







# TEXT-BOOK OF PETROLOGY

CONTAINING

A DESCRIPTION OF THE ROCK-FORMING MINERALS  
AND A SYNOPSIS OF THE CHIEF TYPES  
OF IGNEOUS ROCKS

BY

FREDERICK H. HATCH, PH.D.

*Fellow of the Geological Society; Member of the Institution of Civil  
Engineers; Member of the Institution of Mining and Metallurgy;  
and formerly of the Geological Survey of the United Kingdom*

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## PREFACE TO THE FIRST EDITION.

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A LITTLE book that should briefly describe the mineral constituents and internal structures of the Igneous Rocks, their mode of occurrence at the surface and their origin beneath the crust of the earth, has long been a *desideratum* among English text-books of Science.

With the view of filling this gap this treatise has been prepared ; and it is hoped that it will be found useful, not only as an introduction to the subject, but also as a handy work of reference.

Von Lasaulx's *Einleitung in die Petrographie* served me as a model in the first instance ; but in working out my scheme I have thought it desirable to deviate considerably from the

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arrangement adopted in that excellent little book. In the verification of data Rosenbusch's *Mikroskopische Physiographie* (2 vols.), Fouqué and Lévy's *Minéralogie Micrographique*, Lévy and Lacroix's *Les Minéraux des Roches* and Teall's *British Petrography* have been of great assistance to me; and the illustrations are, in many cases, taken from these works. I have also to thank the Council of the Geological Society and the Editor of the Geological Magazine for permission to reproduce illustrations that have appeared in their journals. The work has profited much by a careful revision of the proof sheets kindly undertaken by Mr. A. Pringle, M.A., B.Sc., of the Museum of Practical Geology, London.

F. H. H.

Nov., 1890.

28, JERMYN STREET  
LONDON, S.W.

## PREFACE TO THE SECOND EDITION.

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I HAVE taken advantage of the opportunity offered by the exhaustion of the first edition of my "Introduction to Petrology" to thoroughly revise the book, while largely increasing its scope. I have been encouraged to do this both by the favourable notices the book has received from its reviewers and the kind hints proffered me by numerous friends. For valuable suggestions and assistance I have especially to thank the following gentlemen:—Professors T. G. Bonney and J. W. Judd, and Messrs. G. Barrow, A. Harker, J. Hort Player, J. J. H. Teall, and W. W. Watts. Mr. Pringle has again been kind enough to revise the proofs.

I have also to acknowledge my indebtedness to Mr. Hinman's *Eclectic Physical Geography* (American Book Co., New York) for the three illustrations forming figures 2, 5 and 6 of my book.

FREDK. H. HATCH.

*July 15th, 1892.*

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# PETROLOGY.



## I.

### INTRODUCTION.

**Petrology** is that department of geological science which has for its object the investigation of the characters and relations of rocks, that is to say, of the various materials of which the earth's crust is built up. A **rock** may be defined as a mineral aggregate, possessing a more or less persistent geological character. In studying rocks, therefore, we have three points of departure: (1) their geological relations, or mode of occurrence; (2) their constituent minerals; and (3) the mode of aggregation of the constituent minerals, or rock-structure.

In classifying rocks, we must allow each of these factors its proper value. The exclusive use of one of them would lead to incongruous results. Two or more rocks, for example, may be composed of the same minerals and yet have originated in totally dissimilar ways, the result being a difference both in structure and in mode of occurrence. Thus, a

granite, a felspathic grit and a gneiss may all three be composed of quartz, felspar, and mica; but in structure and mode of origin they differ widely. The granite has been produced by the consolidation of a molten magma or paste at some considerable depth beneath the surface: hence it possesses a coarse-grained, highly crystalline structure. The grit, on the other hand, is composed of fragments of minerals, that have been derived from the disintegration of other rocks, and transported and deposited by the agency of moving water. Lastly, in gneiss there is a banded structure, generally considered to have been produced by a re-arrangement of the minerals since the first formation of the rock.<sup>1</sup>

The three rocks made use of in our example, may be taken as types of the three chief classes into which rocks may be divided; viz., **Igneous**, **Aqueous** and **Metamorphic**.

In the following pages it is proposed to discuss briefly the characters, origin and distribution of the chief Igneous rocks.

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<sup>1</sup> The banding of some gneisses, however, possibly took place before final consolidation, and is comparable to "fluxion-structure" in lavas.

## II.

### MODE OF OCCURRENCE.

THE Igneous Rocks are those that have been formed by the consolidation of molten material. We have good reason for believing that the temperature of the interior of the earth is very high—high enough, indeed, to melt all rocks with which we are acquainted at the surface. It is probable, however, that the liquefaction of the igneous masses is held in check by the enormous pressure existing at such great depths. The discussion of this question need not detain us. For, whether the interior of the earth is occupied by rock in the molten condition, or by solid material at a sufficiently high temperature to become liquid under a diminished pressure, the ultimate result is the same: at the moment of eruption the pressure is relieved and the liquid rock injected in the direction of least resistance. According to the nature of the resistance presented by the environment, the molten rock pierces the solid crust of the earth to a greater or less distance; perhaps, ultimately reaching the surface and flowing out in

the form of lava, or being reduced by the violence of the explosion to cinders, or even to fine ash.

This consideration leads to a two-fold division of igneous rocks; namely, into those that consolidate at considerable depths beneath the surface, and those that penetrate to upper portions of the crust and are poured out upon the surface. The former are termed **plutonic**, the latter **volcanic** rocks. The different conditions under which plutonic and volcanic rocks consolidate, are the cause of considerable differences in structure. In the one case the gradual consolidation necessitated by the slow rate of cooling, accompanied perhaps by a considerable amount of pressure, produces a highly crystalline and coarse-grained texture; while the rapid hardening of a lava, chilled by being poured out at the surface and spread over a large area of cold rock, and subject, moreover, to a diminished pressure, imparts to it a vitreous character. Granite and rhyolite—rocks of similar chemical and mineralogical composition—illustrate this difference. The granite is wholly crystalline, its large crystals completely filling space to the exclusion of all interstitial matter; while in the rhyolite the crystals are imbedded in a glassy or a devitrified paste, the streaky character of which often betrays its former viscous condition.

Volcanic rocks are connected with their deep-seated or plutonic roots by necks and pipes, or by a

ramifying system of dykes and veins. The plutonic masses also send off into the surrounding rocks tongues or apophyses, which do not reach the surface, and in some cases even the superficial strata are pierced by dykes and sheets of igneous material that have found no actual outlet. (See Fig. 1.) All such igneous masses, penetrating older rocks, are termed **intrusive**. They form the connecting link between plutonic and volcanic rocks.

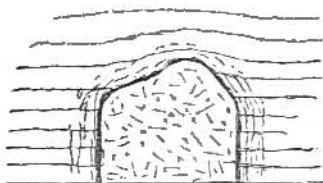


FIG. 1.

Showing the upper termination of a dyke. (After Teall.)

The plutonic rocks, being essentially deep-seated, can only appear at the surface in places where there has been much denudation, the overlying strata having been then removed by erosive agencies (frost, rain, fluvial and marine action, etc.); unless, as sometimes happens, they have been upraised by powerful earth movements. They are therefore exposed more frequently in the older than in the younger strata. For this reason granites, syenites, diorites, gabbros and similar plutonic rocks are considered by some geologists to have been formed only

in Pre-Tertiary times. That this view is erroneous has been shown in places where the denuding agencies have been sufficiently powerful to expose plutonic rocks of comparatively recent age, as in the Western Isles of Scotland, where granites and gabbros, etc., have been intruded into bedded basalts of Tertiary age.

The shape assumed by an intrusive rock is of necessity regulated by the nature of the passage along which it is injected; or, in the words of Sir Archibald Geikie,<sup>1</sup> the shape of the intrusive mass is that of the "channel of escape." On the other hand, volcanic rocks erupted at the surface appear in beds or streams.

The following terms are used in describing the chief forms in which igneous rocks occur:—

**Boss.**—Any irregularly shaped mass. The outcrop often forms a roughly circular patch on the map, as in the case of Dartmoor and other granite masses in Devon and Cornwall. The plutonic rocks—granite, syenite, diorite and gabbro—occur frequently in bosses.

**Laccolite.**—A dome-shaped mass, produced by the intrusion of molten rock between two beds, where, having a limited lateral extension, it has *elevated* the overlying strata. This is one of the

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<sup>1</sup> "Text-book of Geology."

commonest forms in which igneous rocks occur. The out-crop produced by it is an "elongated oval, or lenticular patch, having the long axis in the direction of strike of the neighbouring strata."<sup>1</sup> Laccolites were first described by Mr. G. K. Gilbert<sup>2</sup> in the Henry Mountains of Utah, where they are very typically developed and well exposed. Many of the

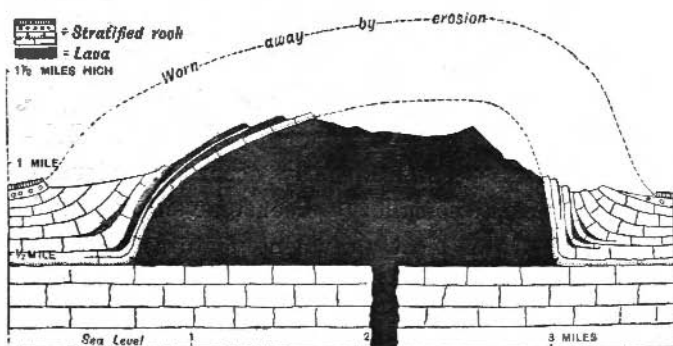


FIG. 2.

Laccolite forming Mount Hillers, Henry Mountains.

intrusive rocks of North Wales have an outcrop which indicates a laccolitic origin<sup>3</sup>; and the same is probably the case with some of the acid intrusives of the Central Highlands of Scotland.<sup>4</sup>

<sup>1</sup> Harker: "The Bala Volcanic Series," 1889, p. 43.

<sup>2</sup> Geology of the Henry Mountains, U. S. Geol. Survey, Washington, 1877.

<sup>3</sup> Harker: *l.c.* p. 43.

<sup>4</sup> According to information supplied by Mr. G. Barrow.

**Intrusive Sheet, or Sill.**—A flat bed of rock produced by the uniform intrusion of molten material between the planes of stratification. Such sheets are liable to be mistaken for contemporaneous lava-flows; from which, however, they may be distinguished by the following points of difference: (1) they break across the bedding, appearing here on one horizon, there on another; (2) they sometimes send off veins into the strata above them, as well as into those below them; (3) they alter the beds both above and below them; (4) they are rarely vesicular or amygdaloidal; (5) they are not accompanied by tuffs. Dolerites and diabases frequently occur in intrusive sheets; and the so-called “greenstone-sills” constitute one of the most prevalent features of many igneous areas (*e.g.*, in the English Lake District and in North Wales).

**Dykes and Veins.**—A dyke is a wall-like mass of igneous rock, produced by the injection of molten material into a vertical or highly inclined crack. Veins are produced by the infilling of smaller and less regular cracks. Dykes sometimes form marked features in the scenery of a district; for, being more capable of resisting the disintegrating action of the weather than the rocks they traverse, they remain standing, like huge walls, when the softer rocks have been worn away. Occasionally, however, they weather more rapidly than the surrounding material,



and then produce hollow troughs. Elvans, mica-traps, basalts, etc., occur as dykes; *e.g.*, the elvan

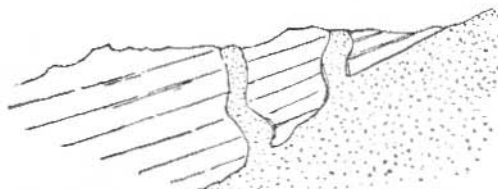


FIG. 3.

Section showing granite sending off veins into bedded rock. (*After De la Beche.*)

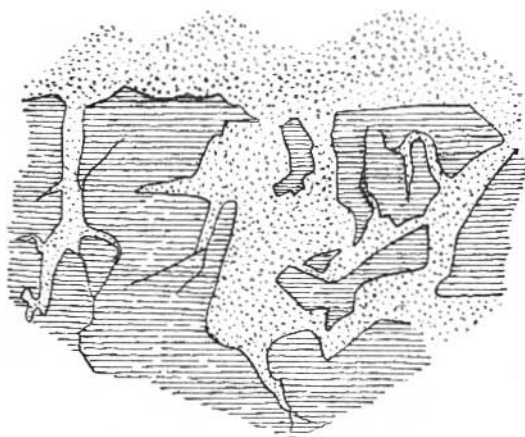


FIG. 4.

Plan showing granite veining slates. (*After De la Beche.*)

dykes of Cornwall, the mica-trap dykes of Yorkshire and Westmorland, the basalt dykes of the North of England and the West of Scotland.

**Necks.**—Necks are the filled-up pipes or vents by which the erupted material made its escape. Usually they are plugs of consolidated igneous rock, surrounded by beds of volcanic ejectamenta. Sometimes, however, they consist entirely of fragmentary material produced by the violence of the explosions

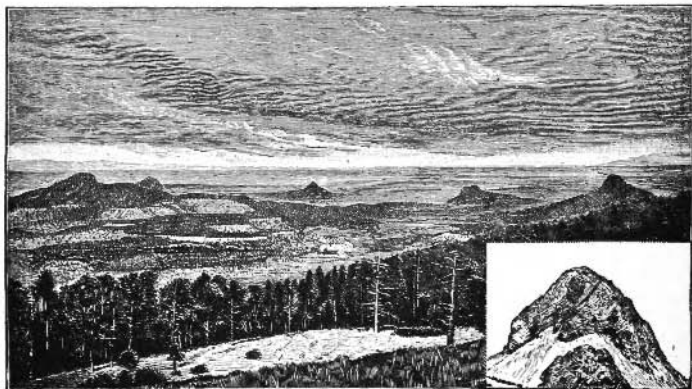


FIG. 5.

Volcanic necks in New Mexico, U.S.

that precede or accompany an eruption. Magnificent examples of both kinds of "necks" are abundantly represented among the Carboniferous volcanic rocks of the basin of the Firth of Forth in Scotland. They are also well developed in Western New Mexico. (See Fig. 5.)

**Lava-flows.**—Lava is the molten rock poured out from a volcanic vent. It forms beds or streams

of greater or less extent, according to the fluidity of the erupted material, the more basic magmas being usually the more fluid. Thus the Icelandic basalts flowed out in streams extending over a distance of forty to fifty miles; while, on the other hand, the more acid lavas (trachytes) of the Auvergne in Central France were erupted in such a viscous condition as to form hummocky or dome-shaped masses on consolidation. Lavas are often distinguished by marked flow-structures (ropy and stringy surfaces, internal streakiness, etc.), due to the rolling-over and pulling-out of the semi-solid mass. They are also characterized by a cellular, vesicular, or slaggy appearance in their superficial layers, owing to the liberation of dissolved vapours on eruption. The vesicles are usually elongated (*amygdaloidal* or almond-shaped), as a consequence of the differential movement of the rock before final consolidation.

When the flows take place in an area of deposition, *e.g.*, on a sea-bottom, the lava-beds lie upon and are covered by sedimentary rocks of practically the same age as themselves. In such cases they are said to be **contemporaneous** with the strata with which they are interbedded. Submarine eruptions have taken place since the earliest Palæozoic times, so that contemporaneous igneous rocks occur in formations of various ages. Bedded lavas constitute a striking feature in the physiography of certain parts

of the British Isles. Much of the beautiful scenery of North Wales and of the Lake District owes its origin to the great development of volcanic lavas (rhyolites and andesites) erupted in the Ordovician Period. The Cheviot andesites are of Old Red Sandstone Age. Plateaux of Carboniferous basalt cover large areas in the Midland Valley of Scotland, while

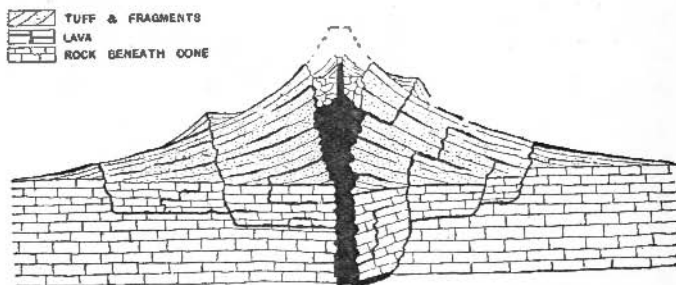


FIG. 6.

Ideal section of a volcano.

bedded basalts of Tertiary age are extensively developed in the north of Ireland and in the Western Isles of Scotland. Basalt-plateaux of a similar character, but on a much greater scale, occur in some of the Western States of North America (Idaho, Oregon, and Washington); and in India an area of 200,000 square miles is covered by the basaltic flows, known as the "Deccan traps."

**Volcanic Ash-beds, or Tuffs.**—When the erup-

tion is accompanied by explosion, the molten rock is ejected in the form of bombs, cinders (*lapilli*), and fine ash, which are deposited in layers. The consolidation of this material produces volcanic breccias or tuffs, according to the degree of coarseness of the fragments. The fragmentary material ejected from volcanoes often becomes mixed with the ordinary



FIG. 7.

A thin section of a volcanic tuff, showing its fragmental nature.  
(After Cole and Jennings.)

sediment on the sea bottom, causing the formation of ashy limestones and shales. Beds of tuff and breccia are associated, in greater or less degree, with the flows of the volcanic areas mentioned in the preceding paragraph.

### III.

#### STRUCTURE.

WHILE in the aqueous rocks the most characteristic feature is the stratification of the deposits, the igneous rocks are essentially unstratified. In general they may be said to possess a *massive*, in contradistinction to the *bedded* character of the sedimentary rocks through which they are usually intruded. There are, however, some cases in which rocks of igneous origin are traversed by horizontal divisional planes, which resemble those of stratification. Thus the intermittent outpouring of lava from a volcanic vent produces a rock which has a true bedded character, each bed representing a distinct flow. Again the differential movement of an igneous mass in a plastic or semi-solid condition causes it to assume a laminated or "fluidal" structure on consolidation. Flow-structures of this kind in rocks of igneous origin have occasionally been mistaken for stratification.<sup>1</sup> Horizontal jointing in massive rocks may also

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<sup>1</sup> The parallel structures produced in igneous rocks by dynamic or pressure metamorphism might also be instanced as examples of "pseudo-stratification."

simulate a thick-bedded character. Thus granite, when exposure to the corrosive action of the weather has brought out its divisional planes, often presents a rudely bedded appearance, which at a distance may be mistaken for stratification. (See Fig. 8.)

We have now to consider what structures are produced as a result of the consolidation of an igneous rock from a molten condition. Under this head reference must first be made to the divisional



FIG. 8.  
Mural jointing in granite.

planes that are developed by shrinkage or contraction in passing from the liquid to the solid state. The divisional planes known as **joints** are found in all varieties of igneous rock; and the appearance of a rock laid bare in a quarry or other section is to a large extent dependent on its mode of jointing. The joints may be disposed in an irregular manner, or the parallelism of one or more systems of divisional planes may impart a more or less definite structure to the rock. The "mural jointing" of granite which was referred to above, is mainly caused by a system



FIG. 9.

Perlite of Tokay, Hungary, under the microscope, illustrating Perlitic and Flow Structures. (After Foucaud and Lévy.)



FIG. 10.

Pitchstone of Bigg, under the microscope, showing Perlitic Structure. The central crystal is Sanidine. (After Teall.)



of roughly parallel planes. In some rocks the surfaces of separation appear to form the concentric shells of a large spherical system of jointing. This character is well exemplified in the rock known as phonolite, which has a tendency to split into slightly curved plates.<sup>1</sup> A micro-structure of a similar nature is frequently developed in vitreous rocks (*e.g.*, obsidian). This is known as the *perlitic structure*. In all such cases the concentric-laminated structure is produced by concentric fissuring due to contraction on cooling.

When the rock is traversed by two or more systems of "master-joints," a columnar structure results. Many igneous rocks present this mode of jointing, but the structure reaches its most perfect development in basalt. In this rock the columns, which are often very long and regular, are bounded by three, four, five, or six planes, producing triangular, quadrangular, pentagonal, and hexagonal prisms. In rocks having a very homogeneous texture the six-sided prisms are the most prevalent, for in this case the centres of contraction are equidistant and the angles of the prisms fit together without any intervening empty space. The long axis of the columns has been shown to be perpendicular to the surface at which the

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<sup>1</sup> The spheroidal weathering of some greenstones is perhaps due to a joint-system of this nature, the existence of which is only demonstrated by the facility it offers to the progress of decomposition.

greatest cooling took place. In accordance with this law the columns are usually vertical in horizontally bedded lavas, as at Staffa and the Giant's



FIG. 11.

Columnar Basalt, Giant's Causeway.

Causeway; while in a dyke they are perpendicular to its bounding wall. Occasionally the columns are subdivided into a series of superimposed tablets by a subsidiary cross-jointing. A good example of this is

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the Cheese Grotto which is pointed out to visitors to Bad Bertrich in the Eifel, Rhenish Prussia.

### MINUTE STRUCTURE.

The examination of a thin section of an igneous rock under the microscope shows that it is composed either entirely of crystals, or of crystals imbedded in a paste or ground-mass of a more or less imperfectly individualized substance. The internal structure of a rock depends mainly on the relation subsisting between the crystals and the ground-mass; it will vary according to the conditions under which the consolidation took place, since the crystals were formed by molecular aggregation in a rock-magma during the process of cooling. Rocks that from some cause were made to cool suddenly are composed entirely or in great measure of glass; but when the conditions were such as to allow of a gradual loss of heat, the molecules had time and opportunity to group themselves into definite mineral compounds, and a crystalline structure was the result.

**Vitreous Rocks.**—Sometimes it is the whole body of the rock that is vitreous, sometimes only a narrow “selvage” that has come into immediate contact with the cooling surface. This natural glass is, however, seldom completely devoid of crystalline material. Examined with the microscope, it is often found to contain numerous minute, spherical, rod-

shaped, and hair-like bodies, which represent the first products of crystallization. These bodies are in general termed *crystallites*. They are not crystals,



FIG. 12.  
Globulites.



FIG. 13.  
Margarites.

for they possess no distinct crystallographic form, nor do they react on polarized light. The different forms have received specific names: thus, the drop-like bodies are termed *globulites*; the rod-shaped ones, *belonites*; and the coiled and twisted hairs, *trichites*. (See Figs. 12-15.)



FIG. 14.  
Trichites.



FIG. 15.  
Belonites.

Besides crystallites there are small needle- and rod-shaped bodies which are known as *microlites*. They are distinguished from crystallites by the fact

that they do react on polarized light (becoming alternately light and dark when rotated between crossed nicols), and can generally be referred to some mineral species—felspar, augite, olivine, magnetite, etc. By combination of the simple microlitic forms, curiously forked and gridiron-like aggregates (*skeleton-crystals*) are produced. (See Figs. 16 and

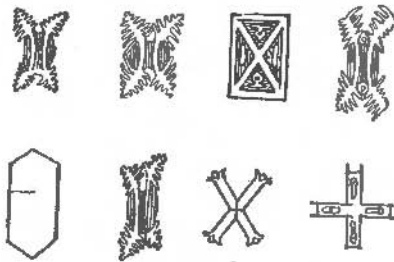


FIG. 16.

Skeleton-crystals of Olivine. (After Rosenbusch.)

17.) The linear arrangement of these various elementary bodies, and the way in which they sweep round the larger crystals, serve to indicate the once fluid nature of the vitreous rocks in which they are found (*fluxion- or flow-structure*). (See Fig. 9.)

An incipient form of crystallization often met with in vitreous rocks consists in the production of small spherical bodies, known as *spherulites*. These bodies, which vary in size from a millet-seed to a pea,



FIG. 17.

*Pitchstone of Arran, under the microscope, showing microlites and skeleton-crystals of Hornblende in a glassy base. (After Teall.)*

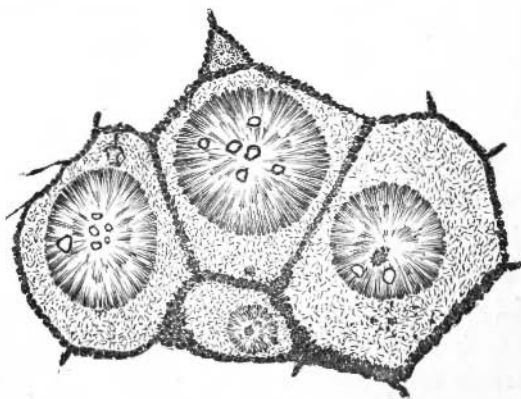


FIG. 18.

*Spherulitic Structure in a Felsite of Arran. (After Bonney.)*

present, when viewed under the microscope, a divergent fibrous structure, and are characterized between crossed nicols by a black cross, the arms of which are parallel to the short diagonals of the two nicols. These fibro-radial crystalline aggregates were pro-



FIG. 19.

Spherulitic Structure, between crossed nicols. (After Fouqué and Lévy.)

duced during the final period of consolidation, for streams of microlites sometimes pass straight through them, showing that the formation of crystals and the arrangement of them in lines of flow preceded the growth of the spherulites. (See Figs. 18 and 19.)

