of sulphur in closed tube. Evolves sulphur dioxide in open tube. Yields copper reactions.
BOURNONITE ($2PbS . Cu_2S . Sb_2S_3$).	2½	5·8	1	Steel-grey.	Black.	Fracture uneven. Sublimate of Sb_2O_3 in open tube and on charcoal. Yellow sublimate of PbI_2 with KI + S on charcoal. Evolves SO_2 in open tube. Copper reactions. Occurs as twinned crystals resembling cog-wheels.
JAMESONITE ($2PbS . Sb_2S_3$). See p. 157.	2½	5·8	1	Greyish black	Black.	Good basal cleavage. Lead and antimony reactions as in bournonite (see above); but no copper reactions.
STROMEYERITE (CuAgS).	2½	6·2	1½	Dark grey.	Black.	Fracture uneven. Gives off SO_2 in open tube. Copper reactions. Decomposed by nitric acid and solution gives white precipitate with hydrochloric acid.
STEPHANITE ($5Ag_2S . Sb_2S_3$). See p. 236.	2½	6·2	1	Greyish black.	Greyish black.	Fracture uneven. Sublimate of Sb_2O_3 in open tube and on charcoal. Residue of malleable silver on charcoal in reducing flame.
POLYBASITE [$9(Ag, Cu)_2S . Sb_2S_3$]. See p. 236.	2½	6·2	1	Black.	Black.	Fracture uneven. Reactions much like those of stephanite (see above); but yields copper reactions also.
TELLURIUM (Te).	2½	6·2	1	Tin-white.	Grey.	Cleavage prismatic. Completely volatile, and gives a greeenish flame-coloration in reducing flame. Associated with gold tellurides and gold
BISMUTHINITE (Bi_2S_3). See p. 163.	2½	6·5	1	Lead-grey.	Greyish black.	Good pinakoidal cleavage. Yields SO_2 and a white sublimate in open tube. Brittle beads on charcoal. Fine and characteristic red sublimate on charcoal with KI + S.

MINERALS WITH METALLIC OR SUBMETALLIC LUSTRE—*Contd.*

Mineral.	H.	Sp. Gr.	Fus.	Colour.	Streak.	Other Characteristics.
ARGENTITE (Ag_2S). See p. 235.	2½	7·2	1½	Dark grey.	Greyish black.	Fracture conchoidal. Evolves SO_2 when heated in open tube. Malleable residue of silver in oxidizing flame. Sectile.
GALENA (PbS). See p. 205.	2½	7·5	2	Lead-grey.	Lead-grey.	Good cubic cleavage. Malleable beads on charcoal. Bright yellow incrustation with KI+S on charcoal. Decomposed by hot hydrochloric acid, giving off sulphuretted hydrogen, and lead chloride separates out from the solution on cooling.
KRENNERITE ($AuTe_2$). Orthorhombic.	2½	8·3	1	White or pale yellow.	Grey.	Good basal cleavage. Residue of gold on charcoal. Reddish violet solution with sulphuric acid. Associated with other tellurides of gold and silver.
HESSITE (Ag_2Te). Cubic.	2½	8·5	1	Steel-grey.	Grey.	Fracture uneven. Silver globules on charcoal. Reddish violet solution with sulphuric acid. Associated with other tellurides and native gold.
COPPER (Cu). See p. 172.	2½	8·7	3	Copper-red.	Copper-red.	Fracture hackly. Malleable. Dissolves in nitric acid, and solution turns blue on adding excess of ammonia.
PETZITE $(Ag, Au)_2Te$. Massive.	2½	8·9	1½	Iron-grey.	Grey.	Fracture uneven. Charcoal reactions and solution in sulphuric acid similar to hessite (see above). Associated with other tellurides and native gold.
CALAVERITE ($AuTe_2$). See p. 186.	2½	9	1	White or pale yellow.	Yellowish grey.	Fracture uneven. Yields a residue of gold on charcoal. Reddish violet solution with sulphuric acid.
BISMUTH (Bi). See p. 163.	2½	9·8	1	White.	White.	Good basal and rhombohedral cleavages. Brittle. Fine red sublimate with KI+S on charcoal. Dissolves in nitric acid and solution gives a white precipitate when water is added.
ELECTRUM (Gold + silver). Cubic.	2½	13 to 16	2½	Yellowish white.	Yellowish white.	Hackly fracture. Malleable. Insoluble in nitric acid. Associated with gold and pyrite.

MINERALS WITH METALLIC OR SUBMETALLIC LUSTRE—*Contd.*

Mineral.	H.	Sp. Gr.	Fus.	Colour.	Streak.	Other Characteristics.
GOLD (Au). See p. 185.	2½	15 to 19	3	Golden yellow.	Golden yellow.	Hackly fracture. Insoluble in hydrochloric acid or nitric acid, but soluble in aqua regia.
ENARGITE ($Cu_2S . As_2S_5$). See p. 175.	3	4·4	1	Greyish black.	Black.	Good prismatic cleavage. Sublimate of sulphur in closed tube. Gives off SO_2 in open tube. Yields metallic copper on charcoal.
PEARCITE [$9(Ag, Cu)_2S . As_2S_3$]. See Polybasite, p. 237.	3	6·1	1	Black.	Black.	Fracture, conchoidal. Silver globules on charcoal. Gives off sulphur dioxide and a sublimate of arsenious oxide in open tube. Copper reactions. Forms an isomorphous mixture with polybasite.
SILVER (Ag). See p. 235.	3	10·5	2	White.	White.	Hackly fracture. Malleable surface usually tarnished. Dissolves in nitric acid, and solution gives a white precipitate with hydrochloric acid.
ALABANDITE (MnS). Cubic.	3½	4	3	Black.	Dark green.	Good cubic cleavage. Gives off SO_2 in open tube. Manganese bead reactions. Associated with zinc-blende and rhodochrosite.
FAMATINITE ($3Cu_2S . Sb_2S_5$). See Enargite, p. 176.	3½	4·6	1½	Grey.	Black.	Uneven fracture. Chemical reactions like those of tetrahedrite (see below). Associated with galena, chalcocite, and enargite.
TENNANTITE ($3Cu_2S . As_2S_3$). See Tetrahedrite, p. 175.	3½	4·6	1½	Grey.	Black.	Uneven fracture. Gives off SO_2 and sublimate of arsenious oxide in open tube. Copper reactions. Distinguished from enargite by absence of cleavage. Associated with galena, zinc-blende, and chalcopyrite.
TETRAHEDRITE ($3Cu_2S . Sb_2S_3$). See p. 174.	3½	4·8	1½	Grey.	Black.	Fracture uneven. Copper reactions. Sublimate of antimony oxide in open tube and on charcoal. The copper of tetrahedrite is in part replaceable by silver (see Freibergite, below).

Mineral.	H.	Sp. Gr.	Fus.	Colour.	Streak.	Other Characteristics.
FREIBERGITE [3(CuAg)$_2$S . Sb$_2$S$_3$]. A variety of tetrahedrite. See p. 175.	3½	5·0	1½	Grey.	Black.	Physical properties and chemical behaviour mostly like tetrahedrite (see above), but solution in nitric acid gives a white precipitate with hydrochloric acid.
BORNITE (3Cu$_2$S . Fe$_2$S$_3$). See p. 174.	3½	5	2½	Reddish brown.	Greyish black.	Fracture uneven. Fuses to a magnetic globule. Sublimate of sulphur in closed tube. Sulphur dioxide in open tube. Copper reactions.
MILLERITE (NiS). Trigonal.	3½	5·6	2	Brassy yellow.	Greenish black.	Usually as acicular crystals. Rhombohedral cleavage. Gives off sulphur dioxide in open tube. Nickel bead reactions. Decomposed by nitric acid, and the solution is apple-green. Associated with chloanthite and gersdorfite as a vein mineral.
ARSENIC (As). Trigonal.	3½	5·7	Volatile.	Tin-white with grey tarnish.	Grey.	Usually as granular crusts. Good basal cleavage. Volatilizes without fusion. Arsenic sublimate and garlic smell in open tube and on charcoal. Associated with galena, chloanthite and proustite.
TENORITE (CuO). Monoclinic.	3½	6	3	Black.	Greyish black.	Occurs as black earthy masses and scaly crystals. Good basal cleavage. Copper reactions. Yields metallic copper when reduced alone on charcoal. Soluble in hydrochloric acid. Associated with malachite, azurite and other copper oxidation products.
CUPRITE See p. 176.	3½	6	3	Deep red.	Red.	See p. 462.
ANTIMONY (Sb). Trigonal.	3½	6·6	1	Tin-white.	Grey.	Occurs as granular masses. Good basal cleavage. Sublimate of antimony oxide in open tube and on charcoal. Volatilizes in blowpipe flame. Associated with stibnite and smaltite.
CHALCOPYRITE (Cu$_2$S . Fe$_2$S$_3$). See p. 173.	4	4·2	2	Brassy yellow.	Greenish black.	Uneven fracture. Fuses to a black magnetic globule. Sublimate of sulphur in closed tube. Copper reactions. Decomposed by nitric acid with separation of sulphur.