## CRYSTALLINE ROCKS.

In some intrusive and in most volcanic rocks there are two distinct phases of crystallization. The first phase consists in the formation of large or **porphyritic** crystals, which float in the molten magma and are sometimes corroded by it. This phase has been termed the *intra-telluric phase of crystallization*, because the crystals are produced before the eruption of the rock, while it is still in the interior. The second phase consists in the consolidation of the magma, which becomes the *ground-mass* in which the "porphyritic constituent" <sup>1</sup> is embedded. The ground-mass usually contains a second crop of smaller crystals of the porphyritic minerals, together with those minerals that only appear in the ground-mass. If the crystallization is complete, the ground-mass is wholly crystalline. More usually, however, a "residuum of crystallization," or mother-liquor, remains after the separation of the crystalline elements, and consolidates as interstitial glassy matter. This is termed the *glassy base*. If the rock is subsequently exposed to meteoric influence, devitrification takes place, and the glassy base is replaced by a *felsitic base*, that is to say a cryptocrystalline

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<sup>1</sup> Iddings (*Bull. Phil.*, Wash., vol. ii. 1889, p. 73) suggests the term *phenocryst*, and Blake (*Annal of Brit. Geol.*, Lond., Dulau & Co., 1891) the term *inset*, for the porphyritic constituent (Ger. = Einsprengling).



aggregate of quartz and felspar. A similar substance is sometimes developed during consolidation.

In certain granitic rocks the larger crystals are embedded in a ground-mass consisting of *micropegmatite*, *i.e.*, an intimate but regular intergrowth of quartz and felspar. This is termed the **granophyric** structure. (See Fig. 20.)

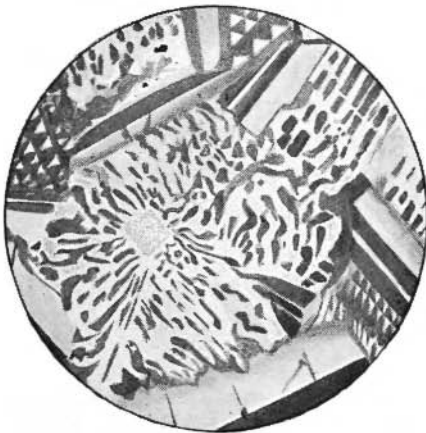


FIG. 20.

## Granophyric Structure.

A great number of igneous rocks, notably the plutonic rocks, are composed of a mass of crystals without any interstitial glassy or felsitic matter. Such rocks are termed **holocrystalline**. They also vary in structure according to the mode in which the constituent minerals separated from the rock-magma.

If the minerals were developed simultaneously, the crystals mutually impeded one another's growth, so that the grains, for the most part, could not assume crystallographic outlines. Such grains are said to be *allotriomorphic*. When, however, a mineral got the start of its fellows, well-contoured crystals were formed. Such a mineral is said to be *idiomorphic* with regard to the others.

In respect to the size of the grain, the structure of a holocrystalline rock may be coarsely crystalline, finely crystalline, or microcrystalline. These terms explain themselves. An apparently homogeneous rock is sometimes found, when examined in thin sections under the microscope, to be resolved into an aggregate of minute granules, some of which act upon polarized light but are too small for even microscopic determination. This is what is meant by the term *cryptocrystalline*.

Rocks having a more or less coarse-grained and holocrystalline texture, in which the grains are of tolerably uniform size and, for the most part, without crystalline contours (allotriomorphic), are said to be **granitoid**. This texture is presented by deep-seated or plutonic masses,—the granites, syenites, diorites, gabbros, etc.

The **ophitic** structure is presented by most dolerites, and some gabbros. The felspar in these rocks appears to have been formed at a slightly



FIG. 21.

Ophitic Structure.

earlier period than the ferro-magnesian constituent; in consequence of this the felspar appears in well-contoured lath-shaped crystals, while the augite or hornblende plays the rôle of ground-mass, enveloping and being penetrated by the felspar. In rare instances the reverse is found to be the case, felspar being present as a matrix in which lie well-formed crystals of augite.

## IV.

### COMPOSITION.

IN discussing this part of the subject we have to distinguish between the chemical and the mineralogical composition of rocks. Although the latter is to some extent dependent on the former, this is not altogether the case, for one and the same rock-magma may develop differences in mineralogical composition, according to the circumstances that govern its consolidation. Differences in chemical composition, however, produce important mineralogical variations; and the first broad sub-divisions in the classification of the igneous rocks have reference to the chemical factor.

#### CHEMICAL COMPOSITION.

Rock-magmas are without exception silicate-magmas; that is, they consist of silica in combination with the bases iron, alumina, lime, magnesia, potash and soda. If the silica is in excess of the bases, it exists in the rock in the free state, namely as quartz, and such rocks are said to be acid. If, on the other hand, the silica percentage is low, the rock is said to

be basic. In the acid rocks the percentage of silica may rise to 80; in the basic rocks it sinks to below 50, and in some excessively basic rocks even lower, reaching a minimum somewhere between 30 and 40.

Among the bases, alumina occupies an important place, being present in a great number of rock-forming silicates (*e.g.*, the feldspars, micas, etc.). The percentage of this base ranges from nothing (in the non-feldspathic peridotites) up to about 20.

The oxides of iron and magnesium also exert considerable influence in determining the character of a rock. The percentage of these bases is low in the acid, but rises considerably in the basic rocks. The lower oxide of iron (FeO) and magnesia are combined in an important series of silicates (biotite, and certain pyroxenes and amphiboles), while the two oxides of iron are also abundantly present in the more basic rocks as free iron ore (magnetite and ilmenite).

But of all the bases it is perhaps the alkalis, potash and soda, that are of greatest importance on account of the part played by them in determining the constitution of rocks. Thus in combination with alumina, and in some cases lime, they give rise to the important group of feldspars. Again they occur in certain varieties of mica, amphibole and pyroxene, and in members of the nepheline-leucite group.

Among compounds that occur in smaller propor-

tions, although widely distributed, are phosphoric and titanitic acids. As phosphate of lime (apatite) the former is present in most basic rocks, and in some even to the extent of two to three per cent. of phosphoric acid. Titanitic acid is rarely completely absent. Titaniferous iron-ore (ilmenite) is a frequent constituent of the basic rocks; sphene (titano-silicate of lime) occurs in the acid rocks; and small quantities of titanitic acid appear also to be present in certain varieties of augite and mica.<sup>1</sup> Fluorine and chlorine occur in minute quantities in some igneous rocks. The latter is chiefly present as a constituent of members of the nepheline-leucite group. Sulphur occurs mainly as a constituent of pyrites, granules of which are dispersed through some igneous rocks.

Among the metals, chromium and manganese are frequently present in minute proportions. A series of Italian gabbros was found on analysis to contain traces of chromic acid ranging from 0·18 to 0·30 per cent. (Vogt). The researches of Sandberger have shown that the metals gold, silver, copper, mercury and tin are present in minute traces in igneous rocks, while native iron, in alloy with nickel and cobalt, has been found distributed in small particles through certain basalts.

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<sup>1</sup> The brown mica of Miask has been shown by Schöpfer to contain 4·73 per cent. of titanitic acid.

## MINERALOGICAL COMPOSITION.

The separation of minerals from a silicate-magma which is undergoing cooling is determined by mass-action, by the affinities of the different bases for one another, and by the readiness with which the different compounds will form supersaturated solutions.

Lagorio has shown that silicate-magmas must be regarded as solutions, and that the laws established with reference to the separation of salts from saturated and supersaturated solutions may be applied to explain the formation of minerals in an igneous rock. A molten magma is a more or less saturated solution of the silicates which go to build up the complex minerals of which igneous rocks are composed. The gradual diminution of temperature causes a magma to be successively supersaturated with these different compounds, which unless other conditions (mass-action and chemical affinity) supervene, will then separate out in the same order.

The influence of mass in determining the formation of minerals is illustrated by the poorness of the acid rocks in iron-ores, the iron uniting with the excess of silica to form iron-silicate. Again, when iron-ore is developed in acid rocks it is as magnetite; whereas in the basic rocks ilmenite predominates: the excess of silica in the acid rocks draws the titanate to combine with it to form sphene,

while in the basic rocks it is left free to combine with the iron-oxides (Vogt).

The effect of pressure on the separation of salts from solutions has been investigated by Sorby. He has shown that the solubility of salts which increase in volume as they pass into solution, is lowered by pressure. The rock-forming silicates behave in this manner. This affords an explanation of the corrosion of crystals that have been formed in a magma prior to eruption. The relief of pressure consequent upon eruption lowers the fusing point of the mineral, and a portion of it passes again into solution, separating out again in many cases during a latter phase of consolidation. With regard to the mineralogical composition of igneous rocks, the acid group is characterized by the presence of free silica or quartz in greater or less abundance. The dominant felspar is orthoclase; but plagioclase also occurs. The intermediate group comprises rocks with little or no quartz, and in which plagioclase felspar is more abundantly developed than orthoclase. In the basic rocks quartz is absent, and orthoclase generally so. Olivine, on the other hand, is frequently present. The pyroxenites, hornblendites and magma-basalts, constitute a type of basic rock in which both felspar and olivine are absent. Lastly, the very basic rocks consist for the greater part of olivine, combined with other ferro-magnesian minerals and iron-ores. With



regard to hornblende and augite, the former has a predilection for the more acid rocks, while the latter favours the basic rocks ; but there are many exceptions to the rule.

Rocks belonging to the acid group are in general of a light colour. As the basic character increases they become darker in colour, owing to the greater abundance of ferro-magnesian minerals and iron-ores. The specific gravity also increases with the basicity, being about 2·6 in acid rocks, and reaching as much as 3·6 in ultrabasic varieties.

#### CHANGE OF COMPOSITION.

Various changes may take place in the composition of rocks, subsequent to consolidation. These are produced by the action of gaseous exhalations (*fumarole* and *solfataric activity*) ; by percolating thermal waters ; by atmospheric weathering ; by the intrusion of fresh igneous masses (*contact-* or *thermo-metamorphism*) ; and finally by earth-movements, involving the crushing down and reconstruction of minerals (*dynamic metamorphism*). The changes brought about by the first three causes consist in the decomposition of the original minerals, the formation of new minerals from the same materials, the removal or introduction of mineral matter in solution, etc. As a result the felspars, originally glassy, perhaps, become opaque or turbid, due to the development of kaolin ; the ferro-

magnesian minerals yield chloritic, serpentinous and ferruginous products; lime-bearing minerals produce calcite, epidote, etc. These secondary minerals are deposited in fissures and cavities, forming veins and amygdules of calcite, epidote, chlorite, serpentine, zeolites, chalcedony, opal and even quartz. By the infiltration of material from without, the composition of a rock may be considerably changed. Thus the percentage of silica in some of the Peru andesites has been considerably raised by the introduction of chalcedonic and opaline silica.

The "silicification" of some of the Rhenish trachytes (Rosenau in the Sieben Gebirge, and at Berkum near Cologne) was described by von Lasaulx, and like phenomena have been observed among the acid volcanic rocks of Caernarvonshire and Shap (Harker).

By processes of this nature the character of a rock is often much modified: the vesicular cavities of lavas are filled; vitreous rocks become dull and stony, devitrified in fact; a fresh rock, in which the mineral structure and composition are easily discernible, is converted into a "weathered" and decayed mass, which can only with the greatest difficulty be referred to its proper category (e.g., *kaolin*, *wacke*, *laterite*). In consequence of these changes altered and fresh varieties of rocks, originally identical in composition and structure, are often designated by different names. Thus dolerites, by alteration, are converted

into diabases; olivine and hornblende rocks give rise to serpentine; rhyolites become felsites; andesites change into porphyrites and propylites; and basalts figure as melaphyres.

With regard to changes produced in igneous rocks by heat, there is not much information available. Allport has shown that the augitic greenstones (dolerites) within the contact zone of the Cornish granites are converted into hornblendic rocks (epidiorites). The same phenomenon has been observed in the Hartz (Lossen), and the syenites of Meissen are reported to have effected the conversion of di-basic rocks into hornblende-schists. Quite recently Marr and Harker have reported that the Borrowdale andesites undergo marked changes in contact with the Shap granite; the metamorphism involves the formation of brown mica, sphene, etc., in the body of the rock, while in the vesicles green hornblende is produced by the alteration of the chlorite that originally filled them.

The subject of the "dynamic metamorphism" of the igneous rocks—*i.e.*, the changes produced as a result of mechanical stress—is too considerable to be adequately discussed here. It must suffice, in passing, to allude to some of the commoner modifications. In many cases these are mainly structural; such as *granulation* of the constituents (*e.g.*, quartz), their linear extension, the formation of lenticular knots, or

“eyes,” and the rolling out of massive rocks into mylonites and perhaps schists (*foliation*). But mineralogical change necessarily accompanies these mechanical processes; whether it proceeds without any essential chemical change, as when augite passes into hornblende (dolerites being converted into epidiorites and hornblende schists); or involves the breaking down of complex silicates and the building up of simpler compounds from the materials thereby produced. Thus the complex feldspars of the igneous rocks are replaced by aggregates of quartz, albite, and muscovite (sericite), while epidote, zoisite, rutile, sphene, and chlorite are formed partly from the feldspathic and partly from the ferro-magnesian constituents.

## V.

### THE CONSTITUENT MINERALS OF THE IGNEOUS ROCKS.

THE rock-forming minerals may be variously classified according to the part played by them in the structure and composition of rocks. A useful division is into essential and accessory. An **essential** mineral is one whose presence is implied in the definition of the rock. An **accessory** mineral is one whose presence or absence does not sensibly affect the character of the rock. Thus, quartz, felspar and mica are essential constituents of granite ; while zircon, sphene and apatite are accessory.

The accessory minerals may be further sub-divided into those of original and those of secondary origin. They are termed **original** when they came into existence with the rock of which they form part, or when they existed before it. They are **secondary** when they result from the alteration or reconstruction of the original minerals (by weathering, contact and dynamic metamorphism, etc.).

Another division is into authigenic and allogenic. An **authigenic** mineral is one that came into exist-

ence with or after the rock containing it. An **allo-genic** mineral is one that is of more ancient origin than the rock containing it, as, for instance, a fragment mechanically included during consolidation.

The following scheme shows the relation of the above terms:—

Authigenic	{	Essential	{	Original
		Accessory		Secondary.

Allogenic.

The chief minerals occurring in Igneous rocks are the following:—

### 1. ESSENTIAL.

Quartz.	}	Colourless. <sup>1</sup>
Felspars.		
Nepheline and Leucite minerals.		
Muscovite.		
Biotite.	}	Coloured ferro-magnesian silicates.
Amphiboles.		
Pyroxenes (sometimes colourless).		
Olivine (colourless when unaltered).		

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<sup>1</sup> This arrangement according to colour (under the microscope) must not be taken too strictly: minerals, which when pure and unaltered are colourless, are sometimes coloured by the presence of a small quantity of some foreign body, or stained by products of decomposition. The degree of thinness of the section also influences the intensity of the colouration.

2. ACCESSORY.

(a) *Original.*

Häüyne and Nosean.	}	Colourless, or slightly coloured.
Scapolite.		
Melilite.		
Sodalite.		
Apatite.		
Zircon.		
Eudialyte.	}	Coloured.
Andalusite.		
Spinel.		
Garnet.		
Tourmaline.		
Sphene.		
Xenotime.	}	Opaque.
Monazite.		
Magnetite.		
Ilmenite.		
Pyrites.		

(b) *Secondary.*

Quartz, Opal, Chalcedony.	}	Colourless.
Felspar.		
Calcite, Dolomite.		
Zeolites.		
Kaolinite.		
Talc.		
Muscovite.		
Zoisite.		

Epidotes.	}	Coloured.
Leucoxene.		
Chlorite.		
Serpentine.		
Hornblende (Uralite).		
Iron-ores (Magnetite, Pyrites, etc.).		

The following minerals are developed in aqueous rocks as a result of contact-metamorphism :—

(a) *In Slates and Shales (Aluminous Minerals).*

Andalusite.  
 Chiastolite.  
 Sillimanite.  
 Staurolite.  
 Tourmaline.  
 Mica, etc.

(b) *In Limestones (Calcareous Minerals).*

Idocrase (Vesuvianite).  
 Dipyre (Couseranite).  
 Grossularia, Essonite and Common Garnet.  
 Wollastonite.  
 Tremolite (Hornblende).  
 Salite, Malacolite, Diopside (varieties of Augite).  
 Mica.  
 Sphene.  
 Perowskite.



With regard to the appearance of the rock-forming minerals in thin sections under the microscope, we must take into consideration variations in (1) External contour or form, (2) Internal or micro-structure.<sup>1</sup>

#### EXTERNAL CONTOUR OR FORM.

If the conditions that prevailed during the consolidation of the rock, have been such as to allow of the free growth of crystals, the minerals are bounded on all sides by crystallographic contours, and are said to be **idiomorphic**. If, on the other hand, the minerals have had to struggle for existence, so to speak, they will have naturally hindered one another in their crystallographic development, and the result is an aggregate of grains bounded by **allotriomorphic** contours. Sometimes a mineral which doubtless originally possessed crystallographic form, owes its present irregular fretted outline to the corrosion of the molten magma in which it floated prior to solidification. Thus the porphyritic quartz grains of the acid rocks are usually rounded and even hollowed out by the magma. Again, the ferromagnesian minerals (hornblende and mica) of the andesites and basalts often present peripheral "zones

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<sup>1</sup> Optical phenomena cannot be gone into in a work of these dimensions. The student should consult *Notes on a new Form of Polarizing Microscope*, by Mr. A. B. Dick, published by Messrs. Swift & Sons, 81, Tottenham Court Road, W.

of corrosion"<sup>1</sup> in which iron-oxides have separated out. Incipient or abortive forms (crystallites, micro-lites, skeleton-crystals, etc.) frequently occur in vitreous rocks where the solidification has been too rapid to permit of full crystallographic development. (See Fig. 22.)

The index of refraction of a mineral also influences its outline as seen under the microscope; for the

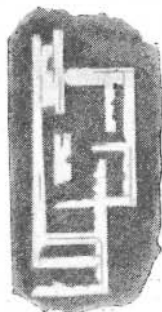


FIG. 22.  
Skeleton-crystal of Feldspar.

greater the difference between the index of refraction and that of the material in which it is imbedded, the more strongly marked will be its bounding edge. Thus grains of feldspar and quartz are scarcely visible in Canada balsam, while augite, hornblende and olivine stand out boldly in this medium. The con-

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<sup>1</sup> "Zone of corrosion," *Ger.* = *Einschmelzungszone*.

tours of minerals possessing a still higher index of refraction, such as sphene, garnet and rutile, appear as broad dark borders, in consequence of the amount of light that undergoes total reflection at the bounding surface.

#### INTERNAL OR MICRO-STRUCTURE.

The principal variations in micro-structure are produced by cleavage, inclusions and alteration.

**Cleavage** shows itself, in thin sections, in lines of greater or less distinctness, precision and regularity, according to its degree of perfection. A perfect cleavage gives numerous fine straight lines, while an imperfect one gives lines which are thick, branching and irregular in proportion to the difficulty of separation. The relative position of cleavage lines depends on the direction of the section through the mineral. A prismatic cleavage produces two intersecting sets of parallel lines unless the section be in the direction of the vertical axis, in which case the two sets coincide. A basal or pinacoidal cleavage furnishes only one set of lines.

**Inclusions.**—During their formation, crystals take up and inclose portions of the matrix from which they have separated and other foreign bodies. These inclusions may bear a definite crystallographic relation in their arrangement to the shape of the crystal (*i.e.*, they may be *central*, *peripheral*, or *zonal*), o.

they may be distributed indefinitely. They are of four kinds:—(1) gaseous, (2) liquid, (3) glassy and (4) mineral. *Gas-inclusions* are small, round, or elliptical pores filled with air or carbon dioxide. Occasionally they have the inverse shape of their host, being, in fact, negative crystals. In consequence of the difference in refractive index between

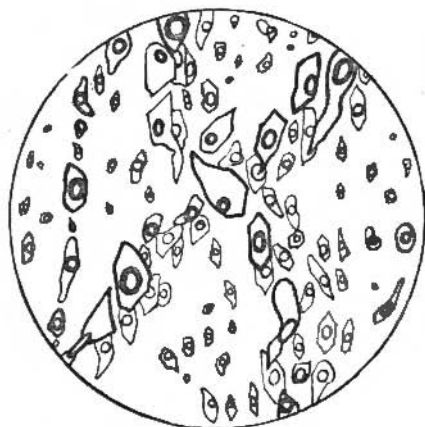


FIG. 23.

Highly magnified Liquid Inclusions in Quartz.  
(After Fouqué and Lévy.)

the gas and the mineral substance inclosing it, gas-inclusions are always bounded by a well-marked dark border. *Liquid-inclusions* are also round, elliptical, or tubular bodies, having a contour somewhat less strongly marked than that of gas-inclusions. The liquid, which may consist of water or carbon

dioxide, liquid under pressure, usually does not quite fill the cavity, and a small movable bubble remains. When sufficiently small, the bubble possesses a constant vibratile motion. The water is sometimes saturated with common salt, and may then contain cubic crystals of that mineral. Liquid-inclusions occur abundantly in many minerals, notably in quartz.



FIG. 24.

Crystal of Angite,  
containing a vitreous core.



FIG. 25.

Glass Inclusions with bubbles and crystallites,  
highly magnified.  
(After Fouqué and Lévy.)

(See Fig. 23.) *Glass-inclusions* are distinguished from liquid-inclusions, by the sharpness of their contours and the fixity of their bubble. Also more than one bubble is frequently present. The inclosed glassy substance is often coloured or turbid, especially when

such is the case with the glassy base of the rock. (See Fig. 24.) Devitrification, or the development of crystallites and microlites, may also have taken place. *Mineral-inclusions* are distinguished from the foregoing by the possession of idiomorphic contours. They may consist of needles, rods, granules, plates or scales, and are often arranged along planes bearing a definite relation to the symmetry of the crystal in which they are included, being then often the cause of the optical phenomena known as *schiller*, *chatoyancy* and *asterism*.

### SILICA GROUP.

**Quartz.** Pure silica,  $\text{SiO}_2$ . Crystallizes in the rhombohedral system, the crystals being usually bounded by the hexagonal prism (recognisable by its horizontal striations) with pyramidal (rhombohedral) terminations. Sometimes, however, the prism faces are absent, the crystals then consisting of the double pyramid of twelve faces. Unattacked by acids, excepting hydrofluoric acid. Insoluble in potash (distinction from opaline silica). Sp.G. = 2.6. Hardness = 7.<sup>1</sup>

Quartz may be recognised by its hardness, pellucidity, vitreous lustre and irregular to sub-conchoidal

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<sup>1</sup> Mohs' Scale, viz., 1=talc; 2=gypsum; 3=calcite; 4=fluorspar, 5=apatite, 6=orthoclase. 7=quartz, 8=topaz, 9=corundum, 10=diamond.

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fracture. Usually it is colourless, sometimes, however, brownish or yellowish (*smoky quartz*, *cairn gorm*, etc.), pink (*rose quartz*), purple (*amethyst*) or bluish (in certain gneisses and Palæozoic grits). Under the microscope it appears in clear colourless grains, characterized by the presence of innumerable minute liquid inclusions generally arranged along lines and planes. High magnification discloses in many of these a minute vibratile bubble, occasionally also cubes of salt, showing that the liquid, in some cases at least, consists of a saturated solution of that substance. In other cases, the inclosed substance has been proved to be carbon dioxide. Between crossed nicols the polarization-colours<sup>1</sup> vary, in moderately thin sections, between a little grey and pale yellow of the first order of Newton's scale of colours. Thicker sections, of course, show brighter colours (yellow,

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<sup>1</sup> All doubly refractive minerals are coloured between crossed nicols, the colouration being a result of the *interference* of the two rays that are produced by the passage of light through such minerals. The *degree* of colouration (*i.e.* in Newton's scale of colours) depends on the amount of separation of the two rays, and this varies with the thickness of the section, for any given mineral, or, the thickness being constant, with the nature of the mineral experimented upon. Thus, in sections of such thickness that the felspar gives a grey between crossed nicols, quartz will give a yellow of the first order, and augite and hornblende bright blues, greens and reds of the second and third orders.

blue, red, etc.). Sections perpendicular to the vertical (here coincident with the optic axis) give a uniaxial interference-figure.<sup>1</sup>

Quartz is the mineral eminently characteristic of the acid rocks. In granite and quartz-diorite, it occurs in irregular grains without definite crystalline contours; and in microgranites, felsites and rhyolites, in rudely contoured, often bipyramidal crystals, generally much corroded by the surrounding magma. As a secondary constituent quartz fills cracks, joints and cavities (*vein-quartz*); similarly it occurs in association with felspar, mica, tourmaline, etc., in the so-called pegmatite-veins.

**Tridymite.** Pure silica,  $\text{SiO}_2$ . Triclinic, but affecting hexagonal symmetry. In thin six-sided colourless tablets, which split up between crossed nicols into a number of depolarizing areas, showing light and dark banding. Insoluble in acids; soluble in alkalis. Sp. G. = 2.3. Hardness = 7. Tridymite occurs in volcanic rocks (rhyolites, trachytes and andesites), lining their cavities with pretty groups of interpenetrating twins and trins. Under the microscope it is described as occurring in imbricated aggregates. Tridymite is only found in lavas, and appears to be produced under the influence of some mineralizing agent.

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<sup>1</sup> A black cross, which in thick sections is surrounded by concentric coloured rings.



**Opal, Hyalite.** Hydrated silica :  $\text{SiO}_2 + \text{Aq.}$   
 This mineral occurs in amorphous masses resulting from the solidification of colloid or hydrated silica. Colour variable : yellow, brown, etc. Translucent to opaque. Soluble in alkalis (distinction from quartz). Sp. G. = 2.2. Hardness = 5.5-6.



FIG. 26.

Spherulitic Opal in a chalcedonic matrix, between crossed nicols.  
 (After Fouqué and Lévy.)

Opal is a secondary constituent of many acid volcanic rocks (rhyolites, trachytes and even the less acid andesites). It is also deposited from the water of hot springs and geysers (*geyserite*). Hyalite, a pure colourless variety, frequently occurs in andesites.

Under the microscope it is isotropic, but occasion-

ally shows weak double refraction and gives a black cross between crossed nicols (spherulitic opal, see Fig. 26).

**Chalcedony.** Silica,  $\text{SiO}_2$ . Mixtures of crystalline and amorphous silica. Cream-coloured to colourless; translucent to semi-opaque. Insoluble in acids; partially soluble in alkalis. Sp. G. = 2.59–2.64.

A secondary constituent of acid volcanic rocks. Under the microscope chalcedony has a fibrous structure, giving an imperfect black cross between crossed nicols.

**Agate** consists of alternating layers of chalcedony, jasper, amethyst and other varieties of quartz. It is found wholly or partially filling the amygdaloidal cavities of old vesicular lavas (melaphyre, basalt, etc.).

## FELSPAR GROUP.

The feldspars crystallize in two systems, the monoclinic and the triclinic; but the forms of the two systems are very similar, and the angles differ by a few degrees only.

The chief *monoclinic* feldspars are orthoclase and sanidine. *Triclinic* are albite, oligoclase, andesine, labradorite and anorthite; they are comprised under the general term plagioclase.

The commonest combination of faces presented by

the felspars consists of the following forms : the basal plane (generally denoted by P), the clino- or the brachy-pinacoid (M), the prisms (T and l), the two ortho- or the two macro- domes (x and y), the clino- or the brachy-dome (n), and the pyramid (o), (Fig. 27). The principal cleavage is basal (P); but this is nearly equalled by the cleavage parallel to M. These two cleavage planes are at right angles in orthoclase,

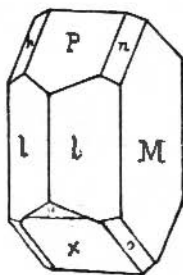


FIG. 27.

Crystal of Orthoclase.

- P. Basal plane.
- M. Clinopinacoid.
- l. Prism.
- x and y. Orthodoms.
- o. Pyramid.
- n. A Clinodome.

(After Rosenbusch.)

but are inclined to one another in plagioclase. Under the microscope orthoclase presents sections that are uniformly affected by polarized light, or are divided into two areas that present uniform polarization respectively (dual twinning on the Carlsbad type); whereas plagioclase usually has a striated appearance

between crossed nicols, due to the fact that the triclinic feldspars are subject to repeated ("polysynthetic") twinning on the Albite type.

Considered chemically, the feldspars are silicates of alumina and one or more of the bases potash, soda and lime. There are three primary feldspar substances: potash-feldspar ( $K_2O, Al_2O_3, 6SiO_2$ ), soda-feldspar ( $Na_2O, Al_2O_3, 6SiO_2$ ), and lime-feldspar ( $CaO, Al_2O_3, 2SiO_2$ ). They occur in nature as orthoclase, albite and anorthite respectively. By their combination in definite proportions two important series of feldspars are formed: a *lime-soda* series and a *potash-soda* series. The lime-soda series comprises the well-known members, oligoclase, andesine and labradorite. The potash-soda series is only represented by the isolated occurrence of feldspars that have been variously described as soda-orthoclase, soda-microcline, and anorthoclase. The crystals have an unusual form, due to the predominance of the prisms (*T* and *l*) and the orthodome (*y*). Like microcline, anorthoclase is generally referred to the triclinic system; and between crossed nicols, intersecting systems of extremely fine twin-lamellæ are generally recognisable. It has been described as occurring in the *Rhombenporphyr* of Southern Norway, in the trachytes of Pantellaria and in the keratophyres of the Hartz.

## 1. MONOCLINIC FELSPARS.

**Orthoclase**, or potash felspar. Chem. comp. =  $K_2O$ ,  $Al_2O_3$ ,  $6SiO_2$  (65%  $SiO_2$ , 17%  $K_2O$  and 18%  $Al_2O_3$ ). Sp. G. = 2.54-2.57. Hardness = 6. Un-attacked by acids except hydrofluoric acid. Two types of crystal are common:—flat tables (with *M* largely developed) and stout prisms. A roof-like

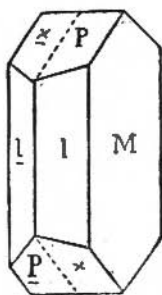


FIG. 28.

Orthoclase Crystal twinned on the Carlsbad-type.

- P. Basal plane.
- M. Clinopinacoid.
- l. Prism.
- x. An Orthodome.

(After Rosenbusch.)

termination is produced by the basal plane (*P*) and the orthodome (*x*), which are about equally inclined to the vertical axis, and form with one another an angle of  $129^{\circ} 43'$ . (See Fig. 27.) The crystals present dual twinning on various types (Carlsbad, Manebach, Baveno, etc.), the commonest being the Carlsbad. When twinned on this type, the crystals

are usually united on the clino-pinacoid ( $M$ ), the basal planes ( $P$ ) of the crystals being inclined in opposite directions. (See Fig. 28.) Twinning of this nature is often revealed in thin sections by the difference in extinction shown by the two halves of a crystal when rotated between crossed nicols. In the Manebach type the twinning-plane is the basal plane ( $P$ ); in the Baveno type it is the clinodome ( $n$ ).

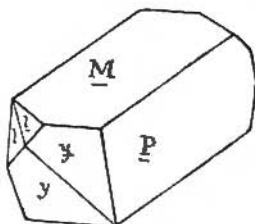


FIG. 29.

Crystal of Orthoclase twinned on the Baveno-type.

- p. Basal plane.
  - m. Clinopinacoid.
  - l. Prism.
  - y. An Orthodome.
- (After Rosenbusch.)

Orthoclase occurs pure and colourless in the variety termed **adularia**. Usually, however, it is turbid and cloudy, due to the development of various decomposition products (kaolinite, muscovite, talc). Between crossed nicols sections of ordinary thinness polarize in grey tints, the double refraction being considerably less than in quartz.

Orthoclase occurs as an essential constituent of the

more acid plutonic and older volcanic rocks (granite, syenite, felsite), often in large well-developed crystals (granite-porphry, felspar-porphry). Also in foliated rocks (gneiss and various schists); and, together with quartz and other minerals, in segregation veins (pegmatites). Among the sedimentary rocks it occurs in the so-called felspathic grits or arkoses, which are derived from the disintegration of granitic rocks.

**Sanidine** is the name given to a clear, glassy, fissured variety of orthoclase occurring in the more recent acid lavas (rhyolite, trachyte, obsidian). It usually occurs in flat tables, twinned on the Carlsbad type; also in prismatic crystals and irregular grains. Under the microscope it differs from orthoclase in its pellucidity. Inclusions (glass, etc.) are, however, common. The crystals have often undergone fracturing and corrosion during the eruption of the lava in which they were suspended.

## 2. TRICLINIC FELSPARS.

**Plagioclase**, or lime and soda feldspars. In crystal form, similar to orthoclase, with the difference that the basal plane (*P*) instead of being normal to the brachypinacoid (*M*) is inclined to it (from left to right) at an angle of  $86^{\circ}$ – $87^{\circ}$ . The distinguishing character of the triclinic feldspars is the lamellar or polysynthetic twinning. The fine lineations pro-

duced by this type of twinning can be easily seen with the pocket lens on the faces of the basal cleavage. In thin section, between crossed nicols, it appears as a parallel striation, consisting of light and dark bands, due to the simultaneous extinction of alternate lamellæ. Usually the striation is parallel to the brachypinacoid (*M*): this constitutes the *albite type* of twinning. (See Figs. 30 and 31.) A

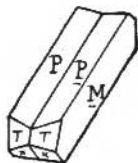


FIG. 30.

Crystal of Plagioclase twinned on the Albite-type.

- P. Basal plane.
- M. Brachypinacoid.
- T. Prism.
- z. A Macrodome.

(After Rosenbusch.)

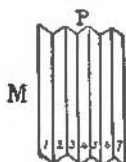


FIG. 31.

Repeated twinning on the Albite-type.

- P. Basal plane.
- M. Brachypinacoid.

(After Rosenbusch.)

second series of twin-lamellæ sometimes crosses these at right angles, constituting the *pericline type* of twinning.

The researches of Tschermak have shown that the members of the lime-soda series may be regarded as isomorphous mixtures of albite and anorthite in varying proportions. They form a graduated series both with regard to their chemical constitution and their optical and other physical properties (specific



gravity, etc.). It is convenient to make use of the names oligoclase, andesine, and labradorite, to fix certain points in the series. If we represent the soda-felspar molecule ( $\text{Na}_2\text{O}, \text{Al}_2\text{O}_3, 6\text{SiO}_2$ ) by Ab and the lime-felspar molecule ( $2 \text{CaO}, 2\text{Al}_2\text{O}_3, 4\text{SiO}_2$ ) by An., then the intermediate felspars have the

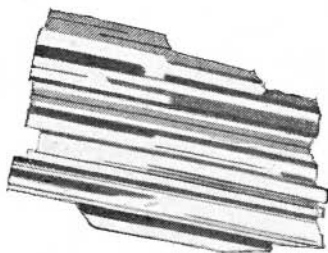


FIG. 32.

Section of twinned Plagioclase between crossed nicols.

composition represented by the following average formulæ<sup>1</sup> :—

	Formulae.	Sp. G.
Albite . . . . .	Ab . . . . .	2·62
Oligoclase . . . . .	$\text{Ab}_{10}\text{An}_3$ . . . . .	2·65
Andesine . . . . .	$\text{Ab}_2\text{An}_1$ . . . . .	2·67
Labradorite . . . . .	$\text{Ab}_2\text{An}_3$ . . . . .	2·70
Anorthite . . . . .	An . . . . .	2·75

<sup>1</sup> Lévy and Lacroix.

With regard to the optical properties of plagioclase, the extinction angles are smaller for the soda end of the series (albite, oligoclase and andesine) than for the lime end (labradorite and anorthite). In general, a high extinction-angle may be taken as indicating a felspar of the basic (or lime) end of the series; while a low extinction-angle indicates a felspar of the albite, oligoclase, or andesine type. Microlites consisting of a felspar intermediate in composition between oligoclase and andesine, extinguish straight.

The plagioclase felspars usually contain numerous inclusions: liquid, glass and mineral matter (hæmatite, rutile, mica, etc.). These may be irregularly distributed or arranged along certain crystallographic planes, or in zones parallel to the periphery of the crystal. A different kind of zonary structure is that produced by the presence of isomorphous layers, marking a varying change of composition in the crystal during its growth.

The following minerals result from the decomposition of plagioclase: epidote and zoisite (in the so-called saussurite) and calcite.

Albite, oligoclase and andesine, are not attacked by hydrochloric acid; labradorite is a little, while anorthite is decomposed with separation of gelatinous silica. The fusibility is greatest in albite and decreases with the diminution of soda and the increase

of lime. The specific gravity, on the other hand, is least at the soda end and greatest at the lime end (see table given above).

Just as orthoclase is characteristic of the acid rocks, so the different plagioclase feldspars are found in rocks of intermediate and basic composition.

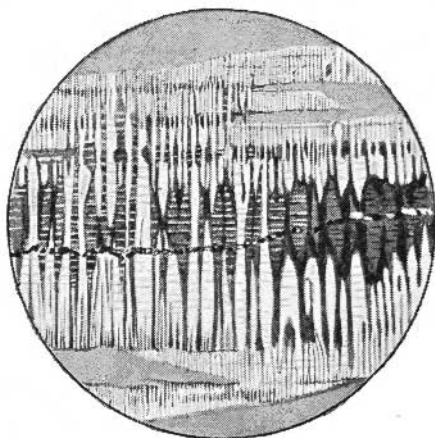


FIG. 33.

Section of Microcline, under the microscope.

Oligoclase and andesine occur in the diorites, porphyrites and andesites; labradorite and anorthite in gabbros, dolerites and basalts. Oligoclase also accompanies orthoclase in many granites and trachytes. Albite is frequently present as a secondary constituent ("secondary feldspar") in the so-called feldspar-quartz mosaic of mechanically metamor-

phosed rocks. Its clear unstriated granules are scarcely distinguishable from quartz but for the fact that they give a *biaxial* interference-figure in convergent polarized light.

**Microcline** is a triclinic potash felspar, very nearly allied in composition and external form to

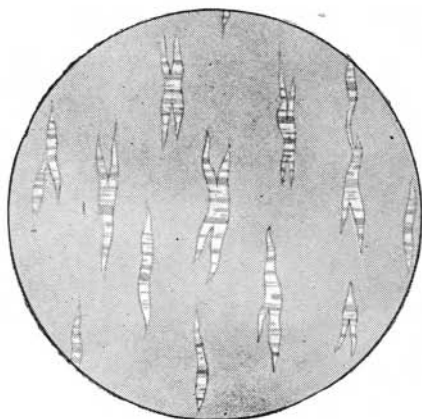


FIG. 34.

Perthite: section parallel to the basal plane.

orthoclase. It is distinguishable from that mineral, however, by a characteristic cross-hatching that becomes visible when the mineral is viewed between crossed nicols. This structure is generally ascribed to intersecting systems of twin-lamellæ, parallel and perpendicular to the edge (*PM*); it differs, however, from ordinary cross-twinning in the fact that in

microcline the lamellæ appear spindle-shaped, instead of being bounded by parallel edges. (See Fig. 33.) The extinction angle of microcline is  $15^{\circ} 30'$  measured to the edge (*PM*).

**Perthite.** Both orthoclase and microcline are often intergrown with triclinic feldspar (albite or oligoclase), the plagioclase occurring in narrow

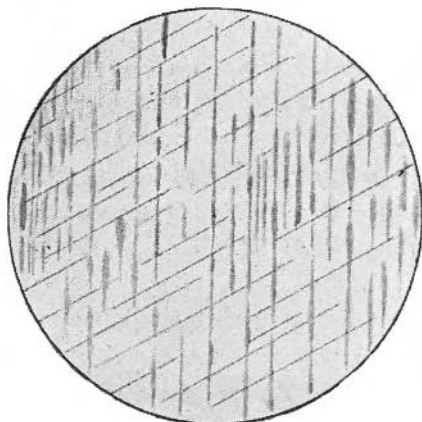


FIG. 35.

Perthite: section parallel to the clinopinacoid.

lamellæ intercalated along planes parallel to the orthopinacoid. In sections parallel to the basal plane or clinopinacoid the included feldspar appears in patches and strips which are distinguishable from the main mass of the orthoclase by their twin-striation or by their different extinction-angle. Such admixtures are known as perthite or micro-perthite.

NEPHELINE-LEUCITE GROUP.<sup>1</sup>

**Nepheline.** Silicate of potash, soda and alumina:  $(\text{NaK})_2\text{O}$ ,  $\text{Al}_2\text{O}_3$ ,  $2\text{SiO}_2$ . Crystallizes in the hexagonal system. It occurs in small colourless and glassy six-sided prisms (combination of hexagonal prism and basal plane).

Soluble in hydrochloric acid with separation of gelatinous silica; the solution gives cubes of salt when evaporated. Sp. G. = 2.6; hardness = 5.5-6. Imperfect basal and prismatic cleavage. Nepheline is essentially a volcanic mineral, being found principally in the cavities of ejected blocks (Monte Somma, Lake Laach). It also occurs as an essential constituent of certain lavas (phonolite, nepheline-basalt, tephrite, etc.).

Under the microscope it gives hexagonal and four-sided sections; but occurs more frequently in small colourless granules the presence of which can often only be demonstrated by gelatinization with hydrochloric acid and subsequent staining with fuchsine. The four-sided sections extinguish straight between crossed nicols; while the six-sided ones give a uniaxial interference figure in convergent light. The double refraction is weak, the polarization colour never exceeding a grey tint.

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<sup>1</sup> Also called FELSPATHOID GROUP, on account of the resemblance of these minerals to the felspars.

This mineral is peculiarly subject to alteration, usually to zeolitic products, such as mesotype (natrolite) and hydro-nephelinite; also to white mica (gieseckite) or to cancrinite.

Nepheline is liable to be confused with apatite. The latter mineral, however, occurs usually in longer needles than nepheline, and has a higher index of refraction. Chemically they may be distinguished by the phosphate-test for apatite, and by gelatinization and staining with fuchsine for nepheline.

**Elæolite** is the name usually given to a dull grey or greenish variety of nepheline occurring in the more ancient crystalline rocks (elæolite-syenite). It forms irregular masses of considerable size, somewhat resembling quartz, from which it may be distinguished by its characteristic greasy lustre.

Elæolite bears the same relation to nepheline that orthoclase does to sanidine.

**Leucite.** Silicate of alumina and potash:  $K_2O$ ,  $Al_2O_3$ ,  $4 Si O_2$ .

Tetragonal, but in symmetrical combinations, closely resembling the icositetrahedron of the Regular System. Colour, dirty white or grey. Attacked slowly by hydrochloric acid with separation of pulverulent silica. Sp. G. = 2.45–2.5. Hardness = 5.5–6. Fusible with difficulty.

Leucite occurs almost exclusively as a constituent

of the more recent volcanic rocks: leucitophyre, leucito-tephrite and leucitite.

Under the microscope it presents colourless polyhedral (usually eight-sided) sections. The double refraction is weak, a pale-grey light being transmitted between crossed nicols. The larger individuals present intersecting systems of alternately light and dark twin-lamellæ. Inclusions (glass, magnetite, belonites, etc.) are common, showing both a zonal and a radial arrangement.

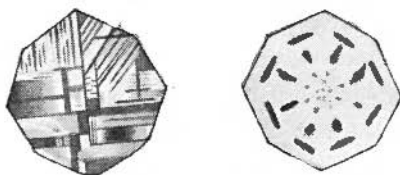


FIG. 36.

Sections of Leucite, showing the double refraction and inclusions.

**Melilite** (Humboldtite). Silicate of alumina, iron, lime, magnesia, and soda:  $12(\text{CaMg})\text{O}$ ,  $2(\text{AlFe})_2\text{O}_3$ ,  $9\text{SiO}_2$ . Tetragonal, occurring in small square tablets and prisms, also in irregular grains. Colour, white to yellow. Gelatinizes easily with hydrochloric acid. Sp. G. = 2.90–2.95. Hardness = 5–5.5.

Occurs as a constituent of certain basalts (melilite-basalt) and nepheline and leucite rocks.

Under the microscope it appears in colourless



grains, which are characterized by a striation normal to the long axis (*peg-structure*).

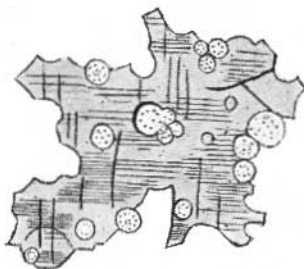


FIG. 37.

Melilite in the lava of Capo di Bove, near Rome.



FIG. 38.

Peg-structure in Melilite, highly magnified.

## MICA GROUP.

The rock-forming micas may be divided for all practical purposes into white and dark micas.

In white mica (muscovite), there is usually a considerable divergence of the optic axes; while the dark mica (biotite) is, in most cases, practically uniaxial, *i.e.*, the two optic axes are nearly coincident. There are, however, certain rare varieties of mica that

have a large optic axial angle. Both micas are monoclinic, but with pseudo-hexagonal symmetry (see Fig. 39); and a very perfect basal cleavage is characteristic for both. The elasticity of the laminae distinguishes mica from other minerals (talc, chlorite, etc.) possessing a similar cleavage.

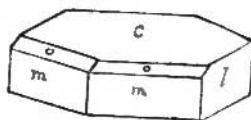


FIG. 39.

Crystal of Mica.

c. Basal plane.

o. Pyramid.

m. Prism.

b. Clinopinacoid.

(After Rosenbusch.)

### WHITE MICAS.

**Muscovite**, or Potash-mica. Hydrated silicate of alumina and potash:  $K_2O, 3Al_2O_3, 6SiO_2, 2H_2O$  (Tschermak).

Not attacked by hydrochloric acid. Sp. G. = 2.76-3.1. Hardness 2-3.

Occurs in granite and gneiss, in plates, leaves, scales and fibres, possessing a silvery white colour and bright lustre. Fragments of muscovite are frequently present in sandstones and shales, and by their parallel arrangement impart to these rocks a

fissile character. Under the name of **sericite** a silvery white or pale green variety occurs as a frequent secondary constituent of the metamorphic schists. There is no doubt that in many cases it results from the alteration of the felspar. Its thin laminæ wrap round the lenticular masses of quartz and felspar, and play an important part in determining the schistosity of these rocks.

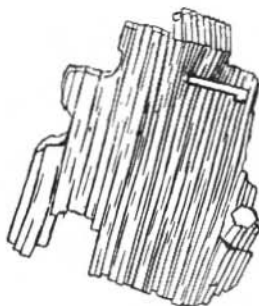


FIG. 40.

Section of Mica showing the cleavage.

Other white micas are **paragonite**, a hydrated silicate of alumina, potash and soda, occurring in schists; **margarite**, a hydrated silicate of alumina and lime, in schists; and **lepidolite** and **zinnwaldite**, hydrated silicates of alumina, potash, soda and lithia, in pegmatites. Under the microscope the white micas give lath-shaped sections, presenting well-marked cleavage-lines, often bent. They also

occur in streaky and ribbon-like bands. Between crossed nicols, brilliant chromatic polarization.

#### BLACK OR FERRO-MAGNESIAN MICAS.

**Biotite** (*Meroæene* and *Lepidomelane*), a hydrated silicate of alumina, iron, magnesia and potash. Attacked by hot hydrochloric acid. Sp. G. = 2·8-3·2. Hardness = 2·5-3.

Occurs as an essential constituent of granite and granitite, mica-trap, trachyte and andesite; also, as an accessory in some basalts. Loose crystals of a reddish brown biotite (rubellan) are found embedded in volcanic ash.

Developed also in diabase by contact with granite.

Under the microscope this mineral appears in plates, scales and lath-shaped sections, the latter showing intense pleochroism (pale-yellow to chestnut-brown and black). The principal absorption takes place when the long axis of the lamella, or the trace of the cleavage, is parallel to the short diagonal of the polarizing nicol, thus distinguishing it from tourmaline, which is equally strongly absorptive, but in a direction at right angles to this.

Inclusions are frequent: tourmaline, zircon, allanite, sphene and apatite, the last four of which are often surrounded by pleochroic borders.

Alters easily to chlorite, the alteration being marked by the gradual assumption of a green colour.

Other dark micas are **anomite** and **phlogopite**, occurring in volcanic and metamorphic rocks. They are of the same general chemical composition, but differ in optical properties.

### AMPHIBOLE GROUP.

The amphiboles are silicates mainly of magnesia and lime, in which the magnesia predominates over the lime; other bases occurring in some varieties are

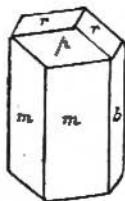


FIG. 41.

Crystal of Hornblende.

p.	Basal plane.		m.	Prism.
r.	Pyramid.		b.	Clinopinacoid

(After Rosenbusch.)

alumina, iron, manganese and soda. They are nearly all monoclinic, only one variety being rhombic (anthophyllite) and one triclinic (cossyrite). (See Fig. 41.)

Sp. G. = 2.90–3.55. Hardness = 5–6. Unattacked by acids. Cleavage, parallel to the prism (angle = 124°), well-marked. (See Fig. 42.)

Under the microscope, sections perpendicular to the vertical axis are generally six-sided (being

bounded by two clinopinacoidal and four prismatic planes) with cleavage-lines intersecting at an angle of  $124^\circ$ . (See Figs. 42 and 43.) They frequently show dual, more rarely multiple, twinning. Between crossed nicols, the extinction-angle, measured to the vertical axis, varies from  $0^\circ$  to a maximum of  $22^\circ$  (in augite, the maximum often reaches  $45^\circ$ ). The double refraction is high, even thin sections giving

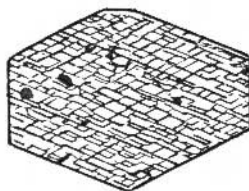


FIG. 42.

Cross-section of Hornblende, showing the prismatic cleavage.

chromatic polarization. The coloured varieties are strongly pleochroic (distinction from augite).

By alteration processes (weathering, metamorphism, etc.) the amphiboles give rise to chlorite, serpentine and calcite.

## 1. MONOCLINIC AMPHIBOLES

### *a. Brown and Green Amphiboles.*

**Common Hornblende.** Monoclinic. Silicate of iron, alumina, lime and magnesia; rich in alumina

and iron. Colour, black by reflected light, brown or green by transmitted light. Pleochroism, strong in brown and yellow, or green and yellow tints.

Occurs in hornblende-granitite and syenite (brown and green varieties), diorite (mainly the green variety), trachyte (usually green variety), and ande-

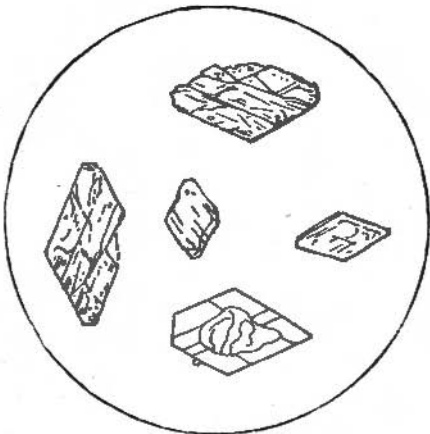


FIG. 48.