MINERALS WITH METALLIC OR SUBMETALLIC LUSTRE—*Contd.*

Mineral.	H.	Sp.Gr.	Fus.	Colour.	Streak.	Other Characteristics.
Stannite ($Cu_2S . FeS . SnS_2$). Massive.	4	4·4	1½	Grey, with a bronzy tarnish.	Black.	Uneven fracture. Magnetic after reduction in blowpipe flame. Sulphur dioxide in open tube. Copper reactions. Decomposed by nitric acid with separation of sulphur. Associated with cassiterite, chalcopyrite and arsenopyrite.
Pentlandite [(Fe, Ni)S]. See p. 225.	4	5	2	Yellowish bronze.	Brownish black.	Octahedral cleavage. Fuses to a magnetic globule. SO_2 in open tube. Nickel bead reactions.
Manganite ($Mn_2O_3 . H_2O$). See p. 214.	4½	4·3	Infus.	Black.	Dark brown.	Lustre submetallic. Good pinakoidal cleavage. Yields water in closed tube. Manganese bead reactions. Dissolves in hydrochloric acid and gives off chlorine.
Pyrrhotite (FeS). See p. 225.	4½	4·5	3	Yellow; typically bronze-coloured.	Black.	Fracture uneven. Highly magnetic. Little or no sulphur in closed tube, but SO_2 given off in open tube. Decomposed by hydrochloric acid, and gives off H_2S.
Platinum (Pt). See p. 230.	4½	16 to 19	Infus.	Steel-grey.	Grey.	Hackly fracture. Insoluble in ordinary acids, but soluble in aqua regia. Malleable.
Smaltite ($CoAs_2$). See p. 170.	5	6·2	2½	Tin-white.	Dark grey.	Usually massive. Uneven fracture. Fuses to a magnetic globule, and gives off arsenical fumes. Mirror of arsenic in closed tube. Cobalt bead reactions.
Iron (Fe). Cubic.	5	7·4	5½	Steel-grey.	Steel-grey.	Hackly fracture. Malleable. Very strongly magnetic. Readily soluble in hydrochloric acid, and solution gives a copious precipitate of ferric hydrate when treated with excess of ammonia. Occurs in dolerites and basalts.
Limonite ($2Fe_2O_3 . 3H_2O$) See p. 195.	5½	3·8	5½	Brown.	Yellowish brown.	Lustre submetallic or earthy. Fracture uneven. Gives off water in closed tube. Highly magnetic after fusion. Iron reactions. Soluble in hydrochloric acid.

MINERALS WITH METALLIC OR SUBMETALLIC LUSTRE—*Contd.*

Mineral.	H.	Sp. Gr.	Fus.	Colour.	Streak.	Other Characteristics.
ILVAITE [$CaFe_2(FeOH)(SiO_4)_2$]. Orthorhombic.	5½	4	3	Black.	Greenish black.	Submetallic lustre. Uneven fracture. Iron reactions. Fuses to a magnetic globule. Decomposed by hydrochloric acid, and yields gelatinous silica. Occurs in crystalline dolomitic limestone associated with actinolite and diopside.
GOETHITE ($Fe_2O_3 . H_2O$). See p. 196.	5½	4·2	5½	Yellow to brown.	Yellow or brownish yellow.	Lustre submetallic. Perfect pinakoidal cleavage. Reactions like those of limonite. Distinguished from limonite by its cleavage and the fact that microfragments are anisotropic, whereas limonite is amorphous.
TURITE ($2Fe_2O_3 . H_2O$). Compact or fibrous.	5½	4·4	5½	Reddish black.	Brown.	Lustre submetallic. Fracture splintery or uneven. Blackens and becomes magnetic on fusion. Gives off water in closed tube. Iron reactions. Associated with limonite.
ILMENITE ($FeO . TiO_2$). See p. 249.	5½	4·7	Infus.	Black.	Black.	Fracture uneven. Weakly magnetic. Fused with $KHSO_4$ and dissolved in HCl yields a yellow solution which turns violet when reduced with metallic tin.
HAUSMANNITE (Mn_3O_4). Tetragonal.	5½	4·8	Infus.	Black.	Brown.	Basal cleavage. No water in closed tube. Manganese reactions. Gives off chlorine when treated with HCl. Associated with braunite, pyrolusite, and other manganese minerals.
LINNÆITE [$(Co, Ni)_3S_4$]. Cubic.	5½	4·9	2	Steel-grey.	Greyish black.	Uneven fracture. Sublimate of sulphur in closed tube. Gives off SO_2 in open tube. Cobalt bead reactions. Decomposed by nitric acid, and yields a rose-coloured solution. Associated with tetrahedrite, pyrite, and chalcopyrite.
MAGNETITE (Fe_3O_4). See p. 193.	5½	5	5½	Black.	Black.	Octahedral parting in some cases. Uneven fracture. Very highly magnetic. Iron reactions. Soluble in strong hydrochloric acid yielding a deep yellow solution.

Mineral.	H.	Sp. Gr.	Fus.	Colour.	Streak.	Other Characteristics.
Glaucodote. [(Co, Fe) AsS)]. Orthorhombic.	5½	5·95	2½	Greyish white.	Black	Basal cleavage. Chemical reactions much the same as cobaltite (see below); but the fused globules are more magnetic. Associated with cobaltite.
Gersdorffite (NiAsS). Cubic.	5½	6	2	Tin-white.	Grey.	Cubic cleavage. Gives off SO_2 in open tube, and yields a sublimate of arsenious oxide. Nickel reactions. Decomposed by nitric acid, and yields an apple-green solution. Associated with chalcopyrite, galena, blende, and fluorite.
Arsenopyrite (FeAsS). See p. 160.	5½	6	2	Tin-white.	Black.	Prismatic cleavage. Fuses to a magnetic globule, and gives off fumes of arsenic. Arsenic and arsenic sulphide sublimates in closed tube.
Cobaltite (CoAsS). See p. 170.	5½	6·1	2½	Tin-white with a pinkish tinge.	Black.	Cubic cleavage. SO_2 given off, and sublimate of As_2O_3 formed in open tube. Cobalt beads. Decomposed by nitric acid, and yields a rose-coloured solution.
Chloanthite ($NiAs_2$). Cubic.	5½	6·6	2	Tin-white.	Black.	Octahedral cleavage. Sublimate of arsenic in closed tube. Strong smell of arsenic in open tube and on charcoal. Decomposed by strong nitric acid, and yields an apple-green solution.
Hübnerite [(Mn, Fe)WO_4]. See p. 251.	5½	7·2	4	Dark reddish brown.	Brown.	Lustre submetallic. Good pinakoidal cleavage. Manganese bead reactions. Decomposed by boiling hydrochloric acid, and yields a yellow residue; solution turns deep-blue on reducing with metallic tin.
Wolframite [(Fe, Mn)WO_4]. See p. 251.	5½	7·4	3	Black.	Brownish black.	Submetallic lustre. Good pinakoidal cleavage. Fuses to magnetic globule. Manganese bead reactions. Decomposed by boiling hydrochloric acid, and leaves a yellow residue; the solution turns deep-blue when reduced with metallic tin.

MINERALS WITH METALLIC OR SUBMETALLIC LUSTRE—*Contd.*

Mineral.	H.	Sp. Gr.	Fus.	Colour.	Streak.	Other Characteristics.
Niccolite ($NiAs$). See p. 226.	5½	7·5	2	Pale copper-red.	Brownish black.	Usually massive Uneven fracture. Sublimate of As_2O_3 and odour of arsenic in open tube and on charcoal. Nickel reactions.
Uraninite (oxide of uranium with some thorium and lead). See p. 431.	5½	9·5	Infus.	Black.	Brownish black.	Lustre submetallic. Uneven fracture. Uranium bead reactions. Soluble in sulphuric acid.
Chromite $(Fe, Mg)O.(Cr,Al)_2O_3$. See p. 167.	6	4·3	Infus.	Black.	Dark brown.	Submetallic lustre. Uneven fracture. Insoluble in acids, but readily attacked by fused soda (Na_2O).
Psilomelane (hydrated oxide of manganese). See p. 213.	6	4·3	Infus.	Black.	Brownish black.	Submetallic lustre. Uneven fracture. Yields water in a closed tube. Manganese bead reactions. Gives off chlorine with HCl.
Hæmatite (Fe_2O_3). See p. 194.	6	5	5½	Reddish black.	Reddish brown.	Lustre submetallic. Uneven fracture. Feebly magnetic as a rule, compared with magnetite. Iron reactions.
Franklinite $(Zn,Fe,Mn)O.(Fe, Mn)_2O_3$. See p. 262.	6	5·2	Infus.	Brownish black.	Dark brown.	Submetallic lustre. Uneven fracture. Magnetic. Manganese bead reactions. Incrustation of zinc oxide on charcoal.
Columbite $(Fe, Mn)O.(Cb,Ta)_2O_5$. See p. 240.	6	5·6	5½	Black.	Greyish or brownish black.	Submetallic lustre. Uneven fracture. Manganese and columbium reactions. Partly decomposed by strong sulphuric acid.
Thorianite (oxide of thorium with some uranium and a little lead). See p. 429.	6	9·5	Infus.	Brownish black.		Submetallic lustre. Uneven fracture. Uranium bead reactions. Soluble in sulphuric acid. Usually in the form of good cube-shaped crystals.
Rutile (TiO_2). See p. 247.	6½	4·2	Infus.	Dark red to black.	Grey or or brown.	Submetallic lustre. Prismatic cleavage. Titanium bead reactions. Readily soluble in fused $KHSO_4$, and the fused mass when dissolved in HCl and reduced with metallic tin yields a violet solution.