Crystals of Hornblende, under the microscope, showing the predominance of the prism faces over those of the pinacoid, and the prismatic cleavage.

(After Teall.)

site (brown variety), and as an accessory constituent of basalt. The crystals are among the first-formed constituents, and have often suffered subsequent corrosion in the still molten magma, being then surrounded by a dark-coloured border.

*b. Green Amphiboles.*

**Actinolite.** Monoclinic. Silicate of iron, magnesia and lime:  $3\text{CaO}$ ,  $(\text{MgFe})\text{O}$ ,  $4\text{SiO}_2$ . Colour, grass-green. Pleochroism, in green tints, not very strong. Maximum extinction angle =  $18^\circ$ . Occurs in long prisms and needles, or in ribbon-like blades and fibres, as a constituent of amphibolite and hornblende-schist.

**Smaragdite, nephrite** and **uralite** are fibrous green hornblendes, generally secondary after pyroxene. Such paramorphic hornblende occurs in gabbros, diabases and epidiorites. **Pilite** is a similar substance produced by the alteration of olivine.

*c. White Amphiboles.*

**Tremolite.** Monoclinic. Silicate of magnesia and lime:  $\text{CaO}$ ,  $3\text{MgO}$ ,  $4\text{SiO}_2$ .

Non-pleochroic, because colourless. Maximum extinction =  $18^\circ$ . Occurs in lamellar and bladed aggregates as a constituent of metamorphic limestones (cipolines).

**Asbestos** is a fibrous variety, used for making fire-proof material, engine-packing, etc.

*d. Soda-Amphiboles.*

**Arfvedsonite.** Monoclinic. Silicate of soda and iron— $\text{Na}_2\text{O}$ ,  $\text{Fe}_2\text{O}_3$ ,  $4\text{SiO}_2$ .

Resembles common green hornblende. Maximum



extinction-angle varies from  $0^{\circ}$ – $12^{\circ}$ . Occurs in association with the soda-minerals—elæolite, nepheline and leucite—in elæolite-syenite, phonolite, etc.

**Glaucophane.** Monoclinic. Silicate of alumina and soda— $\text{Na}_2\text{O}$ ,  $\text{Al}_2\text{O}_3$ ,  $4\text{SiO}_2$ . Colour, blue. Pleochroism striking, in blue and reddish violet tints, ( $\gamma$  = blue,  $\beta$  = reddish violet,  $\alpha$  = colourless to yellow). (See Fig. 44.) Maximum extinction-angle =  $5^{\circ}$ . Occurs in prisms and blades in glaucophane-schist (Anglesey, Isle of Syra, Japan). **Gastaldite** is a variety.

**Riebeckite.**<sup>1</sup> Monoclinic. Silicate of soda and iron— $\text{Na}_2\text{O}$ ,  $\text{Fe}_2\text{O}_3$ ,  $4\text{SiO}_2$ . Colour, deep blue. Pleochroism in blue and green tints, ( $\gamma$  = green,  $\beta$  = blue,  $\alpha$  = deep blue and nearly coincident with the vertical axis). (See Fig. 44.) Maximum extinction =  $5^{\circ}$ – $7^{\circ}$ . Riebeckite occupies a position among the amphiboles equivalent to that of ægirine among the pyroxenes. Occurs in certain felsites (Socotra, Mynydd Mawr in Wales, Ailsa Craig in Scotland). **Crocidolite** is a similar variety.

## 2. RHOMBIC AMPHIBOLE.

**Anthophyllite.** Rhombic. Silicate of magnesia and iron— $(\text{MgFe})\text{O}$ ,  $\text{SiO}_2$ . Colourless. Extinction straight. Occurs in bladed forms in amphibolites.

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<sup>1</sup> Discovered by Sauer (1888) in granite collected by Dr. Riebeck in Socotra.

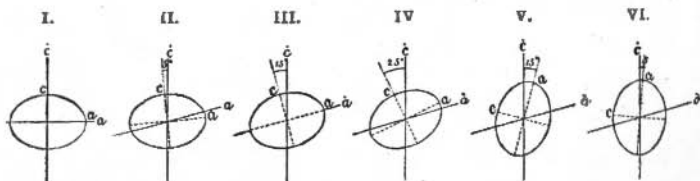
Also in fibrous zones around the olivines of some gabbros.

### 3. TRICLINIC AMPHIBOLE.

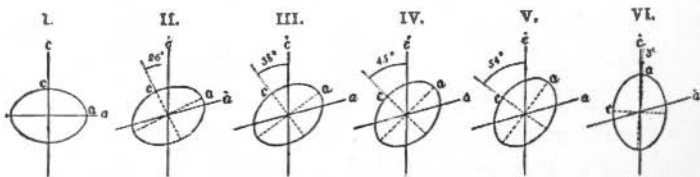
**Cossyrite.** Triclinic. Silicate of alumina, iron and soda. Under the microscope this mineral appears in prisms of a deep reddish-brown colour, only transmitting light in very thin sections.

It is only known to occur in the rhyolites of Pantelleria (pantellerites).

Diagram showing the relation existing between the morphological axes and the axes of elasticity in the principal amphiboles and pyroxenes. The angle given is that of extinction. (After Iddings.)



I. Anthophyllite. II. Glaucophane. III. Tremolite, etc. IV. Brown hornblende. V. Blue amphibole (Silver Cliff). VI. Riebeckite (P).



I. Enstatite, etc. II. Spodumene. III. Diopside, etc. IV. Augite. V. Augite. VI. Ægirine.

## PYROXENE GROUP.

The pyroxenes are silicates of iron, magnesia and lime, the lime predominating over the magnesia: the bases alumina, manganese, soda and lithia, also occur in some varieties. They are unattacked by acids. Sp. G. = 3-3.5. Hardness = 5-6. Cleavage parallel to the prism (angle =  $87^{\circ}$ ), very imperfect.

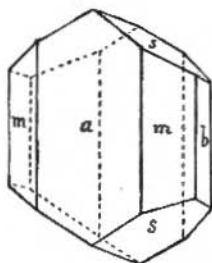


FIG. 45.

Crystal of Pyroxene.

a. Orthopinacoid.

b. Clinopinacoid.

m. Prism.

s. Pyramid.

(After Rosenbusch.)

The smaller angle between the prism-faces and the inferior degree of cleavage constitute the main points of distinction from hornblende. Under the microscope sections perpendicular to the vertical axis are octagonal, being bounded by the faces of the prism and of both pinacoids.

The pyroxenes may be divided into two groups:—the rhombic and the monoclinic pyroxenes.

### 1. RHOMBIC PYROXENES.

Silicates of iron and magnesia— $(MgFe)O$ ,  $SiO_2$ . According to the percentage of iron they contain, the following varieties may be distinguished:—



FIG. 46.

Longitudinal section of Enstatite.

**Enstatite**, with less than 5% of FeO.

**Bronzite**, 5–14% of FeO.

**Hypersthene**, above 14% of FeO.

Intensity of colour and pleochroism increase with the percentage of iron, enstatite being colourless and non-pleochroic in thin section, bronzite slightly coloured and pleochroic, and hypersthene strongly so. The most highly ferriferous variety has been termed **amblystegite**.

The rhombic pyroxenes are characterized by the possession of a fairly perfect pinacoidal cleavage, in addition to the prismatic cleavage common to all pyroxenes. In some varieties the pinacoidal cleavage surfaces have a sub-metallic (bronzy or coppery) lustre. This phenomenon is caused by reflection from the surfaces of innumerable parallel rods and

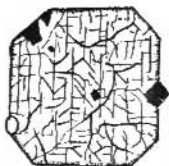


FIG. 47.

Cross-section of Enstatite.

flakes of foreign matter intercalated along these planes, and said to be of secondary origin.

Between crossed nicols the rhombic pyroxenes extinguish, of course, straight. The double refraction is not high, the colours being of low grade. The pleochroism of hypersthene is as follows:  $\alpha$  = sea-green,  $\beta$  = salmon-red,  $\gamma$  = reddish yellow.

They occur in various igneous rocks: diorites, porphyrites, andesites and some peridotites, and pass by alteration into a fibrous substance known as bastite.

## 2. MONOCLINIC PYROXENES.

*a. Brown Pyroxene.*

**Common Augite.** Silicate of alumina, lime, magnesia and iron:  $(CaMgFe)O$ ,  $(AlFe)_2O_3$ ,  $4SiO_2$ . Sp. G. = 3.30-3.50. Hardness = 5-6.



FIG. 48.

Longitudinal section of Augite



FIG. 49.

Cross-section of Augite.

This mineral is black by reflected light. In thin section it is of a pale-brown colour, sometimes with a violet tinge, especially when the mineral contains titanium. Pleochroism, faint or absent. Between

crossed nicols, fairly bright chromatic polarization. Extinction-angle, in sections parallel to the vertical



FIG. 50.

Crystal of Augite showing hour-glass structure.

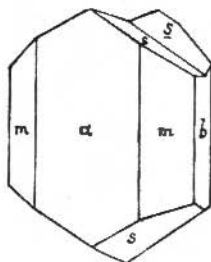


FIG. 51.

Crystal of Augite twinned on the Orthopinacoid.

a. Orthopinacoid.

b. Clinopinacoid.

m. Prism.

s. Pyramid.

(After Rosenbusch.)

axis, reaches a maximum of  $45^\circ$ . (Distinction from hornblende.) Slight variations in the extinction-

angle in different peripheral layers often produce in the crystals a zonal structure, occasionally assuming the form of an hour-glass. (See Fig. 50.) The cleavage is less perfect than in hornblende, the cracks being irregular, thick, and branching in thin section. Dual and even multiple twinning (parallel to the orthopinacoid), not uncommon. (See Fig. 51.)

Augite passes readily into chlorite by the ordinary process of weathering: dynamic metamorphism converts it into green hornblende (uralite, actinolite, etc.).

Loose crystals of black opaque augite occur among the material ejected from volcanoes (lapilli, cinders, ash, etc.). It is a very common constituent both of plutonic and volcanic rocks, especially of the more basic varieties: gabbro, dolerite, diabase, basalt, andesite, etc.

#### *b. Green and White Pyroxenes.*

**Malacolite, Salite, Diopside, Coccoelite, Omphacite.** Silicates of lime, magnesia and iron. Sp. G. = 3.3.

In colour these pyroxenes vary from a very pale green (malacolite) to a bright grass-green (omphacite, chrome-diopside). Malacolite occurs in grains and prisms in certain diorites, epidiorites and metamorphic schists. Bright green pyroxene (omphacite,



chrome-diopside) occurs in some peridotites, also in eclogite, pyroxene-granulite, etc.; coccolite occurs in metamorphic limestones.

Under the microscope malacolite gives colourless sections, which on account of their fairly high index of refraction (shown by strongly marked outline) and bright chromatic polarization, may easily be mistaken for epidote. It is distinguished from this mineral, however, by an oblique extinction in lath-shaped sections, and by the absence of pleochroism.

**Diallage** is a laminated variety of augite, usually of a greenish colour, occurring in gabbro. The lamination is parallel to the orthopinacoid; it appears in thin section as a fine lineation, which constitutes the chief diagnostic character of the mineral. The faces of this lamination or pseudo-cleavage are characterized by a pearly or sub-metallic lustre, due to the presence of minute included plates and rods. Thin pieces, flaked off in this direction and examined in convergent polarized light, present the oblique emergence of an optic axis (distinction from the rhombic pyroxenes).

*c. Soda-pyroxene.*

**Aegirine** and **Acmite** ( $\text{Na}_2\text{O}, \text{Fe}_2\text{O}_3, 4\text{SiO}_2$ ), corresponding to arfvedsonite, glaucophane, etc., among the amphiboles. They are of rare occurrence as

rock-forming minerals, being found only in elæolite-syenite and certain phonolites and trachytes.

**Olivine.**—Silicate of iron and magnesia:  $2(\text{MgFe})\text{O}$ ,  $\text{SiO}_2$ . Rhombic. Occurs in tabular or prismatic forms, made up of pinacoids and domes, or in irregular grains. Sp. G. = 3.2–3.5. Hardness = 6.5–7. Gelatinizes with hydrochloric acid. Colour, olive-green

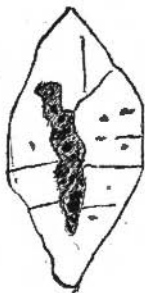


FIG. 52.

Corroded crystal of Olivine.

to yellow. Pinacoidal cleavage, imperfect. Under the microscope olivine presents colourless sections, sometimes bounded by crystallographic contours, oftener by irregular and indented outlines, due to corrosion. (See Fig. 52.) Its index of refraction is high, the outlines being strongly marked and the surface of the sections having a roughened appearance. The double refraction is also high, the sec-

tions polarizing in bright colours. Straight extinction in all principal sections. Inter-penetration twins are not infrequent in basalt. (See Fig. 53.) They are best seen between crossed nicols on account of the difference in extinction shown by the two individuals.

Olivine is very prone to decomposition; it alters readily into serpentinous products, also into calcite or dolomite, limonite, and more rarely into hornblende (pilite).

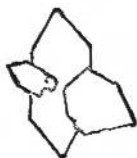


FIG. 53.

Twin-crystal of Olivine.

Olivine occurs only in basic and ultrabasic rocks: in gabbros, diabase, dolerites, basalts, limburgites, picrites, peridotites, etc. The peridotites are mainly composed of this mineral. Olivine alters readily into fibrous aggregates of serpentine; the alteration proceeding along cracks, and being often accompanied by a separation of iron-ores (magnetite, limonite, etc.).

**Hatyne** and **Nosean**.—Silicates of alumina, lime and soda, together with sulphate of lime or soda. Regular. Sp. G. = 2.27–2.50. Hardness = 5–5.5. Gelatinizes easily with hydrochloric acid; on evaporation, needles of gypsum are formed in the case of

häüyne, none in the case of nosean. The minerals are very similar in composition and appearance. Häüyne, however, is generally blue, and nosean, colourless or yellow. They are essentially volcanic minerals, occurring as sporadic grains in phonolites, andesites and basalt; also in volcanic ejectamenta (Vesuvius, Lake Laach in the Eifel).

Under the microscope they present square or six-

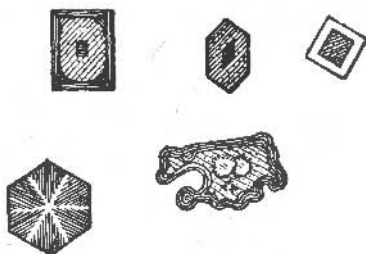


FIG. 54.

Crystals of Häüyne, showing the mode of arrangement of the inclusions.  
(After Rosenbusch.)

sided sections, which remain dark when rotated between crossed nicols. The sections are characterized by the presence of numerous minute inclusions aggregated to a marginal or zonal dark band, or accumulated in the centre as a grey shaded patch. In other cases they are arranged along axes intersecting in the centre at  $60^\circ$ . (See Fig. 54.)

**Scapolite.** Silicate of alumina, lime and soda, + sodium chloride. Tetragonal. Sp. G. = 2.6 – 2.8.

Hardness = 5-5.5. Colourless. Of infrequent occurrence in igneous rocks: oftener in gneisses and crystalline schists. Under the microscope, occurs in irregular colourless grains, possessing a well-defined cleavage. Between crossed nicols, bright chromatic polarization. **Couseranite** and **dipyre** are varieties of this mineral.

**Sodalite.** Silicate of alumina and soda, + sodium chloride. Regular. Sp. G. = 2.1 - 2.3. Hardness = 5.5. Gelatinizes easily with hydrochloric acid.

Occurs in blue, greenish, or colourless grains in elæolite-syenite and in volcanic ejectamenta. Under the microscope it presents colourless sections, which remain dark when rotated between crossed nicols. Numerous inclusions.

**Wollastonite.** Silicate of lime:  $\text{CaO}, \text{SiO}_2$ . Monoclinic. Sp. G. = 2.78 - 2.9. Hardness = 4.5 - 5. Colourless. Occurs in columnar crystals, and in fibres in metamorphic limestones and crystalline schists. Easily gelatinizes with hydrochloric acid.

**Apatite.** Phosphate of lime + chloride or fluoride of lime:  $3(\text{Ca}_3\text{P}_2\text{O}_8) + \text{Ca}(\text{ClF})_2$ . Hexagonal. Sp. G. = 3.16 - 3.22. Hardness = 5. Imperfect cleavage parallel to basal plane and prism. When fresh, colourless and glassy; altered varieties are dull green and red. Soluble in acids without gelatinization; the nitric acid solution gives a yellow precipitate with ammonium molybdate (distinction from nepheline).

Apatite occurs in long hexagonal prisms and needles; also in short prisms. It is one of the commonest accessory minerals, being found in most igneous rocks. It is especially abundant in the greenstones (dolerites and diabases), and the basalts. It is also one of the earliest-formed constituents; for its needles are usually found penetrating all other minerals. Under the microscope it is colourless and presents six-sided cross sections and elongated lath-shaped longitudinal sections. The former remain dark when rotated between crossed nicols, the latter extinguish straight. Double refraction weak, the polarization colour being grey. Index of refraction rather high (distinction from nepheline). There is often a central core of inclusions; and in such cases there is usually a slight absorption of light when the long axis of the section is parallel to the short diagonal of the nicol. Apatite may be easily mistaken for nepheline. It is distinguished from this mineral by the chemical reactions mentioned above, and by the fact that apatite occurs in rocks in slender, needle-like prisms, nepheline, on the other hand, in shorter and thicker prisms.

#### IRON-ORES.

The iron-ores that occur as common accessory constituents of rocks are magnetite or magnetic iron-ore, ilmenite or titaniferous iron-ore and pyrites.

**Magnetite.** Magnetic oxide of iron:  $\text{FeO}$ ,  $\text{Fe}_2\text{O}_3$ .  
Regular. Sp. G. = 4.9-5.2. Hardness = 5.5-6.5.

One of the commonest accessory constituents of igneous rocks, occurring in black octahedral grains, skeleton-crystals, and minute particles. Under the microscope it is perfectly opaque, even in the thinnest sections. In reflected light it has a bluish-black metallic lustre (distinction from pyrites and ilmenite). (See Fig. 55.) The amount of magnetite present in

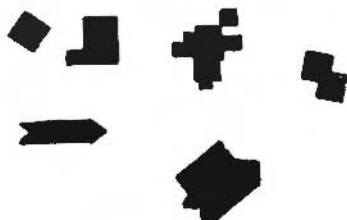


FIG. 55.

Crystals of Magnetite.  
(After Rosenbusch.)

the igneous rocks varies. It sometimes increases locally to a considerable extent, as in the dark patches of granitic rocks. Törnebohm and Vogt have shown that in certain basic igneous rocks a gradual increase in the percentage of iron-ore may be observed up to 90 per cent.

**Ilmenite.** Titaniferous oxide of iron:  $(\text{TiFe})_2\text{O}_3$ .  
Rhombohedral. Sp.G. = 4.5-5.2. Hardness = 5-6.

Infusible. Attacked with difficulty by acids. Black and opaque in thin section. Occurs in hexagonal sections, but often in irregular grains, and then not easy to distinguish from magnetite. It may be distinguished from that mineral, however, by the fact that it is very liable to alteration into a white opaque substance, known as leucoxene (a variety of sphene), by which it is almost invariably accompanied. The alteration takes place along three systems of lamellæ intersecting at  $60^\circ$ , thus indicating the rhombohedral



FIG. 53.

Section of Ilmenite.

character of the mineral. Ilmenite occurs in basic igneous rocks, especially in gabbro, dolerite and diabase.

**Pyrites.** Sulphide of iron:  $\text{FeS}_2$ . Regular, in cubes and pentagonal dodecahedra. Sp. G. = 4.9-5.2. Hardness = 6-6.5. Occurs abundantly disseminated in minute yellow specks and grains in both igneous and sedimentary rocks.

Under the microscope, it is opaque; in reflected light, however, its brassy yellow colour at once characterizes it.



**Spinel.** The spinel group consists of a series of minerals crystallizing in the regular system and composed of a double molecule formed by the union of a sesquioxide ( $\text{Fe}_2\text{O}_3$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Cr}_2\text{O}_3$ ) with a protoxide ( $\text{FeO}$ ,  $\text{MgO}$ ,  $\text{MnO}$ ,  $\text{ZnO}$ ,  $\text{CrO}$ ).

The commonest combinations occurring in rocks are the following :—<sup>1</sup>

	Formula.	Colour.	Sp. G.	H
Spinel .	$\text{MgO}, \text{Al}_2\text{O}_3$	red	3·5-4·1	8
Pleonaste	$(\text{MgFe})\text{O}, (\text{AlFe})_2\text{O}_3$	dark green	3·6	8
Hercynite	$\text{FeO}, \text{Al}_2\text{O}_3$	"	3·9	7·5-8
Picotite	$(\text{FeMg})\text{O}, (\text{CrAl})_2\text{O}_3$	{ yellowish brown }	4·0	8
Chromite	$(\text{FeMgCr})\text{O}, (\text{CrAlFe})_2\text{O}_3$	{ dark brown to opaque }	4·8	5·5
Magnetite	$\text{FeO}, \text{Fe}_2\text{O}_3$	{ black and opaque }	4·9-5·2	5·5-6·5

The spinels are abundant in igneous and metamorphic rocks, occurring in small grains and octahedral crystals. Under the microscope they are isotropic (exerting no influence on polarized light). The dark-coloured spinels (pleonaste, hercynite, picotite and chromite) occur frequently in peridotites and serpentines. Magnetite has already been described with the iron-ores.

<sup>1</sup> Lévy and Lacroix.

**Garnets.** Silicates of alumina, iron, manganese, chromium, lime and magnesia, having the general formula  $3MO, R_2O_3, 3SiO_2$ .<sup>1</sup> According to the variation of MO and  $R_2O_3$ , the following varieties may be distinguished:—<sup>2</sup>

	MO	$R_2O_3$	Colour.	Sp. G.
Grossularia	CaO	$Al_2O_3$	pale green	3·4-3·6
Almandine	FeO	$Al_2O_3$	claret	3·5-4·3
Pyrope	FeO, MgO, CaO	$Al_2O_3, Cr_2O_3$	blood red	3·7-3·8
Melanite	CaO	$Fe_2O_3$	{ blackish brown }	3·6-4·3
Spessartine	MnO	$Al_2O_3$	{ light reddish }	3·7-4·3
Ouvarovite	CaO	$Cr_2O_3$	green	3·4-3·5

Other garnets consist of mixtures of these molecules.

The garnets are insoluble in acids. They have a hardness of 6·5-7·5, irregular fracture and resinous lustre.

The garnets crystallize in the Regular System, the most common form being the rhombic dodecahedron, the edges of which are sometimes truncated by icositetrahedral faces.

<sup>1</sup> M stands for metals like calcium, magnesium, etc., forming protoxides; R for those like aluminium and chromium, forming sesquioxides.

<sup>2</sup> Lévy and Lacroix.

Under the microscope garnet appears in irregular or in 4- and 6-sided grains of a pink or salmon colour. Rotated between crossed nicols they remain dark; in exceptional cases, however, they are "optically anomalous," giving evidence of double refraction in a feeble transmission of light between

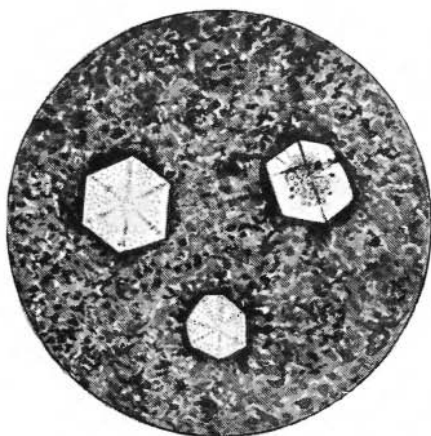


FIG. 57.

Section of a rock containing Garnets. (After Renard.)

crossed nicols. The sections are traversed by irregularly branching cracks produced by an imperfect cleavage parallel to the rhombic dodecahedron. The index of refraction is fairly high, giving the grains bold contours.

As an accessory constituent, garnet is common enough, occurring in granites, microgranites (granu-

lite, aplite), and trachytic rocks, in the gneisses and crystalline schists, and in the sands produced by the disintegration of these and similar rocks. It is constant in its occurrence in some of the peridotites and allied rocks: eclogite, pyroxene-granulite, etc.

**Zircon.** Silicate of zirconium:  $ZrO_2, SiO_2$ . Tetragonal, occurring in small prisms terminated at both ends by the pyramid. Colour, red and brown.

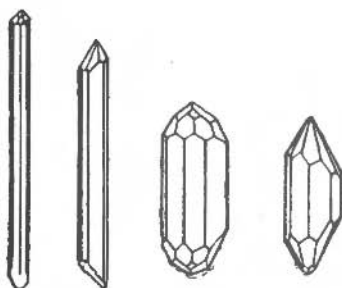


FIG. 58.

Crystals of Zircon. (After Rosenbusch.)

Infusible; unattacked by acids. Sp.G. = 4.4–4.7. Hardness = 7.5. In thin sections zircon occurs in small, colourless grains, with well-marked contours. Between crossed nicols the polarization colours are brilliant pinks and greens, the double refraction being high.

Zircon has a wide distribution in eruptive (both plutonic and volcanic) and metamorphic rocks. It

occurs frequently as an inclusion in black mica, in which case the grains are surrounded by a pleochroic zone. Being undecomposable it is found in the sands derived from granitic and gneissose rocks, and also in the sandstones and quartzites produced by their consolidation. (See Fig. 58.)

**Eudialyte** is a hexagonal mineral allied to zircon. Chemical composition,  $\text{Na}_2, (\text{CaFe})_2, (\text{SiZr})_6, \text{O}_{18}$ . Specific gravity, 2.95-3.0. It is of rare occurrence.

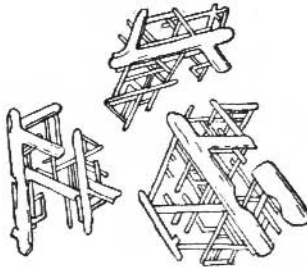


FIG. 59.

Crystals of Rutile (Sagenite). (After Rosenbusch.)

**Rutile.** Titanic Oxide:  $\text{TiO}_2$ . Tetragonal, crystallizing in slender prisms and needles. Frequently twinned, on two types, producing geniculated and heart-shaped forms. Colour, yellow to red. Sp.G. = 4.20-4.27. Hardness = 6-6.5. Unattacked by acids. Distinguished under the microscope by its yellow colour and strongly marked borders, due to the high index of refraction it possesses. It fre-

quently presents a peculiar interlaced structure, known as *sagenite*. (See Fig. 59.) Rutile occurs as prisms and twins in the crystalline schists, especially in hornblende-schist; also in sands and sedimentary rocks. Fine hair-like bodies occurring in quartz and clay-slates (*Thonschiefernädelchen*), are referred to rutile.



FIG. 60.

Crystals of Tourmaline, from the Bagshot Sands at Hampstead, under the microscope. (After Teall.)

**Tourmaline.** A complicated silicate and borate of alumina, magnesia and iron. Rhombohedral, occurring in triangular prisms with rhombohedral termination. The prisms show a vertical striation. Often in fibrous veins and stellate aggregations. Sp.G. = 2.94 - 3.24. Hardness = 7 - 7.5. Unattacked by acids. Colour usually black. Vitreous lustre.

Under the microscope, the lath-shaped, prismatic sections extinguish straight. Marked pleochroism in violet, blue, green and brown colours; the deeper colour always appearing when the long axis of the section is perpendicular to the short diagonal of the polarizing nicol (distinction from biotite). The variety schorl occurs in microgranites (*e.g.*, the elvans of Devon and Cornwall), in the marginal portion of granites (schorlaceous granite), and in the altered rock in contact with granite (schorl-rock). It also occurs in pegmatite veins. (See Fig. 60.)

**Xenotime** (phosphate of yttrium) and **Monazite** (phosphate of cerium and lanthanum) are rare minerals, occurring in sands and china-clays, and probably derived from igneous rocks. Prof. Derby has described them in the muscovite-granites of Brazil. Xenotime occurs in pyramidal crystals which are transparent, yellow, or colourless, with highly polished faces. By alteration it becomes opaque.

**Sphene.** Silicate and titanate of lime:  $\text{CaO}$ ,  $\text{SiO}_2$ ,  $\text{TiO}_2$ . Monoclinic. In flat cuneate crystals of a greenish yellow to blackish-brown colour. Sp. G. = 3.3–3.7. Hardness = 5–5.5. Unattacked by hydrochloric acid. Under the microscope sphene appears in irregular strongly contoured grains, which are occasionally wedge-shaped. Its colour, in thin section, is reddish-yellow. Pleochroism feeble. Double refraction very

high, but not producing brilliant characteristic polarization, the colour effect between crossed nicols being an indefinite brownish grey. The white opaque substance surrounding ilmenite, and resulting from its alteration, is a variety of sphene known as **leucoxene**.

Sphene occurs in granites, syenites and crystalline schists; leucoxene in gabbros, diabases, epidiorites and hornblende and chlorite schists.

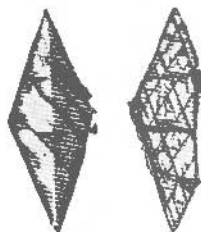


FIG. 61.

Crystals of Sphene.

**Epidote.** Silicate of lime, alumina and iron:  $H_2O, 4CaO, 3(AlFe)_2O_3, 6SiO_2$ . Monoclinic, in crystals elongated parallel to the orthodiagonal axis. Lath-shaped sections therefore give straight extinction between crossed nicols. Sp. G. = 3.39. Hardness = 6-7. Unattacked by hydrochloric acid. Colour, yellowish-green. Perfect cleavage parallel to the basal plane. Epidote occurs as a frequent alteration-product of the ferromagnesian minerals, in gabbros, diabases, diorites, melaphyres, epidiorites and hornblendic and



chloritic schists. It is also found veining these rocks, or associated with other secondary minerals in the amygdules of old lavas. Under the microscope it appears in small colourless to yellow grains or prisms, showing strong relief due to a high index of refraction. When coloured it is faintly pleochroic. Brilliant chromatic polarization between crossed nicols. **Piedmontite** (withamite) is a red, markedly pleochroic, variety of epidote occurring in the Glencoe porphyrite (Scotland), in the famous *Porfido rosso antico* of Egypt, and in certain Japanese mica-schists (Piedmontite-schist).

**Zoisite.** Silicate of lime and alumina:  $H_2O$ ,  $4CaO$ ,  $3Al_2O_3$ ,  $6SiO_2$ . Rhombic, occurring usually in columnar aggregates of a whitish-grey colour. Sp. G. = 3.25–3.36. Hardness = 6. Unattacked by hydrochloric acid. Under the microscope it presents colourless prisms and granules, resembling epidote, but distinguishable from that mineral by its low double refraction, a feeble bluish light being transmitted between crossed nicols. Occurs in association with epidote in altered basic igneous rocks and metamorphic schists.

#### CARBONATES.

The carbonates of lime, lime-magnesia and iron (calcite, dolomite and siderite) are isomorphous, and can replace one another in any proportions.

**Calcite.** Carbonate of lime :  $\text{CaCO}_3$ . Rhombohedral. The crystalline forms assumed by calcite are innumerable : it occurs in rhombohedra, which may be either flat or have any degree of acuteness ; in sharp-pointed scalenohedra (dog-tooth spar) ; in thick-set or slender six-sided prisms crowned by the faces of the rhombohedron ; or in prisms terminated by the basal plane. It also occurs in amorphous masses and in veins. Sp. G. = 2.72. Hardness = 3 (easily scratched with the knife). Cleavage parallel to the rhombohedron, perfect rhombohedra being produced by the fracture. Effervesces with acids in the cold. Colourless to white, but often stained yellow, red and brown by ferruginous impurities. Under the microscope it occurs in irregular grains, traversed by fine cleavage lines, intersecting at an acute angle. Between crossed nicols, the polarization colour is an iridescent pinkish grey ; and broad colour-bands, produced by lamellar twinning, are often visible along the diagonals of the cleavage rhomboids.

As a secondary constituent, calcite occurs in the more basic igneous rocks—diorites, gabbros, diabases, etc. It is the principal constituent of the altered limestones (marbles). It often forms the cementing material of fragmental rocks (*e.g.*, calcareous sandstones).

**Dolomite** is the isomorphous admixture of the carbonates of lime and magnesia. It resembles

calcite in its crystallographic and optic properties. Chemically it is less soluble than calcite, being not acted upon by acetic acid and cold dilute hydrochloric.

**Aragonite** is the rhombic carbonate of lime. Its crystals are often six-sided, and, especially when twinned, resemble the hexagonal combination of prism and basal plane. Sp. G. = 2·9-3. Hardness = 3·5-4. It is found in fibrous and spherulitic aggregates in many igneous and metamorphic rocks. It frequently fills cavities in basalt, or traverses the same rock in strings and veins. Stalactites are often built up of fibrous aggregates of aragonite. The small spherular bodies formed in warm calcareous springs and giving rise to pisolitic and oolitic rocks, consist of radiate and fibrous aragonite.

**Zeolites.** A group of hydrated silicates of various bases: alumina, potash, soda, lime, baryta and strontia. They are secondary products, occurring in igneous rocks as the infillings of amygdaloidal cavities (especially of melaphyres and basalts), or as pseudomorphs after decomposed minerals (*e.g.*, nepheline).

Under the microscope they are always colourless, and occur in fibrous and radiate aggregates. They are easily decomposed by hydrochloric acid, with separation of gelatinous silica.

Some of the more commonly occurring varieties are:

natrolite (or mesotype), analcime, phillipsite, prehnite, scolecite and apophyllite.

**Chlorites.**<sup>1</sup> Hydrated silicates of magnesia, iron and alumina. Monoclinic (pseudo-hexagonal). Gelatinize with hydrochloric acid. Sp. G. = 2·60–2·96. Hardness = 1–1·5. Colour, green: pleochroic in green and yellow tints. Occur in six-sided plates, scales, and fibres, sometimes united to spherular and spiral aggregates (ripidolite and helminth). Basal cleavage, less perfect than in mica; cleavage-flakes non-elastic. The double refraction is low, the usual colour between crossed nicols being a grey or steel-blue of the first order. When heated on platinum-foil, chlorite becomes black and opaque.

Chlorite is essentially a secondary mineral resulting from the decomposition of dark mica, hornblende and augite. It occurs abundantly in altered igneous rocks, especially in the more basic types—gabbro, diabase, melaphyre, etc., which largely owe their greenish colour to this mineral; also in epidiorites and chlorite-schists. It is sometimes confounded, under the microscope, with secondary hornblende and with serpentine, with which it is often associated

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<sup>1</sup> Under the name of chlorite is included a number of allied minerals, differing but slightly from one another in regard to their optic properties (*pennine*, *ripidolite*, *helminth*, *clinochlore*, *kämmererite*, *prochlorite*, *metachlorite*, *delessite*, *chlorophæite*, *corundophilite*, etc.).

and which it much resembles. It may be distinguished from the former by its low double refraction, and from the latter by its pleochroism.

**Viridite** is an indefinite name given to the various green alteration products (chlorite, serpentine, etc.) occurring in diabase.

**Ottrelite and Chloritoid.** Hydrated silicates of alumina, magnesia, iron and sometimes manganese. Monoclinic, but with pseudo-hexagonal symmetry. Sp. G. = 3·52–3·57. Hardness = 6·5. Colour, bluish-green. Pleochroism in bluish and green tints. Occur in lustrous 6-sided plates in metamorphic schists. Under the microscope, characterized by lamellar twinning.

**Serpentine.** Hydrated silicate of magnesia and iron:  $2\text{H}_2\text{O}$ ,  $3(\text{MgFe})\text{O}$ ,  $2\text{SiO}_2$ . Sp. G. = 2·5–2·7. Hardness = 3–4. Colour, dull green; often stained red and yellow with iron oxides. Occurs most frequently as an alteration-product of olivine, less frequently of hornblende and augite. Under the microscope it usually presents a confusedly interlaced aggregate of colourless blades, scales and fibres, which frequently enclose unaltered fragments of the mineral from the alteration of which it takes its origin. (See Figs. 62 and 63.) Serpentine derived from olivine, is said to possess a “mesh-structure”; that arising from the alteration of hornblende is more “bladed”, while augite gives rise to a “netted” form of the

mineral. These different structures are produced by the variable nature of the cleavages in these minerals, the alteration into serpentine invariably proceeding along these planes of weakness. Serpentine



FIG. 62.

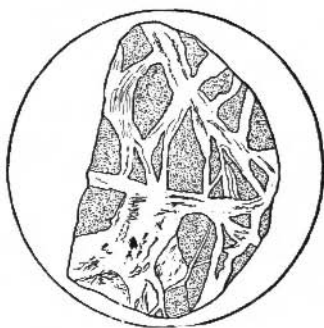


FIG. 63.

Olivine altering into Serpentine.  
(After Bonney.)

also occurs massive, and may then be considered as a rock. *Pseudophite* is an aluminous variety of serpentine produced by the alteration of the felspar in gabbro (Lizard).

**Kaolinite.** Hydrated silicate of alumina :  $2\text{H}_2\text{O}$ ,  $\text{Al}_2\text{O}_3$ ,  $2\text{SiO}_2$ . Rhombic, but with pseudo-hexagonal symmetry. Sp. G. = 2.34 - 2.57. Hardness = 1 - 2. Dissolved by boiling sulphuric acid.

Occurs in colourless six-sided plates and scales as an alteration-product of felspar ; and the turbidity of altered felspar is chiefly due to the development of

this mineral. It is the chief constituent of china-clay or kaolin. (See Fig. 64.)

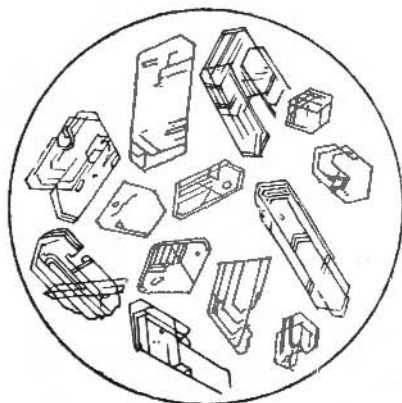


FIG. 64.

Crystals of Kaolinite, under the microscope. (After Teall.)

**Talc.** Hydrated silicate of magnesia:  $\text{H}_2\text{O}$ ,  $3\text{MgO}$ ,  $4\text{SiO}_2$ . Rhombic, but with pseudo-hexagonal symmetry. Sp. G. = 2.7–2.8. Hardness = 1. Scratched by the finger-nail. Pale green or colourless. Cleavage, basal. Flakes, flexible but non-elastic.

Occurs, in thin section, in colourless scales, giving brilliant chromatic polarization between crossed nicols, and resembling muscovite. It occurs as an alteration-product of magnesian minerals, mainly in metamorphic schists (talc-schist). *Steatite* or *soapstone* is a variety of talc.

**Andalusite.** Silicate of alumina:  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ .

Rhombic. In square thick-set prisms, terminated by the basal plane. Sp. G. = 3.1-3.2. Hardness = 7-7.5. Unattacked by acids.

Crystals of this mineral usually appear dark-coloured owing to the presence of included graphite. Under the microscope, however, the grains are either

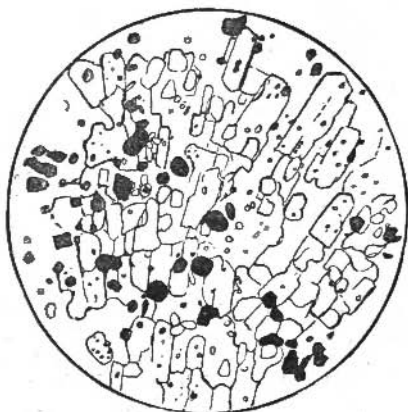


FIG. 65.

Andalusite, under the microscope. (After Cohen.)

colourless or pink; in the latter case, they often present a marked pleochroism (yellow to red). The pleochroism is sometimes manifested in irregularly distributed spots and patches.

Occurs in slates and shales that have undergone extreme metamorphism in contact with granite; also in gneisses and crystalline schists, and as an accessory



constituent of granite (*e.g.*, at the Cheesewring in Cornwall). **Sillimanite**, or **fibrolite**, is a fibrous mineral allied to andalusite and occurring in gneisses.

**Chiastolite** is a variety of andalusite, containing graphitic material arranged along the diagonals of the prisms. Occurs in small light-coloured prisms in chiastolite-slate, in the immediate neighbourhood of granite (*e.g.*, Skiddaw).

**Staurolite**. Silicate of alumina and iron:  $\text{FeO}$ ,  $2\text{Al}_2\text{O}_3$ ,  $2\text{SiO}_2$ . Rhombic. In prismatic forms terminated by the basal plane; commonly twinned, forming symmetrical Maltese and St. Andrew's crosses. Sp. G. = 3.3 – 3.8. Hardness = 7 – 7.5. Unattacked by acids. Occurs in the crystalline schists, and in rocks of the granite contact-zone.

**Cordierite**. Silicate of alumina, iron and magnesia:  $3\text{MgO}$ ,  $3(\text{AlFe})_2\text{O}_3$ ,  $8\text{SiO}_2$ . Rhombic, with pseudo-hexagonal symmetry. Sp. G. = 2.60 – 2.66. Hardness = 7–7.5. Often twinned. Colour, dark blue; in thin section usually colourless. Feeble pleochroism when coloured. Yellow pleochroic spots or halos round inclusions of zircon and apatite, which disappear on rotation of the section.

Cordierite may be distinguished from andalusite by its lower index of refraction, a grain placed in Canada balsam being scarcely visible, whereas andalusite stands out with well-marked contours.

This mineral occurs in granite and gneiss (cordie-

rite-gneiss); more rarely in volcanic rocks (*e.g.*, basalt, andesite). It alters easily into mica-like decomposition products (pinite, esmarkite, praseolite, gigantolite, etc.).

**Idocrase.** (Vesuvianite.) Silicate of lime and alumina:  $\text{H}_2\text{O}$ ,  $8\text{CaO}$ ,  $2\text{Al}_2\text{O}_3$ ,  $7\text{SiO}_2$ . Tetragonal. In square prisms with basal plane and pyramid. Sp. G. = 3.3–3.4. Hardness = 6.5. Colour, dark green, brown, red, yellow. Vitreous lustre. Occurs in limestones that have undergone alteration by contact with igneous rocks.

## VI.

### THE CLASSIFICATION AND DESCRIPTION OF THE IGNEOUS ROCKS.

To produce a satisfactory classification of the igneous rocks, a classification which shall be at once simple and comprehensive, is one of the most difficult problems a petrologist can attack. The various types are so intimately related, that any attempt at rigid and systematic arrangement is not likely to meet with any great measure of success. But some method of grouping rocks is a necessity that must be faced. In the arrangement adopted in these pages, chemical composition (as far as the percentage of silica is concerned) and mode of origin or occurrence, occupy a chief place. Mineralogical composition is, on account of its extreme variability, allowed to play only a subsidiary *rôle*.

In respect to the percentage of silica, igneous rocks fall naturally into four groups, viz. :—

- (1) **An acid group** with 65–80% of silica, Sp.

G. below 2·75; *e.g.*, granites, elvans, rhyolites, felsites.

(2) **An intermediate group** with 55–70% of silica, and Sp. G. between 2·70 and 2·80; *e.g.*, syenites, diorites, trachytes, andesites, porphyrites.

(3) **A basic group** with 45–60% of silica, and Sp. G. between 2·80 and 3·00; *e.g.*, gabbros, dolerites, and basalts.

(4) **An ultrabasic group** with silica between 35 and 50%, and Sp. G. between 2·85 and 3·4; *e.g.*, the peridotites.

Three of these groups may be sub-divided into three families, the first embracing the more coarse-grained holocrystalline rocks, which have consolidated in deep-seated portions of the earth's crust; the second, the microcrystalline and porphyritic rocks, which, for the most part, have been injected into fissures or between bedding-planes; and the third, the sub-vitreous volcanic rocks. It must not be supposed that these divisions correspond to hard and fast lines in nature. On the contrary, every gradation exists from one to another. (See p. 34.) Both groups and families overlap. All that has been done in the present instance, is to select a few convenient points around which to group allied types.

## ACID GROUP.

1. The Granite Family.
2. The Elvan Family.
3. The Rhyolite Family.

## INTERMEDIATE GROUP.

4. The Syenite and Diorite Family.
5. The Mica-trap and Lamprophyre Family.
6. The Trachyte and Andesite Family.

## BASIC GROUP.

7. The Gabbro Family.
8. The Dolerite Family.
9. The Basalt Family.

These groups permit thus of a fairly symmetrical sub-division. The ultra-basic group, the members of which consist almost exclusively of ferromagnesian minerals, must, however, be divided into four families:—

10. Magma-basalt Family.
11. Picrite Family.
12. Pyroxenite and Hornblendite Family.
13. Peridotite Family.

## I. THE GRANITE FAMILY.

The granites<sup>1</sup> are wholly crystalline aggregates of quartz, orthoclase, with one or more varieties of mica, hornblende or augite. (See Fig. 66.) According to the nature of the latter, the following types may be distinguished :—

**Granite proper**, with both light and dark mica.

**Muscovite-granite**, with white mica alone.

**Biotite-granite** or **granitite**,<sup>2</sup> with dark mica alone.

**Hornblende-granite** or **hornblende-granitite**, with hornblende alone, or in addition to dark mica.

**Augite-granite**, with augite in addition to black mica.

The essential minerals are present in approximately equal proportions. They can easily be distinguished in the hand-specimen. The quartz is recognisable by its vitreous lustre, pellucidity, conchoidal fracture and absence of cleavage. It is either colourless, or possesses a smoky tinge.

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<sup>1</sup> The word *granite* was first introduced by Cæsalpinus in the year 1596.

<sup>2</sup> Granitite is the name given by Rose to a granite containing much oligoclase and black mica. But it is used as above by Rosenbusch.

The orthoclase is usually the predominant mineral. It is generally of a pinkish colour and non-transparent. Its cleavage is well-marked, the divisional planes being large and lustrous.

The crystals are usually twinned on the Carlsbad



FIG. 66.

Granite (Hornblende-granite), under the microscope.

f. Feldspar (orthoclase and plagioclase).

g. Quartz. m. Mica.

h. Hornblende, with granules of Epidote.

(After Fouqué and Lévy.)

type, and the two halves can be readily distinguished by the opposed inclination of the cleavage surfaces. Under the microscope, the sections of orthoclase are seen to contain cumulous aggregates of kaolin, pro-

ducing a characteristic turbidity. This is due to decomposition, and is known as "kaolinization." Very frequently orthoclase contains included patches and lamellæ of triclinic felspar, intercalated along orthopinacoidal planes. The resulting structure is known as *microperthite*. A common associate of the orthoclase is microcline, which is at once distinguished under the microscope by its characteristic cross-hatching.

The plagioclase is usually the soda-lime variety known as oligoclase. It occurs in less quantity than the orthoclase, and may generally be distinguished from it by its white or greenish-white colour; also by a fine parallel twin-striation, visible on the cleavage-faces.

The micas may be recognised by their extreme cleavability. The muscovite is silvery white, and the biotite brownish-black with metallic lustre. The hornblende is black or dark-green; it occurs in crystals showing a cleavage parallel to the prism, the angle of which is  $124^{\circ}$ . The augite is a pale variety (*malacolite*).

Numerous accessory minerals occur in granite: apatite, zircon, sphene, orthite, garnet, topaz, cordierite (*pinite*); schorl (in schorlaceous granite), fluorspar (*e.g.*, in *trowlesworthite*), molybdenite and iron-pyrites. Talc, chlorite, epidote and calcite are secondary minerals, resulting from decomposition.



The chemical composition of the granites varies according to the proportion of the ingredients. The following analysis expresses roughly the mean values :—

$\text{SiO}_2 = 72\%$ ,  $\text{Al}_2\text{O}_3 = 16\%$ ,  $\text{FeO} + \text{Fe}_2\text{O}_3 = 1.5\%$ ,  $\text{CaO} = 1.5\%$ ,  $\text{MgO} = 0.5\%$ ,  $\text{K}_2\text{O} = 6.5\%$ ,  $\text{Na}_2\text{O} = 2.5\%$ ; Sp. G. = 2.59 – 2.75 (v. Lasaulx).

## ANALYSES OF SOME TYPICAL GRANITES.

	<i>Granite. Carn Brea. (Phillips.)</i>	<i>Soda-granite. Aughrim. (Sollas.)</i>	<i>Granitite. Shap. (15 lb. sample.) (J. B. Cohen.)</i>
$\text{SiO}_2$ - - -	74.69	70.69	68.55
$\text{Al}_2\text{O}_3$ - - -	16.21	15.20	16.21
$\text{Fe}_2\text{O}_3$ - - -	trace	3.76	2.26
$\text{FeO}$ - - -	1.16	—	not estim.
$\text{MnO}$ - - -	.58	—	0.45
$\text{CaO}$ - - -	.28	3.31	2.40
$\text{MgO}$ - - -	.48	.45	1.04
$\text{K}_2\text{O}$ - - -	3.64	2.31	4.14
$\text{Na}_2\text{O}$ - - -	1.18	4.69	4.08
$\text{Li}_2\text{O}$ - - -	.10	—	—
Loss on ignition	1.23	.56	not estim.
	99.55	100.97	99.13

With regard to structure, there is also considerable variability; the commonest structure is that in which the minerals appear to have separated nearly simul-

taneously. They form then a holocrystalline "granitoid" aggregate, the boundary of each grain being formed by those of its immediate neighbours, to the exclusion of crystal faces. In many cases, however, the felspar crystals have idiomorphic contours, while the quartz is interstitial. The size of the individual grain varies considerably, and accordingly we have fine-grained and coarse-grained granites. Many granites are coarse-grained in the interior of the mass, but pass into a fine-grained, or even microcrystalline variety, at the margin or in the apophyses sent off from the main mass, where the cooling has necessarily taken place more rapidly.

Some granites contain large porphyritic crystals of orthoclase. In such cases, the ground-mass has the composition of an ordinary granite, and contains a second crop of felspars. Such rocks are termed **granite-porphyry**.

In other granites there is a base of fine micropegmatite, surrounding the crystals of quartz and felspar. The surrounded grain is often in optical continuity with the quartz or felspar of the micropegmatite.

Granite often contains dark patches, in which the more basic minerals have segregated during consolidation. Such "concretionary patches" are known to the quarry men under the name of "heathen." In rarer instances, the constituents have assumed during consolidation a radial and concentric arrangement

around certain smaller patches, producing **spheroidal** or **ball-granite**.