Mineral.	H.	Sp. Gr.	Fus.	Colour.	Streak.	Other Characteristics.
BRAUNITE (Mn_2O_3 with some $MnSiO_3$). See p. 214.	6½	4·8	5	Black.	Black.	Lustre submetallic. Pyramidal cleavage. No water in closed tube. Manganese bead reactions. Gives off chlorine with hydrochloric acid.
MARCASITE (FeS_2). Orthorhombic.	6½	4·9	3	White to pale yellow.	Black.	Frequently nodular. Uneven fracture. Burns with a blue flame and emits a pungent smell of SO_2. Fuses to a magnetic globule in reducing flame. Not decomposed by hydrochloric acid. Associated with pyrite, galena, and blende.
PYRITE (FeS_2). See p. 424.	6½	5	3	Brassy yellow.	Black.	Usually as cubes. Acts chemically like marcasite (see above), but less liable to decomposition.
CASSITERITE (SnO_2). See p. 241.	6½	7	Infus.	Brownish black.	Brown.	Submetallic lustre. Uneven fracture. Metallic globules of tin on charcoal (see p. 242). Insoluble in acids. A grain placed on zinc in a drop of HCl becomes covered with a white metallic skin.
TANTALITE (Fe, Mn)O. $(Ta, Cb)_2O_5$. See p. 240.	6½	7·5	Infus.	Black.	Black.	Submetallic lustre. Uneven fracture. Reactions for iron and manganese, but otherwise somewhat inert in its behaviour towards ordinary tests.
SPERRYLITE ($PtAs_2$). See p. 230.	6½	10·6	2	Tin-white.	Black.	Conchoidal fracture. Yields a sublimate of arsenious oxide in open tube and a residue of spongy platinum.
OSMIRIDIUM and IRIDOSMIUM (Alloy of iridium, osmium, and other rare metals). See p. 192.	6½	20	Infus.	Tin-white	Greyish black.	Good basal cleavage. Give off osmium oxide in open tube. High specific gravity a noticeable feature. Insoluble in single acids.
IRIDIUM (with platinum). See p. 192.	6½	22·5	Infus.	Tin-white.	Greyish black.	Hackly fracture. Gives no odour of osmium oxide in open tube. Insoluble in single acids.

2.—MINERALS WITH A NON-METALLIC LUSTRE.

Mineral.	H.	Sp. Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
OZOKERITE. See p. 391.	1	0·9	Melts readily.	Low.	Low. Compact texture.	Greasy to the touch. Burns with smoky flame and floats on water.
CARNALLITE ($KCl . MgCl_2 . 6H_2O$). See p. 401.	1	1·6	1½	$\alpha=1{\cdot}466$	$\gamma-\alpha=0{\cdot}027$.	Deliquescent. Yields water in closed tube. Flame-coloration violet; azure-blue with copper oxide. Soluble in water.
ULEXITE ($Na_2O . 2CaO\ 5B_2O_3 . 16H_2O$). See p. 334.	1	1·65	1	About 1·5	Low.	White. Silky lustre. Strong yellow flame-coloration. Yields water in closed tube. Gives an alkaline solution with hot water.
TALC ($3MgO . 4SiO_2 . H_2O$). See p. 413.	1	2·7	5½	$\alpha=1{\cdot}55$.	$\gamma-\alpha=0{\cdot}040$.	Pearly lustre. Yields a little water when strongly heated in closed tube. Pink colour after moistening with cobalt nitrate and re-heating in blowpipe flame (distinction from pyrophyllite). Insoluble in ordinary acids.
MIRABILITE ($Na_2SO_4 . 10H_2O$). See p. 422.	1½	1½	1½	About 1·44.	Low.	White. Gives off water in closed tube. Strong yellow flame-coloration. Soluble in water.
HALLOYSITE (hydrated silicate of aluminium). See p. 361.	1½	2·1	Infus.	About 1·53.	Amorphous.	Sectile. Gives off water in closed tube. Swells and disintegrates in water. Decomposed by sulphuric acid.
NITRATINE ($NaNO_3$). See p. 386.	1½	2·2	1	$\omega=1{\cdot}587$	$\omega-\epsilon=0{\cdot}250$	Deliquescent. Soluble in water. Strong yellow flame-coloration. Yields a reddish vapour in closed tube with potassium bisulphate.
PYROPHYLLITE ($Al_2O_3 . 4SiO_2 . H_2O$). See p. 412.	1½	2·8	Infus.	$\alpha=1{\cdot}57$.	$\gamma-\alpha=0{\cdot}02$.	Usually yellowish and fibrous, or compact in texture. Yields a little water in closed tube when strongly heated. Blue colour after moistening with cobalt nitrate and re-heating in blowpipe flame (distinction from talc). Not decomposed by ordinary acids.

Mineral.	H.	Sp.Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
Realgar (AsS). See p. 161.	1½	3·5	1	Very high.	Very high.	Red colour. Resinous lustre. Good pinakoidal cleavage. SO_2 and a deposit of As_2O_3 in open tube. Red sublimate of AsS in closed tube. Mirror of arsenic in closed tube when heated with sodium carbonate.
Orpiment (As_2S_3). See p. 161.	1½	3·5	1	Very high.	Very high.	Lemon-yellow colour. Pearly lustre. Good pinakoidal cleavage. Chemical reactions like those of realgar (see above), except that the closed tube sublimate is yellow.
Kermesite ($2Sb_2S_3 . Sb_2O_3$). See p. 157.	1½	4·5	1	—	—	Brownish red colour. Adamantine lustre. Good pinakoidal cleavage. SO_2 and sublimate of antimony oxide in open tube. Volatilizes completely on charcoal in blowpipe flame and gives a dense sublimate of antimony oxide.
Sulphur (S). See p. 422.	2	2	1	$\gamma=2{\cdot}24$.	$\gamma-\alpha=0{\cdot}29$.	Colour yellow. Burns with a blue flame and gives off the pungent smell of sulphur dioxide.
Nitre (KNO_3). See p. 386.	2	2·1	1	$\alpha=1{\cdot}33$.	$\gamma-\alpha=0{\cdot}172$.	Colourless or white. Potash flame reaction (violet). Soluble in water. With $KHSO_4$ in closed tube gives off red fumes of NO_2.
Gypsum ($CaSO_4 . 2H_2O$). See p. 419.	2	2·3	2½	$\gamma=1{\cdot}53$.	$\gamma-\alpha=0{\cdot}010$.	Perfect pinakoidal cleavage. Gives off water in closed tube. Reddish yellow flame-coloration. Soluble in dilute hydrochloric acid.
Erythrite [$Co_3(AsO_4)_2 . 8H_2O$]. Monoclinic.	2	3	2	$\alpha=1{\cdot}626$.	$\gamma-\alpha=0{\cdot}072$.	Crimson colour. Good pinakoidal cleavage. Mirror of arsenic when heated in a closed tube with charcoal. Cobalt bead reactions. Decomposed by hydrochloric acid and yields a rose-coloured solution. Associated with smaltite.

Mineral.	H.	Sp. Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
ANNABERGITE $[Ni_3(AsO_4)_2 . 8H_2O]$. Monoclinic.	2	3·1	4	$\alpha = 1{\cdot}65$.	$\gamma - \alpha = 0{\cdot}03$.	Apple-green colour. Good pinakoidal cleavage. Usually earthy. Nickel bead reactions. Mirror of arsenic when heated in closed tube with charcoal. Decomposed by hydrochloric acid and yields a green solution. Associated with niccolite and chloanthite.
KERARGYRITE (AgCl). See p. 237.	2	5·5	1	2·0.	Isotropic.	Usually massive. Cuts like horn. Lustre, resinous to adamantine. Azure-blue flame - coloration with microcosmic salt and copper oxide. Button of silver on charcoal. Insoluble in acids. Soluble in ammonium hydrate.
BROMYRITE (AgBr). Cubic.	2	5·9	1	2·25.	Isotropic.	Colour green or yellow. Adamantine lustre. Uneven fracture. On charcoal with sodium carbonate yields metallic silver. Associated with silver.
AMBER (fossil resin). See p. 269.	2½	1·05	1	About 1·54.	Isotropic.	Yellow to brownish, and amorphous. Melts readily and burns with a yellow smoky flame.
MEERSCHAUM $(2MgO . 3SiO_2 . 2H_2O)$. See p. 412.	2½	1·2	5	About 1·54.	Compact texture.	Earthy. Yields water in closed tube. Decomposed by hydrochloric acid with gelatinization.
BORAX $(Na_2O . 2B_2O_3 . 10H_2O)$. See p. 335.	2½	1·7	1	$\gamma = 1{\cdot}47$.	$\gamma - \alpha = 0{\cdot}026$.	Whitish or greyish. Perfect cleavage. Strong yellow flame-coloration. Soluble in water.
EPSOMITE $(MgSO_4 . 7H_2O)$. See p. 419.	2½	1·7	1	$\alpha = 1{\cdot}43$.	$\gamma - \alpha = 0{\cdot}030$	Colourless or white. Gives off water in closed tube. Soluble in water, and solution reacts for magnesium and sulphate.
SYLVITE (KCl). See p. 403.	2½	2	1½	About 1·49.	Isotropic.	Perfect cubic cleavage. No water in closed tube. Violet flame-coloration. Soluble in water, and solution gives a copious white precipitate with silver nitrate.

Mineral.	H.	Sp. Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
TRONA ($Na_2CO_3 . NaHCO_3 . 2H_2O$). See p. 352.	2½	2·1	1½	—	—	Colourless, white or greyish. Flame-coloration intense yellow. Yields water in closed tube. Soluble in water, and solution has a strong alkaline action on litmus paper.
KAINITE ($KCl . MgSO_4 . 3H_2O$). See p. 403.	2½	2·1	2	β about 1·5.	$\gamma - \alpha =$ 0·03.	Not deliquescent if pure. Yields water in closed tube Flame-coloration violet. Soluble in water, and solution gives a heavy white precipitate with barium chloride.
HALITE (NaCl). See p. 354.	2½	2·2	1	1·54.	Isotropic.	Perfect cubic cleavage. Flame-coloration intense yellow, and azure-blue when mixed with copper oxide. Soluble in water, and has a characteristic taste.
CHALCANTHITE ($CuSO_4 . 5H_2O$). Triclinic.	2½	2·2	3	$\gamma = 1{\cdot}54$	$\gamma - \alpha =$ 0.030.	Blue colour. Conchoidal fracture. Yields water in closed tube. Soluble in water, and gives a white precipitate with barium chloride. Associated with chalcopyrite.
MUSCOVITE ($K_2O . 2H_2O . 3Al_2O_3 . 6SiO_2$). See p. 381.	2½	2·8	5	$\gamma = 1{\cdot}597$.	$\gamma - \alpha =$ 0·038.	Perfect basal cleavage; cleavage flakes show a good centric biaxial figure with a fairly wide angle and a negative sign. Not decomposed by ordinary acids.
FUCHSITE (Chrome-mica). See p. 312.	2½	2·85	5	—	—	Emerald-green colour. Perfect basal cleavage. Chromium bead reactions. Not decomposed by hydrochloric acid.
PHLOGOPITE ($K_2O . 2H_2O . 6MgO . Al_2O_3 . 6SiO_2$). See p. 383.	2½	2·85	5	$\gamma = 1{\cdot}60$.	$\gamma - \alpha =$ 0·04.	Colourless or pale brown. Perfect basal cleavage; cleavage plates show a centric figure which is approximately uniaxial or shows only a low optic axial angle. Decomposed by hot strong sulphuric acid.
LEPIDOLITE (Lithia-mica). See p. 379.	2½	2·9	2	$\gamma = 1{\cdot}60$.	$\gamma - \alpha =$ 0·04.	Perfect basal cleavage. Optic axial angle much like that of muscovite. Flame-coloration red due to lithium. Partly decomposed by hydrochloric acid.