Granite occurs in large intrusive masses, bosses and laccolites, altering, and sending off veins or apophyses into, the slates in contact with it. The contact-zone extends around some of the large masses (*e.g.*, that of Mt. Leinster, in S. E. Ireland) to the distance of a mile away from the granite. Within the contact-zone the slates are crumpled and rendered crystalline. The characteristic contact-minerals in the slates are mica, schorl, chiastolite, andalusite, kyanite and staurolite. The chiastolite and andalusite first indicate their presence by the formation of spots and knots, producing the so-called spotted and knotted slates (*Fleck-, Frucht- and Garbenschiefer* of the Germans). Limestones in contact with granite are converted into marble, which generally contains one or more of the following lime-silicates—wollastonite, idocrase, diopside, etc.

Granite, when subjected to dynamic metamorphism, assumes a foliated character, the quartz and felspar being drawn out into eye-like masses, the central part of which may consist of the original mineral, while the external layers are composed of a granular aggregate of secondary quartz and felspar. These "eyes" are usually wrapped round by fibrous and ribbon-like laminæ of muscovite. Such granites may be termed **gneissose granites**.

On the other hand, some granites undoubtedly possess a parallel structure which is original and due to fluxional movements prior to consolidation.

#### DISTRIBUTION OF BRITISH GRANITES.

WEST OF ENGLAND. Five large masses of granite (granite-porphry) occur in *Devon* and *Cornwall*. They have been respectively designated the Dartmoor, Brown Willy, St. Austell, Penryn (or Carn Menezes), and Land's End masses. Besides these larger protrusions there are many smaller bosses—*e.g.*, those of St. Michael's Mount, Godolphin Hills, Carn Brea and Carn Marth, Belovely Beacon, Kit Hill and Hingston Down, and Lundy Island in the Bristol Channel. The rocks have usually a grey colour. Some are very handsome, owing to the presence of large porphyritic crystals of white felspar, and are largely used as ornamental building stones.

MIDLAND COUNTIES. *Malvern Hills* (*Worcestershire*), *e.g.*, the gneissose granite of Great Malvern (North Hill) and the hornblende-granitite occurring north of the Wych. *Charnwood Forest district* (*Leicestershire*), *e.g.*, the hornblende-granitite of Mount Sorrel, and the granitite of Cliff Hill, Ashby.

LAKE DISTRICT. Three principal masses:—Shap Fells in *Westmorland*, Skiddaw and Eskdale (or Muncaster) in *Cumberland*. The Shap rock is a granitite, containing felspars, brown mica and sphene.

It is much prized as an ornamental building stone

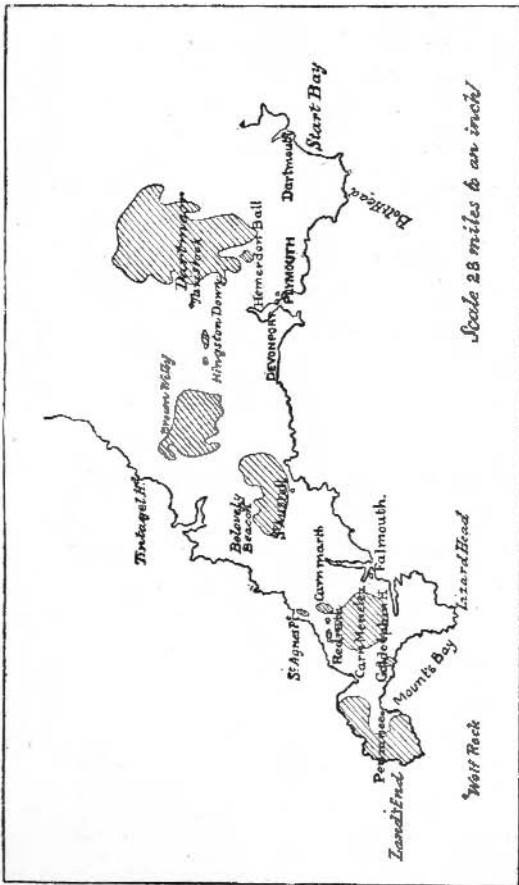


FIG. 57.  
Sketch-map of Cornwall and Devon, showing the chief granite-masses.

on account of the beauty of its porphyritic pink fel-

spar. The Skiddaw rock is a grey and dun-coloured granitite, cropping out on the north-west side of Saddleback, in the Caldew valley. It is surrounded by a contact-zone of chiasmolite-slate and andalusite rock. The Eskdale and Muncaster rock (granitite, granophyric in places) is a large irregular mass extending from Wastwater and Eskdale Fell, through Eskdale and Muncaster, southwards to Bootle. It is a medium to coarse-grained rock, often much reddened by hæmatite stains.

CHEVIOT DISTRICT. Augite-granitites occur near Staindrop Rigg and Hedgehope.

WALES. *South Wales.* Granitite occurs at St. Davids in Pembrokeshire.<sup>1</sup>

*North Wales.* The most important mass of granite is that of the Sarn district in the Lleyn peninsula (S.W. extremity of Caernarvonshire). It is a granitite, consisting of crystals of orthoclase (somewhat kaolinized), oligoclase and biotite, moulded by abundant granular quartz. In addition to these constituents there is a little iron-ore, apatite and zircon. It is intrusive in Ordovician<sup>2</sup> slates. It builds the round hill of Mynydd Cefn Amwlch, N.W. of Sarn, and extends in an elongated patch, four miles long, by Bryn-Croes to beyond Meillionydd. An outlier

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Dimetian of Dr. Hicks.

Lower Silurian of the Geol. Survey.

of the same rock occurs at Pyllau-giach. A similar rock (granitite) crops out at Tan y Grisiau, two miles N. of Ffestiniog (Merionethshire), forming an elongated patch (laccolite?)  $2\frac{1}{2}$  miles long. Most of the acid intrusives of North Wales and Anglesey, however, belong to the group of granophyres and microgranites, and will be referred to on p. 130.

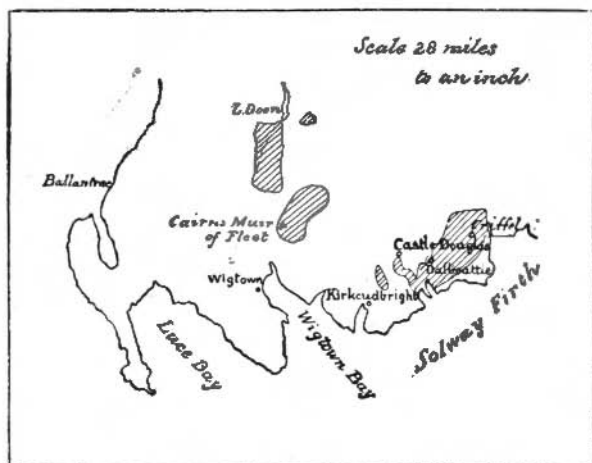


FIG. 68.

Sketch-map of S.W. of Scotland, showing the granites.

**SOUTH SCOTLAND.** In *South Scotland* there are three principal *massifs*; namely, (1) Dalbeattie and Criffell, (2) Cairns Muir of Fleet and New Galloway, and (3) Loch Doon and Loch Dee. These *massifs* comprise a great variety of rocks, including granitites and hornblende-granitites.





Old Red Sandstone. Among the *older intrusions* one of the most important is the granitite of Ben Vuroch (nine miles N.E. of Pitlochry, in Perthshire), the great part of which has been sheared into a gneiss showing well-marked eye-structure ("augen-gneiss"). The true Aberdeen granite with two micas also belongs to this category. It passes laterally into a muscovite-biotite gneiss—a rock which crops out over a large portion of the Central Highlands.

The *younger acid intrusions* consist chiefly of masses of granitite. The most important of these is the Dee-side granite, which forms the plateau of the Cairngorm Mountains and Ben Macdhui, and extends on the south side of the Dee from Lochnagar (Balmoral) to within eight miles of the coast between Stonehaven and Aberdeen: it also builds the fine peaks of Mount Keen and Mount Battock in Forfarshire. On the north side of the Dee a great mass of the same rock stretches to the north of Ballater; another extends in an easterly direction to near Aberdeen; while tongues of the same granitic rock run out far to the north. The well-known red granite of Peterhead, in Aberdeenshire, is of a similar character, and appears to belong to the same period of intrusion.

Several small masses of granitite crop out in the neighbourhood of Dalwhinnie, near the summit of the Highland Railway. Large intrusions of the same

rock occur north of the Moray Firth (Ben Loyal, Halladale, Strath of Fleet).

WESTERN ISLES OF SCOTLAND. The majority of the



FIG. 70.

Sketch-map of S.E. of Ireland, showing the Mount Leinster granite.

acid intrusive rocks in Mull and Skye are granophyres of Tertiary age. An older granite (granitite)

occurs, however, in Arran, and another in Mull (Ross of Mull).

IRELAND. The largest mass of granite in the British Isles is that of the Mount Leinster range in the S.E. of Ireland. The stone, which varies considerably in texture and quality, is quarried at Killiney and elsewhere for building and paving purposes. In the N.E. of Ireland there are three

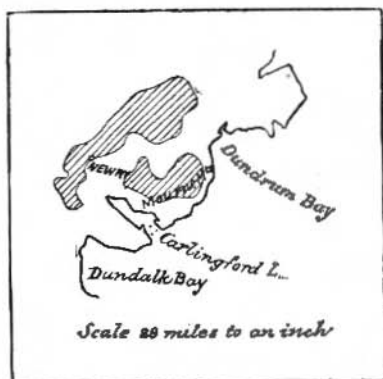


FIG. 71.

Sketch-map of a portion of the E. coast of Ireland, showing the Mourne Mountains granite.

principal occurrences: namely, the Mourne Mountains (biotite-granite), Carlingford (granophyric granite), and Newry. In the W., gneissose granites occur in Donegal, Galway and Mayo.

CHANNEL ISLANDS, ETC. Granite with two micas occurs in the Scilly Islands, and granitite is quarried in the Channel Islands, for instance at St. Brelade in Jersey.

## 2. THE ELVAN<sup>1</sup> FAMILY.

This family comprises rocks that have the same general composition as granite, but which occur in small bosses or in dykes and veins. In many cases they are doubtless apophyses or tongues sent off from some mass of granite into the surrounding slates.

They may be subdivided into :—

Microgranites and Granophyres,

Quartz and Felspar Porphyries, and Pitchstones.

**Microgranite and Granophyre.**—The microgranites are those elvans that possess no porphyritic constituent, and consist of a granitoid but finely crystalline aggregate of quartz and felspar, together with a small amount of muscovite or some ferromagnesian constituent. (See Fig. 72.) Small red garnets and fine needle-like prisms of dark schorl are frequent accessories. The rocks are generally of a light colour, varying from white to buff. Veins and dykes of microgranite abound in the neighbourhood of granite, which they also penetrate. The white microgranite, consisting of quartz, felspar, muscovite and garnet, that is so frequently found

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<sup>1</sup> "Elvan" is the Cornish miner's term for certain granitic and porphyritic rocks that occur abundantly in the mining districts of Devon and Cornwall.

traversing granite in narrow dykes and veins, is variously known under the names of **eurite**,<sup>1</sup> **aplite** and **granulite**.<sup>2</sup>

In the granophyres, the porphyritic grains are imbedded in a base of micropegmatite. The micro-

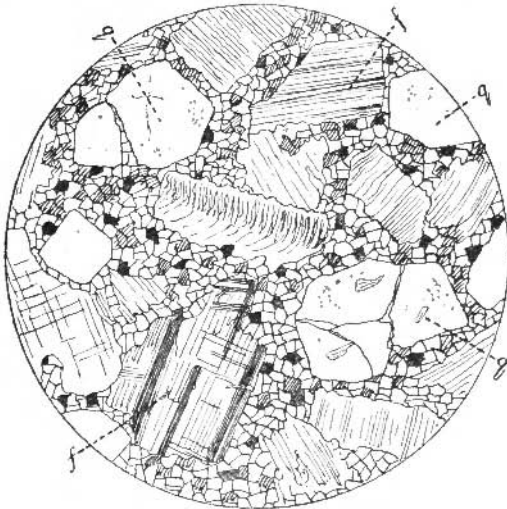


FIG. 72.

Microgranite, under the microscope.  
Crystals of Quartz and Felspar in a microcrystalline ground-mass,  
q. Quartz. f. Felspar.  
(After Fouqué and Lévy.)

<sup>1</sup> Introduced by Daubuisson in 1819. Its revival has been recently advocated by Cole and Jennings.

<sup>2</sup> This is a use of the term totally distinct from the signification attached to it by the French, who apply it to an ordinary muscovite-biotite granite; while the biotite-granites are called by them simply "granite."

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pegmatite surrounds the porphyritic crystals, and shows a definite orientation towards them. In many cases there is evidence of optical continuity between the crystals and the surrounding zone of micropegmatite. Beautiful pseudo-spherulitic structures are frequently produced in such rocks by a radial arrangement of the alternating lamellæ and fibres of quartz and felspar.

**Quartz-porphyry**—consists of porphyritic crystals of quartz and felspar, or of quartz alone, imbedded in a finely crystalline or compact ground-mass composed of the same minerals. In **felspar-porphyry** the porphyritic constituent consists of felspar alone.

“The quartz, which may be colourless, white, or smoky, occurs sometimes in bi-pyramidal crystals, but oftener in rounded grains, sinking in size to mere blebs. The felspar is frequently present in the form of large, well-defined crystals, which may be either transparent and colourless, or white, pink, red, or grey; in other varieties the crystals are very minute and can only be discovered by the aid of the lens. They decompose readily under the influence of weather into kaolin,”<sup>1</sup> and the cavities thus produced are often filled with schorl or chlorite.

Ferro-magnesian minerals are subordinate, being

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<sup>1</sup> J. A. Phillips.

generally represented by a small quantity of brown mica, often more or less altered to chlorite. In the Cornish porphyries, schorl or black tourmaline is frequently present in isolated crystals or stellate groups.

The ground-mass of the porphyries consists of a microcrystalline or cryptocrystalline aggregate of quartz and felspar. The cryptocrystalline structure is often spoken of as *felsitic*. The individual granules of which the "felsitic matter" is composed, are so minute as scarcely to be recognisable even under high powers of magnification. Between crossed nicols such a ground-mass has a characteristically dappled or flecked appearance, produced by the transmission of innumerable mere points of light. Occasionally the ground-mass is microcrystalline in the central part of a dyke, and cryptocrystalline or felsitic towards the margin.

**Pitchstone.**—This name is applied to more or less vitreous rocks, having the same chemical composition as granite, which are produced by a rapid consolidation of the acid magma, when injected into narrow fissures or between bedding planes. It is characterized by a resinous appearance, conchoidal fracture and streaky fluidal structure. The colour is usually a dark-green, but sometimes black or red. Under the microscope the glass is seen to contain numerous crystallites and microlites, often arranged in beautiful stellate and feathery groups, or resem-

bling fern-growths. (See Fig. 73.) Spherulitic structures are not infrequent.<sup>1</sup> Imbedded in the glassy ground-mass are often porphyritic crystals of quartz, orthoclase, mica, hornblende and augite.

With regard to chemical composition, the pitch-



FIG. 73.

*Pitchstones of Arran, under the microscope, showing minute microlites of Hornblende aggregated to feathery forms, in a glassy base.*

(After Teall.)

stones differ from the granites, microgranites and obsidians only by containing some 6-8% of water.

By processes of devitrification they assume a stony or felsitic character (*felsitic pitchstones*); and it is

<sup>1</sup> Many of the *Pyromerides* (Hatty, 1814) of the French or *Kugelporphyre* of the Germans are spherulitic rocks of this type.



probable that many of the compact flinty felsites have been produced from pitchstones by subsequent alteration.

## ANALYSIS BY J. H. PLAYER.

<i>Pitchstone from Arran.</i>	<i>Per Cent.</i>
SiO <sub>2</sub> - - - - -	72·6
Al <sub>2</sub> O <sub>3</sub> - - - - -	12·4
Fe <sub>2</sub> O <sub>3</sub> - - - - -	·7
FeO - - - - -	1·1
CaO - - - - -	·9
MgO - - - - -	trace
K <sub>2</sub> O - - - - -	4·7
Na <sub>2</sub> O - - - - -	1·7
Loss by ignition - - - - -	5·2
	99·3
Specific gravity - -	2·340

*DISTRIBUTION IN THE BRITISH ISLES.*

DEVONSHIRE AND CORNWALL. Dykes of elvan are abundant in these counties. They are especially numerous in the mining districts (*e.g.*, Redruth and St. Austell). In some cases they are possibly connected with the granite bosses. Thus the Brown Willy mass appears to send off apophyses of elvan-rock into the surrounding slates. The rocks vary in petrographical character from compact felsites and

microgranites to porphyries containing large crystals of felspar and quartz, such as occur near St. Hilary, at Sydney Cove, at Croft Michel near Crowan, and at Grenofen near Tavistock. An aplite-like microgranite, containing muscovite, occurs at Meldon in Devonshire, and a similar rock crops out between Row Tor and Scarey Tor in Dartmoor.

LAKE DISTRICT. Augite-granophyre builds the pike of Carrock Fell. The so-called "Syenite" of Buttermere, which extends from Buttermere to Ennerdale, is a typical granophyre. The Armboth dyke, which is composed of bright red felspar (orthoclase) and dark quartz grains scattered evenly through a dun-coloured ground-mass, containing small garnets, is granophyric. Microgranite also forms bosses and dykes in the Lake District. Thus the two intrusive masses in St. John's Vale, one of which is quarried near Threlkeld station, are microgranites; and dykes of the same rock, with or without porphyritic crystals of quartz and felspar, occur, for instance, at the following localities:—East side of Hawes Water, Kirk Fell, Ulpha near Broughton, and Black Combe. A remarkable microgranite, containing large plates of muscovite, occurs at Dufton in Westmorland ("Dufton granite"). A dyke of spherulitic felsite traverses the rocks of High Fell in Cumberland.

NORTH WALES. Intrusive bosses of microgranite and granophyre are abundant in Caernarvonshire,

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Anglesey, and Merionethshire. According to Mr. Harker,<sup>1</sup> these rocks are characterized by the abundant presence of augite and biotite. Only in two localities is the place of these minerals taken by a peculiar blue soda-hornblende ("riebeckite-rock" of Mynydd Mawr and Bwlch Cywion). A good type of microgranite ("Nevin type" of Mr. Harker) is found at Trefor and Nant Gwrtheyrn in Yr Eifl and at Mynydd Nevin. The rocks of Mynydd Mawr<sup>2</sup> and Bwlch Cywion may also be classed as microgranites. Microgranite (*eurite* of Messrs. Cole and Jennings) forms the ridge of Cader Idris, south-west of Dolgelly, and another ridge of the same rock runs due north to the east of Rhobell Fawr (Allt Llwyd and Ddualt).

Granophyres occur in *Caernarvonshire* in the Moel Perfedd laccolite, at Y Drosogl and Craig-dol-Owen, at Pen-y-gaer (2½ miles east of Llanaelhaiarn, between Pistyll and Nevin,<sup>3</sup> at Llanbedrog and Mynydd-tir-y-cwmmwd.

In *South Wales* granophyric quartz-porphyrines and

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<sup>1</sup> l.c., p. 49.

<sup>2</sup> Mynydd Mawr is a boss-like mass three miles west of Snowdon. According to Harker it is probably the plug of a volcanic vent of Bala age, marking the source of some of the lavas of Snowdon, Moel Hebog and Llwyd Mawr.

<sup>3</sup> Harker, l.c., p. 55.

microgranites occur at St. David's (Arvonian of Dr. Hicks).

A dyke of granophyre traverses the ridge of the Stanner Rock, near Old Radnor.<sup>1</sup>

SCOTLAND. *South Scotland.* Elvan dykes are abundantly developed in connection with the granitic intrusions of the southern uplands. They consist of porphyries, microgranites (*e.g.*, Dalbeattie, Castle Douglas, Carsphairn), felsites, and aplites (*e.g.*, Bennan Hill, west of Loch Ken, and Loch Head, Loch Doon).

A few intrusive bosses of elvan occur in the *Midland Valley*. The quartz-porphyry of Tinto Hill may be taken as an example of these.

*Central Highlands.* Small bosses of quartz-porphyry occur sporadically in the Central Highlands (*e.g.*, in the neighbourhood of Lintrathen in Forfarshire). The so-called Lintrathen "porphyrite" belongs here. It contains bi-pyramids of quartz and black wide-angled potash mica, set in a ground-mass of orthoclase.

*Western Isles.* The granophyres and microgranites of Mull, Skye, Eigg and Rum form a characteristic feature of the Tertiary volcanic geology of these islands. They occur in intrusive bosses, sills and dykes. Typical masses are those of Loch Ba' and

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<sup>1</sup> Cole.

Glen More in Mull. Three small bosses occur in the island of Eigg. In Rum the same rocks build the summit of Orval. In Skye they occur in the Strath Valley, at Beinn-na-Cro between Strathmore and Strathbeg; and in the south-west of the island they extend from Loch Sligachan into the heart of the Cuillin Hills. Pitchstone in veins and dykes is also common in the Western Isles. Thus it occurs in Skye (Glamaig, Glas Beinn Bheag in Strath Beg, and Beinn-na-Caillich), in Rum (Orval), in Eigg (Rudh an Tangairt, near Laig, and at the harbour), Arran (Brodick, Corriegills, Caisteal Abhail, Tor-more), and Ardnamurchan (Ben Hiant). At the Scur of Eigg there is remarkable superficial flow of pitchstone, filling an ancient valley eroded in the plateau basalts.

IRELAND. In the south-east of Ireland (Wicklow) microgranites appear in narrow dykes, lenticular masses or round bosses; *e.g.*, at Croghan Kinshelagh, Clonroe Bridge, Wicklow Gap, and Cross-Patrick, five miles east of Shillelagh. The granite of Mount Leinster is often traversed by veins of white, fine-grained, garnetiferous aplite (*e.g.*, at Killiney Hill). Pitchstones and felsites occur as dykes in the tertiary volcanic plateau of the north-eastern portion of the island; *e.g.*, the pitchstone of Sandy Braes,  $1\frac{1}{2}$  miles north of Tardree, Co. Antrim, of Newry, Co. Armagh, and of the Barnesmore range, Co. Donegal.

### 3. THE RHYOLITE FAMILY.

The **rhyolites**<sup>1</sup> are the volcanic equivalents of the granites and elvans. They are highly acid rocks, containing, in most cases, free silica in the form of quartz. Having been poured out as subaerial or submarine lavas, they present marked fluidal spherulitic and perlitic structures. Occasionally they are compact, but more usually they have a porphyritic structure. The porphyritic constituents are quartz and felspar, imbedded in a light-coloured trachytic ground-mass, which is mainly composed of microlites of felspar. Prisms of augite and hornblende, plates of biotite and granules of magnetite also occur. A glassy base is present in variable proportion, according to the conditions that prevailed during cooling. If the proportion of glass is so largely increased that the crystals become subordinate, the rocks pass into **obsidians**.

Accessory minerals are magnetite, tridymite, apatite, cordierite, garnet, sphene and allanite.

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<sup>1</sup> The name *rhyolite* was given to these rocks by Richthofen (1860) on account of the fluidal structure frequently shown by them. They have also been termed **Quartz-trachytes**, and again **Liparites** (Roth, 1860), this designation having been given them on account of their occurrence in the Lipari Islands. A crystalline and granitoid variety of rhyolite has been described under the name of **Nevadite** by Richthofen.

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The grains of quartz are sometimes bi-pyramidal, but oftener without definite shape. Though usually pellucid and colourless, they have frequently a dark-coloured or smoky hue. In some rhyolites the conditions of eruption have been such as to prevent the separation of quartz; but the high percentage of silica shown by chemical analysis facilitates the correct diagnosis of such rocks.

The felspar is usually sanidine—a glassy variety of orthoclase. It occurs frequently in large tabular crystals, which are glassy, clear and much fissured; but also in smaller and less regular grains. In addition to the orthoclase there is often present a striped (triclinic) felspar. This is sometimes oligoclase, but more frequently albite, soda-microcline or anorthoclase. In some rhyolites (Hungary) the sole porphyritic constituent is a soda-felspar, having the same glassy habit as the potash-felspar (sanidine), and consequently liable to be mistaken for it. According to the predominance of potash-felspar or soda-felspar, the rhyolites may be divided into potash-rhyolites and soda-rhyolites.<sup>1</sup>

Fluxion-structure is often shown in the ground-mass by the beautiful wavy lines of flow which sweep

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<sup>1</sup> Those containing anorthoclase (soda-potash felspar) have been termed **pantellerites** (Förstner), because of their occurrence in the island of Pantellaria, off the coast of Sicily.

round the larger imbedded grains. The same structure is also occasionally brought out under the microscope by the strict parallelism of the felspar-microlites, or by bands of crystallites and trichites in the glassy rhyolites and obsidians. (See Fig. 74.)



FIG. 74.

Obsidian, with bands of microlites and trichites, under the microscope. The linear arrangement is due to flow during consolidation. (After Fouqué and Lévy.)

**Felsite.**<sup>1</sup>—The identity of many felsites with the rhyolites has been demonstrated by the researches of

<sup>1</sup> Term introduced by Gerhard (1814). A synonymous term is *petrosilex*, introduced by Brongniart.