MINERALS WITH A NON-METALLIC LUSTRE—*Contd.*

Mineral.	H.	Sp.Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
BIOTITE See p. 381.	2½	2·95	5	$\gamma = 1{\cdot}60$.	$\gamma - \alpha = 0{\cdot}04$.	Dark brown or black. Perfect basal cleavage. Decomposed by strong sulphuric acid. Nearly uniaxial.
CRYOLITE ($3NaF . AlF_3$). See p. 154.	2½	3	1½	1·36.	Very low.	Colour, white or brownish. Vitreous lustre. Good cleavage, yielding almost cube-shaped fragments. Intense yellow flame-coloration. Decomposed by sulphuric acid, and gives off hydrofluoric acid.
AUTUNITE ($Ca(UO_2)_2(PO_4)_2 . 8H_2O$). See p. 433.	2½	3·1	3	About 1·62.	Feeble in cleavage plates.	Colour yellow. Good basal cleavage. Pearly lustre. Yields water in closed tube. Uranium bead reactions. Lime and phosphate reactions.
TORBERNITE ($Cu(UO_2)_2(PO_4)_2 . 8H_2O$). See p. 433.	2½	3·5	3	About 1·61.	Isotropic in cleavage plates.	Colour bright green. Good basal cleavage. Pearly lustre. Yields water in closed tube. Green flame-coloration. Uranium bead reactions. Decomposed by nitric acid, and solution gives phosphate reaction.
HYDROZINCITE ($ZnCO_3 . 2Zn(OH)_3$). See p. 263.	2½	3·7	Infus.	Very high.	Doubly refracting.	Chalk-like. Cryptocrystaline texture. Gives off water in closed tube. White sublimate on charcoal which turns green after moistening with cobalt nitrate. Dissolves with effervescence in hydrochloric acid.
SENARMONTITE (Sb_2O_3). See p. 157.	2½	5·25	1½	Very high.	Isotropic.	Colourless or white. Adamantine lustre. Uneven fracture. Completely volatile. White sublimate of antimony oxide in open tube and on charcoal.
VALENTINITE (Sb_2O_3). See p. 157.	2½	5·55	1½	Very high.	Doubly refracting.	Colourless or white. Adamantine lustre. Perfect pinakoidal cleavage. Chemical reactions same as senarmontite (see above).

MINERALS WITH A NON-METALLIC LUSTRE—*Contd.*

Mineral.	H.	Sp. Gr.	Fus.	Refr.Index.	Biref.	Other Characteristics.
PROUSTITE ($3Ag_2S . As_2S_3$). See p. 236.	2½	5·6	1	$\omega = 2·98$	$\omega - \epsilon =$ 0·27.	Scarlet-vermilion colour. Scarlet streak. Adamantine lustre. Sublimate of AsS in closed tube. SO_2 and sublimate of As_2O_3 in open tube. Button of silver on charcoal Decomposed by nitric acid, with separation of sulphur.
PYRARGYRITE ($3Ag_2S . Sb_2S_3$). See p. 235.	2½	5·8	1	$\omega = 3·08$.	$\omega - \epsilon =$ 0·20.	Colour cochineal-red to reddish black. Lustre, metallic-adamantine. SO_2 and sublimate of Sb_2O_3 in open tube. Bead of silver on charcoal. Decomposed by nitric acid with separation of sulphur and antimony oxide.
CROCOITE ($PbCrO_4$). Monoclinic.	2½	6	1½	About 2·4.	Very high.	Red colour. Adamantine lustre. Chromium bead reactions. Lead bead on charcoal with sodium carbonate. Darkens and decrepitates in closed tube.
CINNABAR (HgS). See p. 232.	2½	8·1	1½	$\epsilon = 3·2$.	$\epsilon - \omega =$ 0·347.	Colour red to black. Adamantine lustre. Volatile. Black sublimate of HgS in closed tube, and globules of metallic mercury if mixed with sodium carbonate. SO_2 and metallic mercury in open tube. Decomposed by nitric acid.
HYDRARGILLITE ($Al_2O_3 . 3H_2O$). See p. 154.	3	2·35	Infus.	γ about 1.56, but variable.	$\gamma - \alpha$ about 0·02, but variable.	White. Basal cleavage. Pearly lustre on cleavage plates. Blue after moistening with cobalt nitrate and heating in blowpipe flame. Soluble in sulphuric acid.
CHRYSOCOLLA ($CuO . SiO_2 . 2H_2O$). Massive.	3	2·2	Infus.	About 1·57.	Very low.	Bluish green colour. Cryptocrystalline texture. Copper reactions. Blackens and gives off water when heated in closed tube. Decomposed by hydrochloric acid, but does not gelatinize. Associated with malachite and chalcopyrite.

Mineral.	H.	Sp. Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
Garnierite (hydrated silicate of nickel and magnesium). See p. 225.	3	2·5	Infus.	About 1·59.	Very low.	Soft and earthy. Pale green colour. Texture cryptocrystalline. Blackens and gives off water in closed tube. Nickel bead reactions. Decomposed by hydrochloric acid, without gelatinization.
Calcite ($CaCO_3$). See p. 342.	3	2·72	Infus.	$\omega =$ 1·658.	$\omega - \epsilon =$ 0·172.	Usually white or colourless. Perfect rhombohedral cleavage. Yellowish red flame-coloration, when moistened with hydrochloric acid, in a cold dilute solution of which the mineral dissolves with much effervescence.
Barite ($BaSO_4$). See p. 415.	3	4·5	3½	$\alpha =$ 1·636.	$\gamma - \alpha =$ 0·011.	Good basal and prismatic cleavages. Crystals decrepitate in blowpipe flame. Flame-coloration yellowish green. Sulphur test on silver coin. Insoluble in acids.
Anglesite ($PbSO_4$). See p. 206.	3	6·3	1½	$\alpha =$ 1·877.	$\gamma - \alpha =$ 0·016.	Colourless or white. Adamantine lustre. Metallic lead on charcoal with sodium carbonate, and the fused mass blackens a silver coin when moistened with water. Difficultly soluble in nitric acid, and the solution gives a white precipitate with barium chloride.
Wulfenite ($PbMoO_4$). See p. 222.	3	6·7	2	$\omega =$ 2·40.	$\omega - \epsilon =$ 0·100.	Platy crystals. Pyramidal cleavage. Adamantine lustre. Metallic lead on charcoal with sodium carbonate. Decomposed by hot hydrochloric acid, and solution turns deep blue when reduced with metallic tin.
Vanadinite [$Pb_4PbCl(VO_4)_3$] See p. 256.	3	7	1½	ω over 2·3.	Low.	Uneven fracture. Lustre resinous to adamantine. Metallic lead on charcoal with sodium carbonate. Azure-blue flame with copper oxide in a microcosmic bead. Sulphuric acid solution turns brown on adding hydrogen peroxide.

MINERALS WITH A NON-METALLIC LUSTRE—*Contd.*

Mineral.	H.	Sp. Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
Kieserite ($MgSO_4 . H_2O$). See p. 421.	3½	2·55	2½	About 1·46.	Low.	Yields water in closed tube. Soluble in water, and solution gives heavy white precipitate with barium chloride. Sodium phosphate gives a white precipitate of ammonium magnesium phosphate if added to a dilute solution of kieserite containing ammonium chloride.
Dolomite [$CaMg(CO_3)_2$]. See p. 344.	3½	2·85	Infus.	$\omega = 1\cdot672$.	$\omega - \epsilon = 0\cdot179$.	Usually white or yellowish. Perfect rhombohedral cleavage. Yellowish red flame-coloration with hydrochloric acid, in a cold dilute solution of which the mineral dissolves, but with less effervescence than calcite.
Ankerite [$Ca(Mg,Fe)(CO_3)_2$]. Trigonal.	3½	3	Infus.	Near dolomite.	Near dolomite.	Distinguished from dolomite by blackening and becoming magnetic in blowpipe flame. Solution in hydrochloric acid turns deep yellow when a few drops of nitric acid are added.
Strontianite ($SrCO_3$). See p. 350.	3½	3·7	Infus.	$\alpha = 1\cdot52$.	$\gamma - \alpha = 0\cdot152$.	Usually white or colourless. Flame-coloration crimson when moistened with hydrochloric acid. Prismatic cleavage. Dissolves with effervescence in hydrochloric acid.
Atacamite [$CuCl_2 . Cu(OH)_2$]. Orthorhombic.	3½	3·75	3½	$\alpha = 1\cdot83$.	$\gamma - \alpha = 0\cdot05$	Colour emerald-green. Perfect pinakoidal cleavage. Yields water in a closed tube, and water has an acid reaction. Copper reactions. Azure-blue flame-coloration. Soluble in acids. Associated with limonite.
Azurite [$2CuCO_3 . Cu(OH)_2$]. See p. 177.	3½	3·8	3	$\alpha > 1\cdot83$.	$\gamma - \alpha = 0\cdot20$.	Azure-blue colour. Yields water in closed tube. Copper reactions. Effervesces with hydrochloric acid, and a deep blue solution is obtained when ammonia is added in excess.

Mineral.	H.	Sp. Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
Brochantite [$CuSO_4 . 3Cu(OH)_2$]. See p. 177.	3½	3·9	3½	$\alpha < 1·74$. $\gamma > 1·74$		Emerald-green colour. Perfect pinakoidal cleavage. Copper reactions. Sulphide test on silver coin after fusion with sodium carbonate. Soluble in hydrochloric acid, and solution gives white precipitate with barium chloride.
Celestite ($SrSO_4$). See p. 418.	3½	3·9	3½	$\alpha = 1·622$	$\gamma - \alpha =$ 0·009.	Perfect basal cleavage. Crystals decrepitate in blowpipe flame. Crimson flame-coloration. Sulphide test on silver coin. Insoluble in ordinary acids.
Malachite [$CuCO_3 . Cu(OH)_2$]. See p. 176.	3½	3·9	3	$\beta = 1·88$.	$\gamma - \alpha =$ 0 20.	Colour, bright green. Yields water in closed tube. Copper reactions. Effervesces with hydrochloric acid, and a deep blue solution is obtained when ammonia is added in excess.
Zinc-blende (ZnS). See p. 259.	3½	4	5	2.37.	Isotropic.	Perfect dodecahedral cleavage. Adamantine lustre. Sublimate of zinc oxide on charcoal, which turns green when moistened with cobalt nitrate and reheated. Decomposed by hydrochloric acid, and gives off sulphuretted hydrogen.
Witherite ($BaCO_3$). See p. 351.	3½	4·3	2	$\gamma = 1·67$.	$\gamma - \alpha =$ 0·15.	White or greyish white. Flame-coloration yellowish green. Dissolves with effervescence in hydrochloric acid, and the solution gives a heavy white precipitate with sulphuric acid.
Greenockite (CdS). Hexagonal.	3½	4·8	Infus.	Very high.	Very high.	Yellow colour. Lustre of crystals adamantine and resinous. Heated on charcoal with sodium carbonate gives a reddish brown encrustation of cadmium oxide. Decomposed by hydrochloric acid, and gives off sulphuretted hydrogen.

Mineral.	H.	Sp. Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
Cuprite (Cu_2O). See p. 176.	3½	6·0	3	About 2·85.	Isotropic.	Red colour. Lustre metallic-adamantine. Easily reduced to metallic copper and gives other copper reactions.
Descloizite ($4PbO . V_2O_5 . H_2O$). Orthorhombic.	3½	6·0	1½	About 1·83.	—	Resinous lustre. Uneven fracture. Yields water in closed tube. Zinc reactions. Vanadium bead reactions. Lead globules on charcoal with sodium carbonate.
Cerussite $PbCO_3$ See p. 205.	3½	6·5	1½	$\alpha = 1{\cdot}80$	$\gamma - \alpha = 0{\cdot}270$	White or colourless. Adamantine lustre. Lead reactions. Effervesces with nitric acid.
Pyromorphite $[Pb_4PbCl(PO_4)_3]$ See p. 206.	3½	7	2	2	$\omega - \epsilon = 0{\cdot}01$	Lustre, resinous. Bluish green flame-coloration, but azure-blue with copper oxide in microcosmic bead. Decomposed by nitric acid; solution gives a good phosphate reaction, and a white precipitate with silver nitrate.
Mimetite $[Pb_4PbCl(AsO_4)_3]$ Hexagonal.	3½	7·1	1½	—	—	Resinous lustre. Uneven fracture. Mirror of arsenic in closed tube when heated with charcoal. Decomposed by nitric acid, and solution gives a white precipitate with silver nitrate.
Serpentine ($3MgO . 2SiO_2 . 2H_2O$). See p. 338.	4	2·5	5½	About 1·57.	$\gamma - \alpha = 0{\cdot}010$.	Compact and usually green. Fracture uneven or splintery. Yields water in closed tube. Decomposed by acids.
Chrysotile ($3MgO . 2SiO_2 . 2H_2O$). See p. 328.	4	2·5	5½	About 1·57.	$\gamma - \alpha = 0{\cdot}010$.	Fibrous. Yields water in closed tube. Decomposed by hydrochloric and sulphuric acids.
Alunite ($K_2O . 3Al_2O_3 . 4SO_3 . 6H_2O$). See p. 404.	4	2·7	Infus.	$\omega = 1{\cdot}57$.	$\epsilon - \omega = 0{\cdot}02$.	Decrepitates in blowpipe flame. In closed tube yields water which has an acid reaction. Partly soluble after heating in closed tube, and the aqueous solution yields cubic crystals of alum on evaporation.

Mineral.	H.	Sp. Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
MAGNESITE ($MgCO_3$). See p. 346.	4	3	Infus.	$\omega = 1{\cdot}717$.	$\omega - \epsilon = 0{\cdot}202$.	Usually white, and granular or cryptocrystalline in texture. Dissolves with effervescence in hot hydrochloric acid.
FLUORITE (CaF_2). See p. 371.	4	3·2	3	1·43.	Isotropic.	Perfect octahedral cleavage. Fuses to a white enamel. Flame-coloration red. Decomposed by hot sulphuric acid, giving off hydrofluoric acid, which etches glass.
CROCIDOLITE ($Na_2O . Fe_2O_3 . 2FeO . 6SiO_2$). See p. 331.	4	3·2	3½	About 1·65.	$\gamma - \alpha = 0{\cdot}025$.	Blue colour. Tough flexible fibres. Silky lustre. Fuses to a magnetic globule. Strong yellow flame-coloration. Not decomposed by hydrochloric acid.
RHODOCHROSITE ($MnCO_3$). See p. 215.	4	3·5	Infus.	$\omega = 1{\cdot}82$.	$\omega - \epsilon = 0{\cdot}220$.	Colour usually pink. Rhombohedral cleavage. Darkens and decrepitates in blowpipe flame. Manganese bead reaction. Dissolves with effervescence in hot hydrochloric acid.
CHALYBITE ($FeCO_3$). See p. 196.	4	3·8	5½	$\omega = 1{\cdot}87$.	$\omega - \epsilon = 0{\cdot}240$.	Usually yellowish brown. Good rhombohedral cleavage. Blackens and becomes magnetic in blowpipe flame. Good iron reactions. Dissolves with effervescence in hot hydrochloric acid.
COLEMANITE ($2CaO . 3B_2O_3 . 5H_2O$). See p. 333.	4½	2·4	1½	$\gamma = 1{\cdot}61$.	$\gamma - \alpha = 0{\cdot}030$.	Colourless or whitish. Perfect cleavage. Flame-coloration green. Yields water in closed tube. Decomposed by hydrochloric acid.
TRIPHYLITE $Li(Fe,Mn)PO_4$. See p. 379.	4½	3·6	2½	About 1·68.	Low.	Perfect pinakoidal cleavage. Fuses to a magnetic globule. Red flame-coloration. Manganese bead reaction. Decomposed by nitric acid, and solution gives phosphate reaction.
THORITE ($ThO_2 . SiO_2$). See p. 429.	4½	4·4 to 5·2	Infus.	High.	Texture usually compact.	Lustre somewhat resinous. Usually yields a little water in closed tube. Decomposed by hydrochloric acid with gelatinization.

MINERALS WITH A NON-METALLIC LUSTRE—*Contd.*

Mineral.	H.	Sp. Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
Zincite (ZnO). See p. 263.	4½	5·6	Infus.	High.	$\epsilon - \omega = 0{\cdot}010$.	Colour usually blood-red. Lustre sub-adamantine. Perfect basal cleavage. Zinc reactions. Dissolves in hydrochloric acid without effervescence.
Scheelite ($CaWO_4$). See p. 252.	4½	6	5	$\omega = 1{\cdot}92$.	$\epsilon - \omega = 0{\cdot}016$.	Colour usually white. Lustre sub-adamantine. Perfect pyramidal cleavage. Decomposed by hydrochloric acid, leaving a yellow residue. The solution gives lime reactions, and the yellow residue turns blue on adding tin.
Bismutite [$BiO \cdot Bi(OH)_2 \cdot CO_3$]. See p. 164.	4½	7·2	1½	—	—	Amorphous or earthy encrustations. Yields water in closed tube. Good bismuth reactions. Decomposed by hydrochloric acid with effervescence.
Apatite [$Ca_4(PO_4)_3CaF$]. See p. 271.	5	3·2	5	$\omega = 1{\cdot}638$.	$\omega - \epsilon = 0{\cdot}003$.	No good cleavage. Flame-coloration bluish green when moistened with sulphuric acid. Soluble in nitric acid, and solution gives a phosphate reaction with ammonium molybdate.
Dioptase ($CuO \cdot SiO_2 \cdot H_2O$). See p. 290.	5	3·3	Infus.	$\epsilon = 1{\cdot}72$.	$\epsilon - \omega = 0{\cdot}056$.	Rhombohedral cleavage. Colour emerald-green. Copper reactions. Yields water in closed tube. Decomposed and gelatinized by hydrochloric acid.
Hemimorphite ($H_2Zn_2SiO_5$). See p. 261.	5	3·4	6	$\alpha = 1{\cdot}613$.	$\gamma - \alpha = 0{\cdot}023$.	Prismatic cleavage perfect. Lustre vitreous. Gives off water in closed tube. Turns blue when moistened with cobalt nitrate, and re-heated in blowpipe flame. Decomposed by hydrochloric acid, with gelatinization.
Kyanite ($Al_2O_3 \cdot SiO_2$). See p. 302.	5	3·6	Infus.	$\alpha = 1{\cdot}717$.	$\gamma - \alpha = 0{\cdot}012$.	Occurs as long blade-shaped crystals. Pinakoidal cleavage perfect. Not decomposed by ordinary acids.
Smithsonite ($ZnCO_3$). See p. 260.	5	4·3	Infus.	High.	$\omega - \epsilon = 0{\cdot}20$.	Perfect rhombohedral cleavage. Turns green after moistening with cobalt nitrate and re-heating in blowpipe flame. Dissolves with effervescence in hot hydrochloric acid.