Rutley and Allport.<sup>1</sup> Many of these rocks, consisting of a cryptocrystalline aggregate of quartz and felspar (felsitic matter), in which porphyritic crystals of quartz and felspar are often imbedded, were found to possess traces of perlitic, spherulitic and fluidal structures. (See Fig. 18.) These structures, being characteristic of rocks that have consolidated in a vitreous or semi-vitreous condition, indicated the true nature of the rocks that possess them. They are, in fact, ancient flows of rhyolitic lava that have subsequently acquired a cryptocrystalline structure by a gradual process of devitrification. Like the rhyolites, they contain porphyritic crystals of both unstriped and striped felspar, and their chemical composition shows that they may be divided into potash-felsites and soda-felsites.<sup>2</sup>

In association with tuffs and breccias, which were doubtless formed by the same volcanic activity, the felsitic lavas are found interbedded with sedimentary strata. A nodular character is very common in rhyolitic lavas. The nodules vary in size from a small marble to a man's fist; in some cases they are even larger. Probably in many instances these nodules are enlarged spherulites, but they have also

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<sup>1</sup> It was, however, Clifton Ward who first indicated the relation of the Welsh felsites to modern volcanic rocks (rhyolites).

<sup>2</sup> Felsites, rich in alkalis, especially soda, are termed **Keratophyres** by German petrologists.

been ascribed to contraction on cooling as in true perlitic structure, and to the infilling of original vesicles with quartz, and agate by infiltration (lithophysæ of Richthofen).

## ANALYSES OF RHYOLITES.

	<i>Rhyolite, Lea Rock, nr. the Wrekin. (J. H. Player.)</i>	<i>Rhyolite, Tardree, Antrim Co. (J. H. Player.)</i>	<i>Soda-Rhyolite, Brittas Bridge, Wicklow Co. (Hatch.)</i>
SiO <sub>2</sub> - -	75·4	76·4	77·29
Al <sub>2</sub> O <sub>3</sub> - -	13·2	14·2	} 14·62
Fe <sub>2</sub> O <sub>3</sub> - -	·8	1·6	
FeO - -	·6	—	—
CaO - -	·4	·6	trace
MgO - -	·2	—	·38
K <sub>2</sub> O - -	7·0	4·2	·16
Na <sub>2</sub> O - -	1·1	1·8	7·60
Loss on ignition -	·7	1·5	·57
	99·4	100·3	100·62

## DISTRIBUTION IN THE BRITISH ISLES.

ENGLAND. *Midland Counties.* Rhyolitic lavas, which appear to be of pre-Cambrian age, occur in Shropshire at the Wrekin near Wellington, and at Caer-Caradoc near Church Stretton. The Lee rock near Wellington consists of a beautiful red spherulitic rhyolite, showing a well-marked flow-structure.

Similar rocks have been noticed in the Charnwood Forest.

*Lake District.* Rhyolites form a part of the Borrowdale Volcanic Series. They are felsitic rocks, presenting strong fluidal structure, and occasionally containing garnets (as at Illgill Head). They occur in Langdale (Dungeon Ghyll), Crinkle Crags (Gunson Knott), Great Gable (Sty Head), Stickle Tarn, in the Copper Mine Valley, near Grizedale Tarn, in Long Sleddale. A nodular variety occurs between Shap Wells and Stockdale.

WALES. *North Wales.* Very acid rhyolites (composed of porphyritic crystals of quartz and felspar in a felsitic base) occur at the base of the Cambrian, forming the Llyn Padarn ridge and cropping out near Bangor. The great majority of the rhyolitic lavas of Caernarvonshire are, however, of Ordovician (Bala) age. Mr. Harker<sup>1</sup> groups them into four series, namely:—

1. Dwygyfylchi and Y Drosogl series.
2. Pen-yr-Oleu-wen and Carnedd Llewellyn series.
3. Y Glyder-fach, Capel Curig and Conwy Mountain series.
4. Snowdonian series.

The Snowdonian lavas can be studied on Snowdon, Moel Hebog, and in the Gwynant and Glaslyn valleys. They form the plateau of Llwyd-mawr, and occur in

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<sup>1</sup> "The Bala Volcanic Series of Caernarvonshire," p. 9.



numerous outliers; *e.g.*, W. of Dolwyddelen, Moel Siabod, Glen Lledr, and near Bettws-y-Coed; also W. and E. of Pwllheli and near Llanbedrog in the Lleyn peninsula.

These rocks consist of a compact felsitic base containing scattered crystals of quartz and felspar. When fresh they are dark-coloured; but when weathered they are lighter in colour and show a laminated character, due to an original flow-structure (Clogwyn-dur-Arddu). Streaks and lenticles of quartz sometimes follow the lines of flow. Ferromagnesian minerals are subordinately developed, and are invariably represented by a pale chlorite. The rocks are frequently nodular, and often present spherulitic and perlitic structures. Some of the best localities for the nodular variety are: Conwy Falls, Digoed and other places near Bettws-y-Coed, near Capel Curig, Glyder-fawr, Esgair-felen, at the head of Llanberis Pass, and in the Lleyn peninsula at Pwllheli and Pen-y-chain.

*In South Wales.* Rhyolites occur in Ramsey and Skomer islands, off the coast of Pembrokeshire. The Skomer I. rocks are nodular.

IRELAND. *S.E. of Ireland.* Rhyolitic lavas of Ordovician (Bala) age occur abundantly in the counties of Wicklow, Wexford, and Waterford. They are compact felsitic rocks, usually dark-coloured when fresh, but weathering to a paler

colour. They consist of a crypto-crystalline aggregate of quartz and felspar. When they contain porphyritic crystals, these as a rule consist of plagioclase. The silica percentage ranges from 70 to 85, while with regard to alkalis they may be divided into three groups according as the potash is in excess of, equal to, or subordinate to the soda.<sup>1</sup>

*South of Ireland.* A nodular or spherulitic rhyolite occurs at Lough Guitane, among the Dingle Beds (Old Red Sandstone) of Killarney.

*North of Ireland.* Fine types of rhyolite occur in the Tertiary volcanic area of County Antrim at Tardree and Ballymena. They are light-coloured rocks containing porphyritic crystals of quartz and sanidine. The Tardree rock was shown by Prof. von Lasaulx to contain tridymite.

*Table showing the mutual relations of the members of the acid group.*

INTRUSIVE.		VOLCANIC.	
<i>Deep-seated (plutonic) masses.</i>	<i>Dykes, and intrusive sheets.</i>	<i>Fresh.</i>	<i>Altered, etc.</i>
Granites	{ Quartz } porphy- { Felspar } ries Microgranites Granophyres Felsophyres Pitchstones	} Elvans.	Rhyolites
Granitites			} Felsites.
Granite-porphyries			
Granophyres			

<sup>1</sup> See paper by the author in *Geol. Mag.*, Dec III, vol. vi. (1889), p. 545.

#### 4. THE SYENITE AND DIORITE FAMILY.

The syenites and diorites are plutonic granitoid rocks, less acid than granite, and consequently containing little or no free silica.

They may be divided into—

Syenites.<sup>1</sup>

Nepheline-syenites.

Diorites.<sup>2</sup>

The syenites are composed essentially of orthoclase and a member of the ferro-magnesian group. According to the nature of the latter we may distinguish between **hornblende-syenite** (or syenite proper), **augite-syenite**, and **mica-syenite**.

A small quantity of quartz is sometimes present, forming a passage to the granitites. Other accessory minerals are oligoclase, sphene, zircon, epidote, apatite and ilmenite.

The orthoclase, which is usually accompanied by a plagioclase felspar (oligoclase), differs in no respect

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<sup>1</sup> The term *syenite* was applied by Pliny to a rock occurring at Syene (Assouan), in Egypt. This rock is a hornblende-biotite-granite or hornblende-granitite. Werner introduced the term in the sense used above.

<sup>2</sup> Term introduced by Haüy. The diorites differ from the hornblende-gabbros and hornblende-diabases by their greater acidity and by their mode of occurrence. They constitute a link between the basic rocks and the granites, just as the andesites do between the basalts and the rhyolites.

from that occurring in the granites. The hornblende, which, with rare exceptions, is a green variety, may be recognised by its pronounced pleochroism, its well-marked cleavage, its prism angle of  $124^\circ$ , small extinction angle, etc. The augite is more variable in character: sometimes it is almost colourless or pale-green; at other times it partakes more of the nature of diallage, having then a violet-brown tint. The mica is always a brown biotite. It is very liable to chloritization, turning green in the first stage of the process. Muscovite is never present unless as a secondary constituent.

The average chemical composition of the syenites is:— $\text{SiO}_2 = 58.4\%$ ,  $\text{Al}_2\text{O}_3 = 19.2\%$ ,  $\text{FeO} = 8.3\%$ ,  $\text{CaO} = 5.6\%$ ,  $\text{MgO} = 2.9\%$ ,  $\text{K}_2\text{O} = 3.2\%$ ,  $\text{Na}_2\text{O} = 2.4\%$ . Sp. G. =  $2.75-2.9$  (von Lasaulx).

True syenites are rare in this country. The celebrated occurrence in the Plauen'scher Grund, near Dresden, may, however, be taken as a type.

**Nepheline-syenite**—is characterized by the presence of an altered variety of nepheline (elæolite), which resembles quartz, but may be distinguished from this mineral by its characteristic greasy lustre. With elæolite green or blue sodalite is often associated. Zircon, sphene, allanite and other rarer minerals, often occur as accessory constituents. Ferro-magnesian minerals (pyroxene, amphibole and biotite) are also present in small proportions.



The best known localities for nepheline-syenites are Låven and Brevig in Southern Norway (**zircon-syenite**, in part), Ditro in Transylvania (**ditroite**, a variety containing sodalite), Foya Hills in Southern Portugal (**foyaite**, a hornblendic variety), the provinces of Rio de Janeiro and Minas-Geraes in Brazil (foyaite), Ilmen Mountains near Miask (**miascite**, a micaceous variety), Kangerdluarsuk, on the S. coast of Greenland (with arfvedsonite and eudialyte).<sup>1</sup>

**Diorite.**—The diorites differ from the syenites in having plagioclase (lime-soda felspar), instead of orthoclase (potash-felspar), as the dominant felspar. In other respects they closely resemble them. Like the syenites, the diorites have a holocrystalline granitoid structure; although, as a rule, the latter are much finer in grain. The ferro-magnesian constituent is usually green hornblende in crystals, grains, or needles;<sup>2</sup> but brown biotite, pale green or colourless augite and enstatite also occur, constituting the varieties,—**mica-diorite**, **augite-diorite**<sup>3</sup> and **enstatite-diorite**. Among accessory minerals the iron-ores (magnetite and ilmenite), apatite, sphene and zircon are the most frequent.

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<sup>1</sup> Haüy (1822).

<sup>2</sup> As in the variety known as needle-diorite (*Nadeldiorit*).

<sup>3</sup> Zirkel: *Lehrbuch der Petrog.* (1866), ii. p. 7.

Secondary minerals are represented by chlorite, epidote, limonite and calcite. Quartz occurs sometimes as a mineral of secondary origin, at other times as an original constituent. Diorites that contain much quartz are termed **quartz-diorite**; but the diorites are rarely without some quartz. **Tonalite** is a quartz-mica-diorite. **Epidiorite** is the name given to a plagioclase-hornblende rock in which the hornblende (uralite) is derived from augite. The epidiorites, however, belong properly to a more basic class, the rocks from which they are derived being gabbros and dolerites.

Spheroidal structure, similar to that described when dealing with the granites, is well developed in the **ball-diorite** or **napoleonite** of Corsica, where the spheroids consist of hornblende and felspar, and show a well-developed radial and concentric arrangement.

Many of the "granites" used for kerbstones and paving-setts belong to the syenite and diorite family. The dark-coloured and fine-grained varieties constitute a durable material for road-metalling, the hornblendic constituent giving great toughness.

## ANALYSES OF SYENITES AND DIORITES.

	<i>Syenite,</i> <i>Plauen'scher</i> <i>Grund.</i> <i>(Zirkel.)</i>	<i>Enstatite-</i> <i>diorite,</i> <i>Penmaen-</i> <i>mawr.</i> <i>(J. A. Phillips.)</i>	<i>Diorite,</i> <i>Benan</i> <i>Flurian.</i> <i>Scotland.</i> <i>(Teall.)</i>	<i>Diorite,</i> <i>Markfield,</i> <i>Charnwood</i> <i>Forest.<sup>1</sup></i> <i>(J.H. Player)</i>
SiO <sub>2</sub>	59.8	58.45	54.09	55.7
Al <sub>2</sub> O <sub>3</sub>	16.9	17.08	15.02	17.5
Fe <sub>2</sub> O <sub>3</sub>	—	0.76	4.12	5.2
FeO	7.0	4.61	5.15	4.7
CaO	4.4	7.60	7.72	6.7
MgO	2.6	5.15	7.28	2.9
K <sub>2</sub> O	6.6	1.02	3.55	2.1
Na <sub>2</sub> O	2.4	4.25	1.99	2.4
H <sub>2</sub> O	1.3	1.07	1.49	Loss by ignition 2.3
	101.0	99.99	100.41	99.5

G. = 2.73      G. = 2.94

## DISTRIBUTION IN THE BRITISH ISLES.

MIDLAND COUNTIES. *Warwickshire.* Fine grained diorites are intrusive in the Cambrian and Pre-Cambrian rocks of Nuneaton (*e.g.*, at Hartshill, Marston Jabet, Bedworth, and Atherstone).

*Leicestershire.* Diorites occur in the Charnwood Forest district at Groby, Markfield, Cliff Hill,

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Bawdon Castle, Bradgate, and Hammer Cliff. The

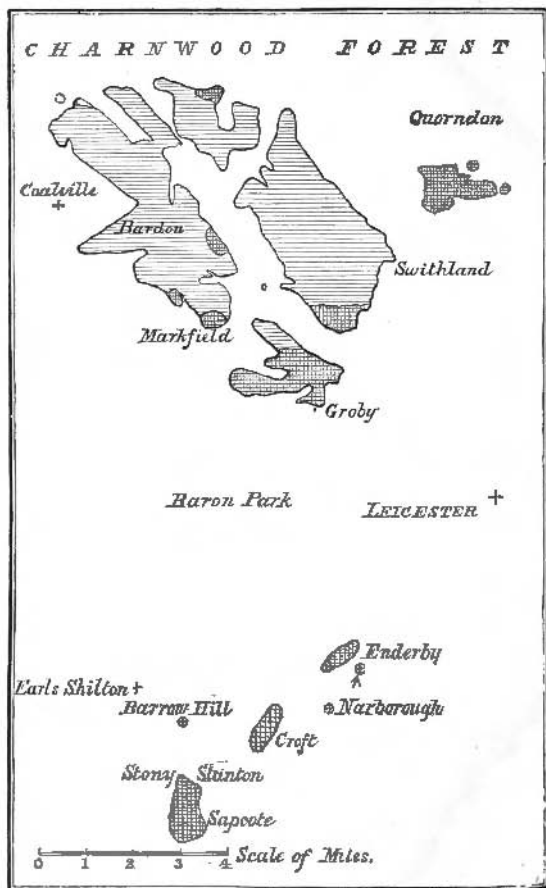


FIG. 76.

Sketch of the igneous rocks of the Charnwood Forest. (After Bonney.)  
 granophyric diorite of Markfield and Groby is a

handsome, even-grained rock of a greenish tint, with pink patches of micropegmatite and black crystals of hornblende. The Bawdon Castle rock (three miles N. of Markfield) is a quartz-diorite of similar appearance. In the *Malvern Hills* diorites occur at several localities.

CORNWALL. Diorite occurs at the Lizard, veining the gabbro (Pen Voose).

WALES. In *South Wales*, fine-grained diorites of a dull greenish colour occur near Solva and St. Elvis, S.E. of St. David's. Quartz-diorites have also been described as occurring in the ridge S. of Haverfordwest and at Talbenny, in Pembrokeshire.

*North Wales.* A coarse-grained syenite, consisting of large crystals of black hornblende and pink orthoclase (together with quartz, augite and other accessory minerals), occurs in intrusive masses of the nature of laccolites at Llanfaglen and Glan-y-mor, 1½ miles S.W. of Caernarvon. Diorites with rhombic pyroxenes (enstatite, bronzite, or hypersthene) are found in N. Wales. They occur in intrusive masses which no doubt represent the vents from which hypersthene-andesites (such as occur among the Ordovician rocks in Shropshire) were erupted. Some of the hypersthene-bearing intrusions of Caernarvonshire present structures which correlate them directly with typical hypersthene-andesites. One of the best-known rocks of this type is the enstatite-diorite of Penmaenmawr. This rock occurs as a boss intrusive

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in Ordovician strata on the north coast of Caernarvonshire (between Conway and Bangor). The typical rock consists of crystals of plagioclase, enstatite, augite, and biotite imbedded in an abundant ground-mass of micropegmatite. The structure may be briefly described as granophyric. The rhombic pyroxene is largely altered into the fibrous mineral known as bastite. The rock is quarried on an extensive scale for paving-setts and for road-metal. Intrusive hypersthene-bearing rocks of a more andesitic character occur at Carn Boduan, one mile S. of Nevin, and at Yr Eifl, in the Lleyrn peninsula. The Carn Boduan rock is described by Mr. Harker.<sup>1</sup> It consists of porphyritic crystals of plagioclase, augite, and hypersthene (represented by a green serpentinous product), imbedded in a ground-mass of small granules of magnetite, microlites of felspar, granules of augite, and an isotropic base. The Yr Eifl rock (quarried under the name of the Eifl Black Rock) consists of porphyritic crystals of fresh plagioclase, pleochroic hypersthene, brown mica, and magnetite, imbedded in a crypto- to micro-crystalline ground-mass.

The bronzite-bearing andesite of Bera Mawr (part of the Y Foel Frâs complex) is a similar rock.

LAKE DISTRICT. Syenites do not appear to occur in the Lake District. The so-called syenite of

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<sup>1</sup> l.c. p. 70.

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Buttermere and Ennerdale is a granophyre. Dykes of dull green close-grained quartz-diorite occur at several localities (Plumbago Mine, Derwentwater, Seathwaite How, Burtness Comb, and Hindscarth).

SCOTLAND. In *South Scotland*, syenites and diorites are associated with the granitic masses of Dalbeattie and Criffel, Loch Dee and Loch Doon, etc.

In the *Midland Valley*, a fine boss of granophyric hypersthene-diorite occurs at Tillicoultry, N. of the Forth. This rock closely resembles that of Penmaenmawr, described above, and, like it, is probably a vent whence flowed hypersthene-bearing andesitic lavas. An augite-diorite occurs at Pap Craig, Tinto

In the *Central and Eastern Highlands*<sup>1</sup> diorites occur (1) as large intrusive masses (*e.g.*, the great moor of Rannoch on the western border of Perthshire, Glen Tilt, Glen Shee, and Ben Chonzie near St. Fillans, in Perthshire, and Glen Doll in Forfarshire); (2) as part of the igneous complexes which occur in many places in the Central Highlands (*e.g.*, at the head of Clova, Forfar, and in Glen Tilt, Perth); and (3) as dykes connected with the intrusive masses and the complexes.

*North-West Highlands.* Intrusive sheets or sills occur in the limestones and quartzites of the Assynt district (Durness, Eriboll series).

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<sup>1</sup> Information supplied by Mr. G. Barrow.

IRELAND. In the *S.E. of Ireland* (Wicklow) diorites are associated with Ordovician volcanic rocks. They consist of quartz-mica-diorite or tonalite (as in the irregular boss extending from Carrigmore to West Aston, four miles E. of Rathdrum), of quartz-diorite (as Bologh Lower, three miles E. of Rathdrum), and augite-diorite (as in the neighbourhood of Kilpatrick House, N. of Arklow).

CHANNEL ISLANDS. Typical diorites and syenites occur in Guernsey and Jersey. Thus diorites compose the whole of the northern part of Guernsey and occur in Jersey in St. Aubyn and St. Clement Bays. Syenite occurs at St. Helier in Jersey.

## 5. THE MICA-TRAP OR LAMPROPHYRE<sup>1</sup> FAMILY.

This family corresponds to the elvans in the acid group. It comprises rocks of intermediate composition which occur always in the form of narrow dykes or veins, unaccompanied by tuffs. They are fine-grained, dark-coloured rocks, usually much altered and inclined to spheroidal weathering. Characteristic of them is the abundant presence of brown mica,

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<sup>1</sup> The name *Lamprophyre* was introduced by Gümbel in describing the mica-traps of the Fichtelgebirge, and adopted by Rosenbusch as a general and comprehensive name for the members of this family.



which also takes the place of felspar as the porphyritic constituent. Rosenbusch divides the lamprophyres into (1) those of a syenitic, and (2) those of a dioritic type. The syenitic mica-traps are composed essentially of orthoclase and biotite, and are termed **minette**.<sup>1</sup> The dioritic lamprophyres are composed of plagioclase and biotite, and are termed **kersantite**.<sup>2</sup>

In both rocks the mica occurs in lustrous scales and plates of a dark brown colour. Under the microscope the plates are of a paler hue and have ragged edges. In convergent light the mineral is seen to be biaxial, but with a small optic axial angle. By alteration it passes into chlorite, thence into limonite, quartz and calcite (or dolomite). Accessory minerals are apatite, iron-ores and quartz (both original and secondary). Calcite and other carbonates (dolomite, magnesite) are rarely absent. The presence of carbonate of lime is

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<sup>1</sup> The term **minette** was introduced by Voltz in 1828. A second type of syenitic lamprophyre, containing hornblende instead of mica, is termed **vogesite** by Rosenbusch (*Physiographie*, p. 314). The name **micro-syenite** has been proposed by Lacroix (1890) for the syenitic equivalents of the micro-granites.

<sup>2</sup> The term "**kersanton**" is used in a more general sense: it is used by Barrois so as to include kersantites and mica-porphyrites, the former being *granular* mica-plagioclase rocks, the latter containing *porphyritic* felspars. Another type of dioritic lamprophyre, consisting of plagioclase and hornblende, is termed **camptonite** by Rosenbusch (*Physiographie*, p. 328).

a striking feature of these rocks. In many cases they are so highly charged with it as to effervesce freely with acid. The mineral (calcite or dolomite) occurs either in scattered dust or as pseudomorphs after the original constituents.

#### DISTRIBUTION IN THE BRITISH ISLES.

ENGLAND. Mica-trap dykes, cutting Ordovician and Silurian rocks, occur at numerous localities in the *North West of England*; e.g., at the following places: Cross Haw Beck; railway cutting, Windermere; Kendal road; railway, Docker Garth; S. of Haygarth; Helm Gill; Taith's Gill; in the Rawthey, at Ward's Intake; in Backside Beck; Holbeck Gill; Uldale Head; Watley Gill; Westerdale; Thornton Beck, near Ingleton; S.E. of Skirwith, near Ingleton; and in Ingleton Beck. Other localities are Crowdundale Beck, *Cumberland*; Swindale Beck and River Lune in *Westmorland*. Lamprophyres of a more variable composition occur in the Cross Fell Range, *Cumberland* (Thack Moor, Sale Fell, Cocklock Scar, Gale Hill, and Rake Beck). In *Cornwall* there is a dyke of minette at Trelissick Creek near Falmouth, and one of kersantite between Rosecreage Beacon and Watergate Bay on W. coast. Excellent mica-traps occur in *Devonshire*, at Rose Ash and other localities.

SCOTLAND. *South Scotland*. Lamprophyres occur

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in considerable variety, cutting Silurian rocks, in Kirkcudbrightshire. Thus they are strongly developed on the Colvend shore and at Craigneuk Point, five to six miles south of Dalbeattie. They comprise dark felsitic rocks with porphyritic crystals of plagioclase and flakes of biotite ("plagioclase porphyries"), red felsitic rocks with porphyritic crystals of quartz and plagioclase, and decomposing mica; black dioritic rocks (*camptonites*), etc. True mica-traps (minettes and kersantites) also abound (e.g., at Greenhill, E. of Micklewood, 4 miles N. of Kirkcudbright; at the Bridge of Dee, 2½ miles S.W. of Castle Douglas; at Glenwharfen Burn, Scarwater, Dumfriesshire).

*Central and Eastern Highlands.*<sup>1</sup> Dykes of lamprophyre (comprising mica-traps, "quartz-porphyrates," *camptonites*, plagioclase-granophyres, etc.) appear in great abundance in the neighbourhood of the granitite and diorite *massifs* and the complexes formed by these rocks, and are probably connected with them in point of origin. Thus the granitites pass into "quartz-porphyrates" and plagioclase-granophyres, and the diorites into kersantites and *camptonites*. A good type of plagioclase-granophyre occurs near the head of Glen Shee (Perthshire), and can be traced into the Deeside granite.

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<sup>1</sup> From information supplied by Mr. G. Barrow.

CHANNEL ISLANDS. Dykes of kersantite occur in Guernsey (*e.g.*, at Moulin Huet and Bec du Nez) and in Jersey (*e.g.*, St. Helier).

## 6. THE TRACHYTE AND ANDESITE FAMILY.

The name *trachyte* was originally applied to all volcanic lavas which, owing to their vesicular texture,<sup>1</sup> are rough to the touch. The use of the term, however, has been gradually limited. First, it was restricted to rocks of intermediate composition; and then these were further subdivided according to the nature of the dominant felspar. This mineral, which occurs in these rocks in glassy porphyritic crystals, is either the monoclinic potash variety (sanidine) or a soda-lime plagioclase (oligoclase, andesine). The term *trachyte* is now applied solely to the former; while the latter, on account of their abundant occurrence in the Andes of S. America, are termed *andesites*.