Mineral.	H.	Sp. Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
Sodalite See p. 299.	$5\frac{1}{2}$	2·3	4	1·48.	Isotropic.	Colourless or blue. Decomposed by hydrochloric acid and yields gelatinous silica. Nitric acid solution gives a white precipitate with silver nitrate.
Haüynite See p. 299.	$5\frac{1}{2}$	2·4	$4\frac{1}{2}$	1·5	Isotropic.	Usually blue. Sulphide reaction on silver coin after fusion with sodium carbonate. Decomposed by hydrochloric acid, yielding gelatinous silica, and solution gives a precipitate with barium chloride.
Leucite ($K_2O . Al_2O_3 . 4SiO_2$). See p. 406.	$5\frac{1}{2}$	2·5	Infus.	$\beta = 1{\cdot}508$.	Isotropic or nearly so.	White or grey. No water in closed tube. Violet flame-coloration. Decomposed by hydrochloric acid, but does not gelatinize.
Nepheline ($Na_2O . Al_2O_3 . 2SiO_2$). See p. 290.	$5\frac{1}{2}$	2·6	4	$\omega = 1{\cdot}543$.	$\omega - \epsilon = 0{\cdot}005$.	No good cleavage. Gem variety opalescent. Readily decomposed by hydrochloric acid, and yields gelatinous silica.
Tremolite ($CaO . 3MgO . 4SiO_2$). See p. 329.	$5\frac{1}{2}$	3	4	$\alpha = 1{\cdot}604$.	$\gamma - \alpha = 0{\cdot}026$.	White and fibrous. No water in closed tube. Fuses to a white globule. Not decomposed by ordinary acids.
Actinolite (ferriferous tremolite; see above).	$5\frac{1}{2}$	3·1	4	$\alpha = 1{\cdot}607$.	$\gamma - \alpha = 0{\cdot}027$.	Colour green. Fuses to a black globule. Not decomposed by ordinary acids.
Anthophyllite ($(Mg,Fe)O . SiO_2$). See p. 330.	$5\frac{1}{2}$	3·1	$5\frac{1}{2}$	$\alpha = 1{\cdot}633$.	$\gamma - \alpha = 0{\cdot}024$.	Pinkish or brownish fibres, more brittle than the finely fibrous varieties of tremolite and chrysotile. Fuses with difficulty to a black globule. No water in closed tube. Not decomposed by ordinary acids.
Hornblende (Calcium, magnesium, iron, and aluminium silicate). Monoclinic.	$5\frac{1}{2}$	3·2	$3\frac{1}{2}$	$\alpha = 1{\cdot}64$ to $1{\cdot}68$.	$\gamma - \alpha = 0{\cdot}016$ to $0{\cdot}072$	Green or brownish black. Perfect prismatic cleavage. Cleavage angle 124°. Extinction angle on prism face about 15°. Fuses to a magnetic globule. Insoluble in hydrochloric acid.
Enstatite ($(Mg,Fe)O . SiO_2$). See p. 291.	$5\frac{1}{2}$	3·2	Infus.	$\gamma = 1{\cdot}66$.	$\gamma - \alpha = 0{\cdot}009$.	Good prismatic cleavage. Slightly pleochroic. Not decomposed by ordinary acids.

Mineral.	H.	Sp. Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
DIOPSIDE ($CaO . MgO . 2SiO_2$). See p. 289.	5½	3·3	4	$\gamma = 1·7$.	$\gamma - \alpha =$ 0·030.	Colourless or pale green. Non-pleochroic. Good prismatic cleavage. Insoluble in ordinary acids.
AUGITE (Silicate of calcium, magnesium, iron and aluminium). Monoclinic.	5½	3·3	4	$\alpha = 1·71$.	$\gamma - \alpha =$ 0·025.	Greenish or brownish black. Prismatic cleavage. Prism angle 87°. Extinction angle on prism face about 33°. Fuses to a magnetic globule. Insoluble in hydrochloric acid.
HYPERSTHENE ($(Mg, Fe)OSiO_2$). See p. 299.	5½	3·4	5	$\gamma = 1·705$.	$\gamma - \alpha =$ 0·013.	Brown, usually with a bronzy sheen. Strongly pleochroic. Slightly decomposed by hydrochloric acid.
TITANITE ($CaO . SiO_2 . TiO_2$). See p. 316.	5½	3·5	3½	$\gamma = 2$.	$\gamma - \alpha =$ 0·121.	Crystals wedge-shaped. Cleavage, imperfect. Violet bead with microcosmic salt in reducing flame. Decomposed by hydrochloric acid.
LIMONITE See p. 195.	5½	3·8	5½	Very high.	Amorphous	See p. 448.
WILLEMITE ($2ZnO . SiO_2$). See p. 262.	5½	4·1	5	$\epsilon = 1·71$.	$\epsilon - \omega =$ 0·02.	Basal cleavage. Gives no water in closed tube. Decomposed by hydrochloric acid, and yields gelatinous silica.
GOETHITE See p. 196.	5½	4·2	5½	Very high.	Anisotropic.	See p. 449.
TURITE ($2Fe_2O_3 . H_2O$). Massive.	5½	4·4	5½	Very high.	—	See p. 449.
MONAZITE [$(Ce, Th)PO_4$]. See p. 426.	5½	5·2	Infus.	$\alpha = 1·796$.	$\gamma - \alpha =$ 0·045.	Usually yellow, especially when in the form of sand grains. Flame-coloration bluish green when moistened with sulphuric acid. Decomposed by sulphuric acid.
SAMARSKITE (Niobate of uranium, etc.) See p. 434.	5½	5·6	5	High	Generally isotropic.	Black or brownish black. Dark reddish-brown streak. Lustre pitchy. Decrepitates in closed tube. Uranium and niobium reactions.
HÜBNERITE See p. 251.	5½	7·4	3	—	—	See p. 450.
WOLFRAMITE See p. 251.	5½	7·2	3	—	—	See p. 450.
URANINITE See p. 431.	5½	9·5	Infus.	—	—	See p. 451.

MINERALS WITH A NON-METALLIC LUSTRE—*Contd.*

Mineral.	H.	Sp. Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
OPAL ($SiO_2 + xH_2O$). See p. 306.	6	2·1	Infus.	About 1·45.	Isotropic.	Amorphous. No cleavage. Conchoidal fracture. Becomes opaque in blowpipe flame. Soluble in caustic potash.
ORTHOCLASE ($K_2O . Al_2O_3 . 6SiO_2$). See p. 295.	6	2·56	5	$\alpha = 1·519$.	$\gamma - \alpha =$ 0·006.	Two good cleavages intersecting at an angle of 90°. Potash flame reaction when mixed with gypsum. No cross twin-striations on basal cleavage flakes. Not decomposed by hydrochloric acid.
MICROCLINE ($K_2O . Al_2O_3 . 6SiO_2$). See p. 295.	6	2·56	5	$\alpha = 1·519$.	$\gamma - \alpha =$ 0·006.	Two good cleavages intersecting at 89° 30′. Cross twin-striations between crossed nicols on basal cleavage flakes. Acts chemically like orthoclase (see above).
TURQUOISE ($2Al_2O_3 . P_2O_5 . 5H_2O$). See p. 319.	6	2·7	Infus.	About 1·62.	Isotropic or nearly so.	Blue or bluish green. Amorphous or cryptocrystalline. No cleavage. Darkens and gives off water in closed tube. Green flame-coloration. Decomposed by hydrochloric acid.
OLIGOCLASE See p. 295.	6	2·64	4½	$\alpha = 1·54$.	$\gamma - \alpha =$ 0·007.	Two good cleavages intersecting at 86° 20′. Lamellar twinning on basal cleavage plates between crossed nicols. Not decomposed by hydrochloric acid.
LABRADORITE See p. 295.	6	2·71	4½	$\alpha = 1·555$.	$\gamma - \alpha =$ 0·008.	Two good cleavages intersecting at 86° 12′. Lamellar twinning on basal cleavage plates between crossed nicols. Slowly decomposed by hydrochloric acid.
RHODONITE ($MnSiO_3$). See p. 215.	6	3·5	3	$\gamma = 1·74$.	$\gamma - \alpha =$ 0·020.	Usually compact. Uneven fracture. Manganese bead reactions. Decomposed by hydrochloric acid.
AMBLYGONITE See p. 380.	6	3	2	$\alpha = 1·57$.	$\gamma - \alpha =$ 0·018.	Perfect cleavage. Flame-coloration red if not much sodium present, green after moistening with sulphuric acid. Decomposed by sulphuric acid.
CHROMITE See p. 167.	6	4·3	Infus.	Very high.	Isotropic.	See p. 451.
HÆMATITE See p. 194.	6	5	5½	$\epsilon = 2·94$	$\omega - \epsilon =$ 0·28.	See p. 451.

Mineral.	H.	Sp. Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
THORIANITE (oxide of thorium and uranium). See p. 429.	6	9·5	Infus.	Very high.	Isotropic.	Black, and occurs usually in the form of cubes. Uranium bead reactions. Decomposed by hot sulphuric acid.
PREHNITE ($2CaO . Al_2O_3 . 3SiO_2 . H_2O$). See p. 309.	6½	2·9	2	$\gamma = 1{\cdot}649$.	$\gamma - \alpha = 0{\cdot}033$.	Usually pale green. Fuses readily with intumescence and yields a white bubbly glass. Yields water in a closed tube. Decomposed by hydrochloric acid.
SPODUMENE ($Li_2O . Al_2O_3 . 4SiO_2$). See p. 315.	6½	3·1	3½	$\gamma = 1{\cdot}67$.	$\gamma - \alpha = 0{\cdot}021$.	Good prismatic cleavage. Fuses to a clear glass. Red flame-coloration. Not decomposed by hydrochloric acid.
AXINITE (a borosilicate of lime, etc.). See p. 273.	6½	3·3	2	$\gamma = 1{\cdot}68$.	$\gamma - \alpha = 0{\cdot}009$.	Usually in acute-edged crystals. Conchoidal fracture. Strongly pleochroic. Intumesces in blowpipe-flame. Insoluble in ordinary acids.
NEPHRITE ($CaO . 3(Mg,Fe)O . 4SiO_2$). See p. 304.	6½	3	4	$\gamma = 1{\cdot}636$.	$\gamma - \alpha = 0{\cdot}025$.	Compact texture. No cleavage. Splintery fracture. Not decomposed by ordinary acids.
VESUVIANITE (a silicate of lime, aluminium, etc). See p. 320.	6½	3·4	3	$\omega = 1{\cdot}722$.	$\omega - \epsilon = 0{\cdot}001$.	No good cleavage. Fuses to a brownish or greenish glass. Not appreciably decomposed by hydrochloric acid.
EPIDOTE (a silicate of lime, aluminium, etc). See p. 291.	6½	3·4	3½	$\gamma = 1{\cdot}767$.	$\gamma - \alpha = 0{\cdot}040$.	Colour, dark green. Strongly pleochroic. Perfect basal cleavage. Partially decomposed by hydrochloric acid.
OLIVINE $2(Mg, Fe)O . SiO_2$. See p. 305.	6½	3·4	Infus.	$\gamma = 1{\cdot}697$.	$\gamma - \alpha = 0{\cdot}036$.	Yellowish to green. No good cleavage. Decomposed by hydrochloric acid, yielding gelatinous silica.
BENITOITE ($BaO . TiO_2 . 3SiO_2$). See p. 274.	6½	3·65	3	$\epsilon = 1{\cdot}804$.	$\epsilon - \omega = 0{\cdot}047$.	Sapphire-blue. Strongly pleochroic. Conchoidal fracture. Insoluble in ordinary acids.
RUTILE (TiO_2). See p. 247.	6½	4·2	Infus.	$\epsilon = 2{\cdot}9$.	$\epsilon - \omega = 0{\cdot}28$.	Reddish black to black. Prismatic cleavage. Titanium bead reactions. Readily soluble in fused $KHSO_4$, and the fused mass, when dissolved in HCl, and reduced with metallic tin, yields a violet solution.

Mineral.	H.	Sp. Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
BADDELEYITE (ZrO_2). See p. 436.	6½	5·7	6	High.	High.	Black or brownish black. Good basal cleavage. Answers zirconium test with turmeric paper when fused in sodium carbonate, and fused mass dissolved in dilute hydrochloric acid.
CASSITERITE (SnO_2). See p. 241.	6½	7	Infus.	$\epsilon = 2{\cdot}09$.	$\epsilon - \omega$ 0·100.	Uneven fracture. Globules of tin on charcoal with sodium carbonate and powdered charcoal. A grain placed on zinc in a drop of hydrochloric acid becomes covered with a white metallic skin.
CHALCEDONY (SiO_2). See p. 277.	7	2·6	Infus.	About 1·54.	Low.	Mammiform. Compact texture. Uneven fracture. Insoluble in ordinary acids.
QUARTZ (SiO_2). See p. 309.	7	2·65	Infus.	$\epsilon = 1{\cdot}553$.	$\epsilon - \omega =$ 0·009.	No cleavage. Conchoidal fracture. Dissolves with effervescence when fused with sodium carbonate, but insoluble in fused microcosmic salt. Insoluble in ordinary acids, but dissolves readily in hydrofluoric acid.
BORACITE ($Mg_7Cl_2B_{16}O_{30}$). Cubic.	7	3	2½	About 1·67.	Low.	Conchoidal fracture. Green flame-coloration; azure blue in microcosmic salt with copper oxide. Decomposed by hydrochloric acid.
JADEITE ($Na_2O . Al_2O_3 4SiO_2$). See p. 300.	7	3·3	2½	About 1·66.	Compact texture.	No cleavage. Splintery fracture. Fuses readily to a bubbly glass. Strong yellow flame-coloration. Not decomposed by ordinary acids.
GROSSULARITE ($3CaO . Al_2O_3 . 3SiO_2$). See p. 297.	7	3·5	3	1·76.	Isotropic.	Colour yellow or dull greenish. Fracture uneven. Not decomposed by hydrochloric acid.
KYANITE ($Al_2O_3 . SiO_2$). See p. 302.	7	3·6	Infus.	$\alpha = 1{\cdot}717$.	$\gamma - \alpha =$ 0·012.	Occurs as long blade-shaped crystals. Pinakoidal cleavage perfect. Not decomposed by ordinary acids.
ANDRADITE ($3CaO . Fe_2O_3 . 3SiO_2$. See p. 297.	7	3·9	3	1·88 (Demantoid).	Isotropic.	Yellow or green. Fracture uneven. Decomposed by hydrochloric acid.

Mineral.	H.	Sp. Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
CORDIERITE [$2(Mg, Fe)O . 2Al_2O_3 . 5SiO_2$]. See p. 281.	7½	2·6	5	γ=1·54.	$\gamma-\alpha$= 0·008.	Blue and strongly pleochroic. No distinct cleavage. Insoluble in ordinary acids.
BERYL ($3BeO . Al_2O_3 . 6SiO_2$). See p. 274.	7½	2·7	5½	ω=1·584.	$\omega-\epsilon$= 0·006.	No good cleavage. Usually as good crystals showing hexagonal shape. Insoluble in ordinary acids, and not readily attacked by hydrofluoric acid.
PHENAKITE ($2BeO . SiO_2$). See p. 308.	7½	3	Infus.	ω= 1·654.	$\epsilon-\omega$= 0·015.	Usually colourless. No good cleavage. Yields a white enamel when fused with sodium carbonate. Not decomposed by hydrochloric acid.
TOURMALINE (a borosilicate of aluminium, iron, etc.). See p. 317.	7½	3·1	3–5.	ω=1·64.	$\omega-\epsilon$= 0·020.	No good cleavage. Pleochroism very strong. Transient green flame-coloration when heated on platinum wire with a mixture of potassium bisulphate and calcium fluoride. Not decomposed by ordinary acids.
EUCLASE ($2BeO . Al_2O_3 . 2SiO_2 . H_2O$). See p. 292.	7½	3·1	5½	About 1·66.	$\gamma-\alpha$= 0·019.	Pleochroic when coloured. Perfect cleavage. Not decomposed by ordinary acids.
ANDALUSITE ($Al_2O_3 . SiO_2$). See p. 270.	7½	3·2	Infus.	α=1·632.	$\gamma-\alpha$= 0·011.	Imperfect prismatic cleavage. Strongly pleochroic. Blue colour after moistening with cobalt nitrate and re-heating in blowpipe flame. Insoluble in ordinary acids.
STAUROLITE (a silicate of aluminium, iron, etc.). See p. 303.	7½	3·7	Infus.	α=1·73.	$\gamma-\alpha$= 0·010.	Brown. Strongly pleochroic. Fracture uneven. Not decomposed by hydrochloric acid.
PYROPE ($3MgO . Al_2O_3 . 3SiO_2$). See p. 298.	7½	3·7	4	1·77	Isotropic.	Crimson-red. Fracture uneven. Not decomposed by hydrochloric acid.
SPESSARTITE ($3MnO . Al_2O_3 . 3SiO_2$). See p. 297.	7½	3·8	3	1·81.	Isotropic.	Red or brownish red. Fracture uneven. Manganese bead reactions. Not decomposed by hydrochloric acid.
ALMANDINE ($3FeO . Al_2O_3 . 3SiO_2$). See p. 297.	7½	about 4·0	3	1·78.	Isotropic.	Deep red colour. Fracture uneven. Fuses to a black magnetic globule. Not decomposed by hydrochloric acid.

Mineral.	H.	Sp. Gr.	Fus.	Refr. Index.	Biref.	Other Characteristics.
ZIRCON ($ZrO_2 . SiO_2$). See p. 321.	7½	4·7	Infus.	$\epsilon = 1·99$	$\epsilon - \omega =$ 0·062.	No good cleavage. Conchoidal fracture. In Bunsen flame brown varieties turn reddish, and smoky varieties pale green. Not decomposed by ordinary acids.
TOPAZ ($2AlF_3 . 2Al_2O_3 . 3SiO_2$). See p. 316.	8	3·5	Infus.	$\gamma = 1·622$.	$\gamma - \alpha =$ 0·009.	Basal cleavage perfect. Usually very clear and transparent. Turns blue after being moistened with cobalt nitrate and reheated in blowpipe flame. Not decomposed by hydrochloric acid.
SPINEL ($MgO . Al_2O_3$). See p. 314.	8	3·6	Infus.	1·72	Isotropic.	No cleavage. Fracture conchoidal. Usually in the form of octahedral crystals. Insoluble in ordinary acids.
CHRYSOBERYL ($BeO . Al_2O_3$). See p. 279.	8½	3·7	Infus.	$\gamma = 1·75$.	$\gamma - \alpha =$ 0·009	Yellow and slightly pleochroic, or green and strongly pleochroic. Cleavage imperfect. Blue after moistening with cobalt nitrate and re-heating in blowpipe flame. Insoluble in ordinary acids.
CORUNDUM (Al_2O_3). See p. 282.	9	4	Infus.	$\omega =$ 1·767.	$\omega - \epsilon =$ 0·008.	Pleochroic when coloured. Often shows basal and rhombohedral parting planes, which give rise to triangular striations on basal plane. Insoluble in ordinary acids.
DIAMOND (C). See p. 285.	10	3·5	Infus.	2·417.	Isotropic	Lustre adamantine. Insoluble in acids. Distinguished from other minerals by its extreme hardness and high refractive power.

LIST OF ECONOMIC MINERALS ARRANGED IN ORDER OF SPECIFIC GRAVITY.

Hardness is given in the second column to facilitate reference to the main tables, in conjunction with which this subsidiary list will be found useful.

Mineral.	Sp. Gr.	Hardness.	Mineral.	Sp. Gr.	Hardness.
Ozokerite	0·9	1	Lepidolite	2·9	2½
Amber	1·05	2½	Biotite	2·9	2½
Meerschaum	1·2	2½	Prehnite	2·9	6½
Mirabilite	1·5	1½	Erythrite	3·0	2
Carnallite	1·6	1	Cryolite	3·0	2½
Bischofite	1·65	1	Ankerite	3·0	3½
Ulexite	1·65	1	Magnesite	3·0	3½
Borax	1·7	2½	Tremolite	3·0	5½
Epsomite	1·7	2½	Amblygonite	3·0	6
Sulphur	2·0	2	Nephrite	3·0	6½
Sylvite	2·0	2½	Boracite	3·0	7
Graphite	2·1	1	Phenakite	3·0	7½
Halloysite	2·1	1½	Annabergite	3·1	2
Nitre	2·1	2	Autunite	3·1	2½
Trona	2·1	2½	Actinolite	3·1	5½
Kainite	2·1	2½	Anthophyllite	3·1	5½
Opal	2·1	6	Spodumene	3·1	6½
Bentonite	2·2	1	Euclase	3·1	7½
Nitratine	2·2	1½	Tourmaline	3·1	7½
Halite	2·2	2½	Breunnerite	3·15	3½
Chalcanthite	2·2	2½	Scorodite	3·2	3½
Chrysocolla	2·2	3	Fluorite	3·2	4
Gypsum	2·3	2	Crocidolite	3·2	4
Wavellite	2·3	3½	Apatite	3·2	5
Sodalite	2·3	5½	Hornblende	3·2	5½
Hydrargillite	2·35	3	Enstatite	3·2	5½
Colemanite	2·4	4½	Andalusite	3·2	7½
Haüynite	2·4	5½	Dioptase	3·3	5
Garnierite	2·4	3	Diopside	3·3	5½
Serpentine	2·5	4	Augite	3·3	5½
Chrysotile	2·5	4	Jadeite	3·3	6½
Leucite	2·5	5½	Axinite	3·3	6½
Kieserite	2·55	3½	Hemimorphite	3·4	5
Bauxite	2·55	Variable	Hypersthene	3·4	5½
Orthoclase	2·56	6	Vesuvianite	3·4	6½
Microcline	2·56	6	Epidote	3·4	6½
Nepheline	2·6	5½	Olivine	3·4	6½
Chalcedony	2·6	7	Orpiment	3·5	1½
Cordierite	2·6	7½	Realgar	3·5	1½
Oligoclase	2·64	6	Torbernite	3·5	2½
Quartz	2·65	7	Rhodochrosite	3·5	4
Talc	2·7	1	Titanite	3·5	5½
Steatite	2·7	1	Rhodonite	3·5	6
Alunite	2·7	4	Grossularite	3·5	7
Turquoise	2·7	6	Topaz	3·5	8
Beryl	2·7	7½	Diamond	3·5	10
Labradorite	2·71	6	Triphylite	3·6	4½
Calcite	2·72	3	Kyanite	3·6	5 to 7
Polyhalite	2·77	2½	Spinel	3·6	8
Pyrophyllite	2·8	1½	Benitoite	3·65	6½
Muscovite	2·8	2½	Hydrozincite	3·7	2½
Phlogopite	2·85	2½	Strontianite	3·7	3½
Dolomite	2·85	3½	Staurolite	3·7	7½

LIST OF SPECIFIC GRAVITIES—*Contd.*

Mineral.	Sp. Gr.	Hardness.	Mineral.	Sp. Gr.	Hardness.
Pyrope	3·7	7½	Kerargyrite	5·5	2
Chrysoberyl	3·7	8½	Valentinite	5·55	2½
Atacamite	3·75	3½	Proustite	5·6	2½
Azurite	3·8	3½	Millerite	5·6	3½
Siderite	3·8	4	Zincite	5·6	4½
Limonite	3·8	5½	Samarskite	5·6	5½
Spessartite	3·8	7½	Columbite	5·6	6
Demantoid	3·83	7	Chalcocite	5·7	2½
Celestite	3·9	3½	Arsenic	5·7	3½
Malachite	3·9	3½	Baddeleyite	5·7	6½
Brochantite	3·9	3½	Jamesonite	5·8	2½
Andradite	3·9	7	Bournonite	5·8	2½
Zinc-blende	4·0	3½	Pyrargyrite	5·8	2½
Alabandite	4·0	3½	Bromyrite	5·9	2
Ilvaite	4·0	5½	Glaucodote	5·95	5½
Almandine	4·0	7½	Crocoite	6·0	2½
Corundum	4·0	9	Cuprite	6·0	3½
Willemite	4·1	5½	Tenorite	6·0	3½
Chalcopyrite	4·2	4	Descloizite	6·0	3½
Goethite	4·2	5½	Scheelite	6·0	4½
Rutile	4·2	6½	Arsenopyrite	6·0	5½
Witherite	4·3	3½	Gersdorffite	6·0	5½
Manganite	4·3	4½	Pearceite	6·1	3
Smithsonite	4·3	5	Cobaltite	6·1	5½
Psilomelane	4·3	6	Tellurium	6·2	2½
Chromite	4·3	6	Stephanite	6·2	2½
Enargite	4·4	3	Polybasite	6·2	2½
Stannite	4·4	4	Stromeyerite	6·2	2½
Turite	4·4	5½	Smaltite	6·2	5
Kermesite	4·5	1½	Anglesite	6·3	3
Barite	4·5	3	Bismuthinite	6·5	2½
Pyrrhotite	4·5	4½	Cerussite	6·5	3½
Covellite	4·6	1½	Antimony	6·6	3½
Stibnite	4·6	2½	Chloanthite	6·6	5½
Tennantite	4·6	3½	Wulfenite	6·7	3
Molybdenite	4·7	1	Vanadinite	7·0	3
Ilmenite	4·7	5½	Pyromorphite	7·0	3½
Zircon	4·7	7½	Cassiterite	7·0	6½
Pyrolusite	4·8	2	Mimetite	7·1	3½
Livingstonite	4·8	2	Argentite	7·2	2½
Greenockite	4·8	3½	Bismutite	7·2	4½
Tetrahedrite	4·8	3½	Hübnerite	7·2	5½
Xenotime	4·8	4½	Wolframite	7·4	5½
Hausmannite	4·8	5½	Iron	7·4	5
Braunite	4·8	6½	Tetradymite	7·5	1½
Linnœite	4·9	5½	Galena	7·5	2½
Marcasite	4·9	6½	Niccolite	7·5	5½
Freibergite	5·0	3½	Tantalite	7·5	6½
Bornite	5·0	3½	Sylvanite	8·0	2
Pentlandite	5·0	4	Cinnabar	8·1	2½
Magnetite	5·0	5	Krennerite	8·3	2½
Haematite	5·0	6	Hessite	8·5	2½
Pyrite	5·0	6½	Copper	8·7	2½
Thorite	5·2	4½	Petzite	8·9	2½
Monazite	5·2	5½	Calaverite	9·0	2½
Franklinite	5·2	6	Uraninite	9·5	5½
Senarmontite	5·25	2½	Thorianite	9·5	6

LIST OF SPECIFIC GRAVITIES—*Contd.*

Mineral.	Sp. Gr.	Hardness.	Mineral.	Sp. Gr.	Hardness.
Bismuth	9·8	2½	Gold	15–19	2½
Silver	10·5	3	Platinum	16–19	4½
Sperrylite	10·6	6½	Iridosmium	20	6½
Mercury	13·6	—	Iridium	22·5	6½
Electrum	13–16	2½			

LIST OF MINERALS HAVING METALLIC LUSTRE GROUPED ACCORDING TO COLOUR, WITH HARDNESS SUBJOINED.

WHITE.

Mercury	—
Tetradymite	1½
Sylvanite	2
Tellurium	2½
Krennerite	2½
Calaverite	2½
Bismuth	2½
Electrum	2½
Silver	3
Arsenic	3½
Antimony	3½
Smaltite	5
Glaucodote	5½
Gersdorffite	5½
Arsenopyrite	5½
Cobaltite	5½
Chloanthite	5½
Marcasite	6½
Sperrylite	6½
Osmiridium	6½
Iridium	6½

BLACK.

Graphite	1
Molybdenite	1
Covellite	1½
Pyrolusite	2
Jamesonite	2½
Stephanite	2½
Polybasite	2½
Argentite	2½
Enargite	3
Pearceite	3
Alabandite	3½
Tennantite	3½
Tenorite	3½
Manganite	4½
Ilvaite	5½
Turite	5½
Ilmenite	5½
Hausmannite	5½
Magnetite	5½
Wolframite	5½
Uraninite	5½
Chromite	6
Psilomelane	6
Haematite	6
Franklinite	6
Columbite	6
Thorianite	6
Braunite	6½
Rutile	6½
Cassiterite	6½
Tantalite	6½

GREY.

Livingstonite	2
Stibnite	2½
Chalcocite	2½
Bournonite	2½
Stromeyerite	2½
Bismuthinite	2½
Galena	2½
Hessite	2½
Petzite	2½
Famatinite	3½
Tetrahedrite	3½
Freibergite	3½
Stannite	4
Platinum	4½
Iron	5
Linnæite	5½

RED.

Copper	2½
Cuprite	3½
Niccolite	5½
Hæmatite	6

REDDISH BROWN.

Bornite	3½
Hübnerite	5½

BROWN.

Limonite	5½
Goethite	5½

YELLOW.

Calaverite	2½
Gold	2½
Millerite	3½
Chalcopyrite	3½
Pentlandite	4
Pyrrhotite	4½
Marcasite	6½
Pyrite	6½

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