**Trachyte.**—The trachytes are the volcanic equivalents of the syenites. They are light-coloured, often porous rocks, consisting mainly of felspar. Ferromagnesian minerals occur only in small proportion. The porphyritic felspar—sanidine—forms either tabular crystals, twinned on the Carlsbad type, or irregular grains. In the ground-mass, however, the

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<sup>1</sup> Gr. *τραχύς*, rough (Haüy, 1822).

felspar appears in long needles and microlites, which are unstriated and doubtless consist also of orthoclase. They often exhibit a parallel arrangement, due to fluidal movements in the mass. Interstitial matter, when present, is usually felsitic, a true glassy base being rare. The ferro-magnesian minerals are brown mica, green amphibole, colourless or pale green pyroxene (malacolite), and a pleochroic rhombic pyroxene (hypersthene, bronzite). According to the nature of the dominant species, the trachytes may be divided into mica-trachytes, amphibole-trachytes, and pyroxene-trachytes.

Accessory minerals are abundant: namely, iron-ores, zircon, apatite, sphene, cordierite, haüyne and nosean. Quartz is occasionally present in small quantity, indicating thus a passage to the rhyolites. On the other hand, some trachytes have had their silica-percentage increased, subsequently to consolidation, by hydro-thermal impregnation with secondary silica (chalcedony, hyalite, opal, etc.).

Trachytes occur in flows, dome-shaped<sup>1</sup> masses, and dykes, in numerous volcanic districts: Auvergne, Siebengebirge, Henry Mountains in America, etc.

The **Phonolites**,<sup>2</sup> or **nepheline-trachytes** are

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<sup>1</sup> Hence the term **domite** applied to the trachytes of the Auvergne.

<sup>2</sup> Name introduced by Klaproth. Gr. φωνή, a sound.

the volcanic equivalents of the nepheline-syenites. They are rocks composed essentially of sanidine, nepheline and a ferro-magnesian constituent. (See Fig. 77.) Sometimes the place of the nepheline is taken by leucite, and then the rock is termed leu-



FIG. 77.

Phonolite, under the microscope.

n. Nosean. s. Sanidine. h. Hornblende.

The microlites are Sanidine, and the square and hexagonal sections, Nepheline. (After Fouqué and Lévy.)

**cite-trachyte** or **leucite-phonolite**. **Leucitophyre** is the name given to a rock containing both nepheline and leucite together with sanidine. **Asse-**

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ciated with the nepheline or leucite are sodalite, nosean and haüyne. The ferro-magnesian constituent is generally a green augite, which is sometimes a soda variety with low extinction angles (aegirine). Brown mica and hornblende occur as accessory constituents. Other accessories are apatite, iron-ore (magnetite), sphene and melanite (black garnet). Natrolite and other zeolitic minerals result from the alteration of the nepheline.

The phonolites are usually very compact rocks of a greyish-green colour, with a spotted appearance. They ring under the hammer, and hence have been termed **clinkstone**.<sup>1</sup> A platy and spheroidal mode of weathering is a characteristic feature of these rocks, the decomposing rock having a concentric shelly structure like that of an onion.

The **andesites** are dark-coloured, compact or vesicular, semi-vitreous volcanic rocks occurring in lava-flows and dykes. They are composed essentially of a glassy plagioclase felspar and a ferro-magnesian constituent together with a glassy base; and may be regarded as the volcanic equivalents of the plutonic diorites. According to the nature of the ferro-magnesian constituent, they may be divided into hornblende-andesites, biotite-andesites and pyroxene (augite and hypersthene)-andesites; and the inter-

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<sup>1</sup> Ger. *Klinkstein*.

mediate varieties produced by the various combinations of these minerals. (See Figs. 78 and 79.)

The hornblende is the common brown variety, occurring in well-formed lozenge-shaped crystals, which often have a dark border, due to the corrosive action of the molten magma in which they floated



FIG. 78.

Andesite (Mica-andesite), under the microscope.

Porphyritic crystals of Plagioclase Felspar (*f*) and Mica (*m*) imbedded in microlitic ground-mass. (After Fouqué and Lévy.)

when first formed. The monoclinic augite is of a pale brown colour and is non-pleochroic. The hypersthene is pleochroic, in pale green and reddish tints. Both occur in well-formed crystals, giving square



sections with truncated corners. The felspar occurs in good-sized crystals, producing a marked porphyritic structure. In its glassy character it resembles sanidine, but it is distinguished therefrom by its twin-striation. Accessory minerals are magnetite, apatite, garnet, sphene, olivine, allanite and cor-

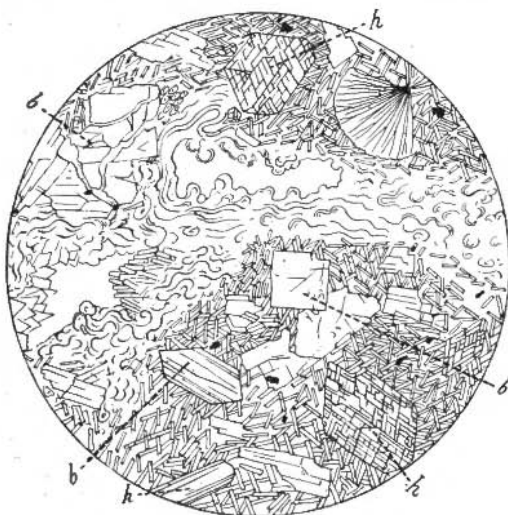


FIG. 79.

Hornblende-Andesite, under the microscope.

Porphyritic crystals of Plagioclase Felspar (*b*) and Hornblende (*h*), in a microlitic ground-mass. (After Fouqué and Lévy.)

dierite. Quartz is sometimes present. When this mineral forms a considerable proportion of the mass, the rock is termed **quartz-andesite** or **dacite**. Some rocks, however, that from chemical analysis

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might be considered as dacites, owe their acidity to secondary impregnation, by hydrothermal agencies (warm springs containing dissolved silica), with chalcedonic and opaline silica. The ground-mass of the andesites is usually microlitic, being composed of needles of felspar and an abundant glassy base. The latter is generally of a pale brown colour, and either clear or partially devitrified. By an increase in the proportion of this base, the rocks gradually pass into true andesitic glasses.

**Tholeiite** is the name given to a variety of andesite in which the felspar occurs in lath-shaped crystals, forming a mesh which is filled up by augite in aggregates of small granules, magnetite and interstitial matter. It frequently occurs in dykes.

The **porphyrites** are altered andesites.<sup>1</sup> In them the felspar, instead of being fresh and glassy, is kaolinized and turbid, the augite is partially or completely converted into chlorite, the hypersthene into the fibrous bastite, and the magnetite into red oxide of iron. The vitreous character of the andesites gives place, in the porphyrites, to a dull stony appearance due to the devitrification of the glassy base; and the rocks are tinged red by much disseminated oxide of iron, or green by diffused chlorite.

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<sup>1</sup> Prof. Judd has recently applied the almost forgotten term **propylite** to such andesites as have been altered by solfataric action.

ANALYSES OF SOME PHONOLITES, TRACHYTES, AND ANDESITES.

	<i>Phonolite, Wolf Rock. (J. A. Phillips.)</i>	<i>Phonolite, Traprain Law. (J. H. Player.)</i>	<i>Trachyte, Peppercraig. (J. Grant- Wilson.)</i>	<i>Andesite of Carn Boduan. (E. H. Acton.)</i>	<i>Hypersthene- Andesite, Buffalo Peak, U.S. (C. W. Cross.)</i>
SiO <sub>2</sub> - - -	56.46	56.8	62.61	61.8	56.2
TiO <sub>2</sub> - - -	—	.5	—	—	—
Al <sub>2</sub> O <sub>3</sub> - - -	22.29	19.7	18.17	16.5	16.1
Fe <sub>2</sub> O <sub>3</sub> - - -	2.70	2.2	0.32	6.7	5.0
FeO - - -	.97	3.5	4.25	not est.	4.4
MnO - - -	tr.	.2	.20	—	—
CaO - - -	1.47	2.2	2.58	4.5	7.0
MgO - - -	tr.	.4	0.74	1.2	4.6
K <sub>2</sub> O - - -	2.81	7.1	4.02	1.4	2.4
Na <sub>2</sub> O - - -	11.13	4.3	6.49	7.2	3.0
Loss on igni- tion - - -	2.05	2.5	.80	0.6	1.3
	99.88	99.4	100.18	99.9	100.0

The famous "*porfido rosso*" and "*porfido verde*" of the ancients belong to this category. The green porphyry of Lambay Island off the E. Coast of Dublin Co., and of the Lake District resembles the *porfido verde*.

#### DISTRIBUTION IN THE BRITISH ISLES.

ENGLAND. *Midland Counties.* Messrs. Bonney and Hill have recorded the occurrence of dacites in the Charnwood Forest (at Peldar Tor, High Sharpley, and Bardon). These lavas are associated with tuffs, and are of Pre-Carboniferous, probably Archæan age. Ordovician andesites occur in the hills which form the boundary between Shropshire and Montgomeryshire. Watts has described hypersthene-andesites of Upper Arenig age to the west of Corndon Hill (*e.g.*, Llanfawr, Roundtain, Todleth), and in the same area are thick sheets of ash of the same composition in the Upper Arenig and the Bala rocks. Precisely similar andesites occur amongst the Bala ashes of the Breidden Hills (*e.g.*, Moel-y-Golfa, six miles N.E. of Welshpool), which are really an outlying portion of the Corndon area. Vesicular andesites and their tuffs also occur near Builth, in the range of the Carneddau (Herefordshire and Radnorshire), where there is an outlier of Ordovician rocks.

*Devonshire and Cornwall.* The Permian (?) rocks of the former county contain a volcanic series which

is developed near Exeter. Some of the lavas are

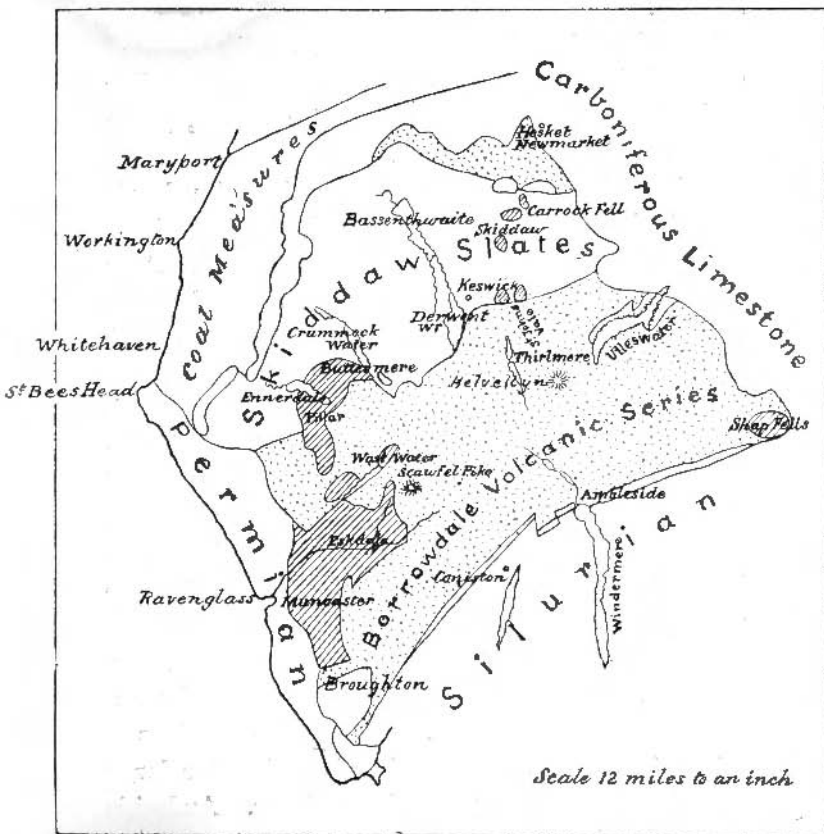


FIG. 80.

Sketch-map of the Lake District.

andesites (as at Ide and Kellerton Park), some are trachytes (Coppelstone, near Knowle Hill), while

others again belong to a more basic group (olivine basalts).

The phonolite of the Wolf Rock off the coast of Cornwall is the only representative of the nepheline rocks in England. It consists of sanidine, green augite, nepheline and nosean.

*Lake District.* The vast accumulation of volcanic material known as the Borrowdale Volcanic Series is mainly made up of andesitic lavas and tuffs. As a rule the lavas are compact, dark-coloured rocks, composed of numerous slender laths of felspar, with occasional porphyritic crystals of plagioclase and a glassy brownish base. The augitic constituent is generally replaced by chlorite. Rocks of this character are well developed to the south of Keswick and in Borrowdale (*e.g.*, Brown Knotts, Bleaberry Fell, Iron Crag, High Rigg), and in Langdale, Westmorland (Lingmoor, Side Pike, Chapel Stile). A more porphyritic type occurs on Great Gable.

The Eycott lavas which occur at Eycott Hill, near Keswick, and in the Cross Fell range, constitute a somewhat more basic type. Some of the members of this series are very porphyritic, containing fine large crystals of a striped plagioclase felspar. Andesitic lavas belonging to the Borrowdale series also occur at Bootle in Cumberland, and at Shap Fell, Westmorland.

*Northumberland.* A series of andesitic lava-flows

occurs in the Carboniferous Limestone Series of the R. Tweed, near Carham Hall.

*Cheviot District.* Andesites (augite- and enstatite-andesite) occur in great abundance in the Cheviot Hills (Northumberland and Roxburghshire). They are lavas of Old Red Sandstone age. In texture they show considerable variety, being fine-grained or porphyritic, felsitic or glassy, compact or vesicular. A glassy type with streaky flow-structure occurs at Yetholm. A glassy and perlitic type occurs at Buckham's Wall Burn (Northumberland), and at the Curr,  $4\frac{1}{2}$  miles E. of Morebattle (Roxburghshire). Occasionally the rocks assume a more trachytic character by the development of sanidine instead of a striped felspar (*e.g.*, near Jedburgh).

WALES. The Arenig rocks of Merionethshire consist largely of andesitic and trachytic lavas and their tuffs, building up a considerable portion of the mountain ranges of Cader Idris, the Arans, the Arenigs, the Manods and Moelwyn. Some of the Bala lavas of Caernarvonshire belong to the intermediate group of trachytes and andesites rather than to the acid rhyolites. Besides the intrusive andesites already referred to (p. 150), Mr. Harker has described augite-andesites from Penmaen Castle one mile W. of Pwllheli, and Y Foel Fawr  $1\frac{1}{2}$  miles W. of Llanbedrog.

SCOTLAND. Augite- and enstatite-andesites of Old

Red Sandstone age are well developed in the Midland Valley, building the hill-ranges of the Pentlands, the Braid Hills, and the Ochils. The rocks are compact, occasionally amygdaloidal, and vary in colour from black through various shades of purple and brown to dun and cream colours. Under the microscope they are seen to consist of porphyritic plagioclase felspar, and more or less altered enstatite and augite, imbedded in a ground-mass of lath-shaped felspars. Strongly amygdaloidal andesites occur in Ayrshire (Turnberry Point and Culzean). Andesites of Lower Carboniferous age have also a wide distribution in the Midland Valley, forming the Campsie Hills, the Kilpatrick Hills, and the Renfrewshire Hills, and occurring in Mull of Kintyre and the Island of Bute. In the Garlton Hills of Haddingtonshire the Carboniferous lavas consist of a well-developed trachytic type, composed of large porphyritic sanidine felspar (with which oligoclase is occasionally associated), imbedded in a ground-mass of lath-shaped felspars. Such rocks are well seen in the Peppercraig quarries near Haddington, at Kae Heughs, under the Hopetoun Monument, in the Phantassie and Bangleigh quarries, and at Skid Hill. A non-porphyritic type of the trachyte occurs at Score Hill, Craigie Hill, and Pencraig. The vents from which these trachytes flowed are represented by the trachyte dome of N. Berwick Law and the



**Bass Rock.** Traprain Law consists of a trachytic phonolite with sparsely developed nepheline and a green soda-augite.

Some of the North of England and South of Scotland "basalt" dykes have an andesitic character; in fact, they are typical tholeiites (*e.g.*, the Acklington and Cleveland dykes in England, and Eskdale Muir (Dumfriesshire) and Wat Carrick dykes in Scotland).

TABLE SHOWING THE RELATIONS OF THE MEMBERS OF THE INTERMEDIATE GROUP TO ONE ANOTHER.

INTRUSIVE.		VOLCANIC.	
<i>Deep-seated (plutonic) masses.</i>	<i>Dykes.</i>	<i>Fresh.</i>	<i>Altered.</i>
Syenites	Minettes	Trachytes	} Some Felsites (?)
Elæolite (or Nepheline) -syenites		Phonolites or Nepheline -trachytes	
Diorites	Kersantites	Andesites	

## 7. THE GABBRO<sup>1</sup> FAMILY.

The members of this family, which comprises the plutonic representatives of the basic group, are granitoid aggregates of a plagioclase felspar and a ferro-magnesian constituent. The variation of the ferro-magnesian constituent produces the following types:—

**Gabbro** proper (plagioclase + augite).

**Hornblende - gabbro**<sup>2</sup> (plagioclase + augite + hornblende).

**Olivine-gabbro** (same + olivine).

**Norite** or **hypersthene-gabbro**<sup>3</sup> (plagioclase + rhombic pyroxene).

**Olivine-norite** (same + olivine).

**Troctolite** (plagioclase + olivine).

**Pyroxene - granulite** (plagioclase + monoclinic and rhombic pyroxenes + garnet).

The felspar of these rocks occurs in allotriomorphic grains, showing well-marked twin-striation. Chemi-

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<sup>1</sup> The term Gabbro (von Buch) is now used in a sense differing from its original application; it was first given to an Italian serpentine containing diallage. A synonymous term is **euphotide** (Haüy), used by the French.

<sup>2</sup> This type forms a passage to the more acid augite-diorites.

<sup>3</sup> Synonyms for this type are **hyperstheneite**, **hyperite** and **Schillerfels**.

cal composition and optical properties (*e.g.*, large extinction angles between crossed nicols) show that it belongs to the anorthite end of the lime-soda series. Though often perfectly fresh, it alters under the influence of surface agencies into an opaque white substance known as saussurite, which can be resolved by microscopic examination into a confused and intimate aggregate of granules and fibres of zoisite, epidote and secondary felspar (albite), the last of water-clear and glassy habit.

The hornblende, when an original constituent, is sometimes a brown, sometimes a green variety. Secondary hornblende (actinolite, smaragdite, urallite), derived from the pyroxene, is also not uncommon, especially in those rocks that have suffered mechanical disturbance. The augite is usually laminated (diallage); and its cleavage surfaces present a marked metallic or pearly lustre. Under the microscope diallage in sections oblique to the lamination appears finely striated. The hypersthene is characterized by its pleochroism; and also presents a well-marked coppery lustre due to reflection from numerous platy and rod-like inclusions arranged along parallel planes. The olivine when fresh is colourless. It is, however, often stained with limonite, and crowded with rods and granules of magnetite.

Minerals accessory to the gabbros are dark mica,

quartz, apatite, ilmenite, rutile and green and brown spinels (pleonaste, picotite, chromite).

In structure these rocks are essentially holocrystalline and granitoid, the constituent grains being allotriomorphic. Sometimes, especially when passing over into dolerites, the rocks show a tendency towards ophitic structure. In size the grains vary considerably, so that both coarse and fine textures occur.

Their chemical composition varies from 48 to 54.6%  $\text{SiO}_2$ ; 10.4–28.9%  $\text{Al}_2\text{O}_3$ ; 4.8–15.8%  $\text{FeO}$ ,  $\text{Fe}_2\text{O}_3$ ; 9–18%  $\text{CaO}$ ,  $\text{MgO}$ ; 0.01–2.69%  $\text{K}_2\text{O}$ ; 0.5–6.2%  $\text{Na}_2\text{O}$ . Sp. G. = 2.9–3.02 (von Lasaulx).

**Troctolite**<sup>1</sup> is a variety of gabbro consisting almost entirely of plagioclase and olivine. This rock derives its name from its spotted appearance, due to the olivine grains being black with included magnetite.

**Pyroxene-granulite**<sup>2</sup> is the name given to certain gabbro-like rocks associated with crystalline schists. Thus they occur in the granulitic area of Saxony, in Sutherlandshire, Madagascar, and the United States. They consist essentially of plagioclase felspar, hornblende, both monoclinic and rhombic pyroxene and garnet; and are characterized by the freshness of the minerals and by a finely granular (or “granulitic”) structure.

<sup>1</sup> Trout-stone (Ger. *Forellenstein*).

<sup>2</sup> Name given by Lehmann. Syn. **Trap-granulite** (Nau-  
mann).

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*DISTRIBUTION IN THE BRITISH ISLES.*

ENGLAND AND WALES. *Devon and Cornwall.* Typical diallagic and hornblendic gabbros (with and without olivine) occur in the Lizard district (Karakclews and Coverack, Pen Voose and Kildown near Cadgwith). These rocks are much foliated in places, passing into gabbro-schists. Some of the greenstone bosses (dolerite) of Devon and Cornwall are coarsely crystalline, and tend to pass into gabbros (Templeton, Cornwall; Botter Rock, near Hennock; Smear Ridge, near Tavistock; Yarner Beacon, near Dartington, etc.).

*Lake District.* Hypersthene-gabbro builds a portion of Carrock Fell, N.E. of Keswick. Another mass occurs in the Cross Fell range at Cuns Fell.

*North of England.* In places the Whin Sill assumes a gabbro-like character (e.g., at Cauldron Snout in Teesdale).

*North Wales.* Two small bosses of gabbro break through the granite of Sarn in the Lleyrn peninsula (at Craig-y-fael, two miles S.W. of Sarn, and Plas Llangwnadl). Mr. Harker<sup>1</sup> describes these rocks as partially amphibolized gabbro, consisting, at Craig-y-fael, of "augite and diallage, hornblende and actinolite, felspar and opaque iron-ore, with some pale-green decomposition-product which has the

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<sup>1</sup> Harker, l. c., p. 89.

character of a chloritoid." The hornblende-plagioclase rocks of the Lleyn peninsula often have a gabbro-like structure (*e.g.*, at Penarfyndd), but I have followed Mr. Harker in classifying these rocks with the diabases.<sup>1</sup>

*South Wales.* A good type of gabbro occurs at St. David's Head in Pembrokeshire. A diallage-gabbro with labradorite-felspar and olivine (?) forms the summit of Hanter Hill in Herefordshire.

SCOTLAND. *South Scotland.* Gabbros which closely resemble those of the Lizard district occur in Ayrshire (Carrick district, Lendalfoot, Colmonell).

*Western Isles.* Some of the most rugged hills of these islands are built up of intrusive masses of gabbro. The largest area of gabbro is in Skye, where it constitutes the group of the Cuillin Hills. A large proportion of the conical mountains of Rum consist of gabbro. The eastern portion of the gabbro-boss of this island consists of a plagioclase-olivine rock (troctolite of Allival). In Mull the gabbro occurs mainly in numerous sheets intruded into the bedded basalts. The promontory of Ardnamurchan consists largely of gabbro.

*Central and Eastern Highlands.* Gabbros and

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<sup>1</sup> Mr. Harker informs me that he uses the term "hornblende-diabase" when the rocks show more or less the structure of typical diabases (idiomorphic felspar moulded by the bi-silicates).

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hornblende-gabbros (without olivine) form a great mass at Portsoy, near Banff. Another mass occurs further to the south, a little north of the Dee (Aberdeenshire). Another crops out in the fork of the rivers Dee and Muick, S.E. of Balmoral; and several small bosses are exposed between this point and Glen Fernate in Perthshire. The ridge on the eastern side of Glen Fernate consists of gabbro. Similar small intrusive masses occur along a line drawn in a south-westerly direction from Ben Bhrackie, near Pitlochry, through Ben Lawers to the west coast.<sup>1</sup>

*North-West Highlands.* Pyroxene-granulites occur as bands in the Lewisian Gneiss of Sutherlandshire.

IRELAND. Gabbros occur in the Carlingford district.

## 8. THE GREENSTONE FAMILY.

This family comprises dark-coloured rocks occurring in the form of intrusive bosses, sheets, laccolites and dykes. In the most common type the chief constituents are plagioclase and augite. The green colour characterizing many of these rocks is due to the presence of a chloritic constituent developed at the

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<sup>1</sup> Mr. Barrow considers that these ancient intrusions of basic material have done much to determine the strike and general structure of the Central and Eastern Highlands.

expense of the augite. The term **diabase**<sup>1</sup> is often used to designate chloritized rock, while the unaltered type is known as dolerite.<sup>2</sup> The time-honoured word "**greenstone**"<sup>3</sup> was formerly used in the same sense, and is still retained as a useful field-term without regard to composition. The augitic constituent is associated with or replaced by other ferro-magnesian minerals, furnishing the following varieties:—

- Dolerite** - - - - plagioclase + augite.  
**Mica-dolerite**, plagioclase + augite + brown mica.  
**Hornblende-dolerite**, plagioclase + augite + original hornblende.  
**Enstatite-dolerite**, plagioclase + augite + enstatite.  
**Olivine-dolerite**, plagioclase + augite + olivine.  
**Epidiorite**, plagioclase + secondary hornblende.  
**Leucophyre** - - - chiefly plagioclase.

<sup>1</sup> This word was introduced in 1813 by Alexandre Brongniart for rocks composed of felspar and hornblende; but the same mineral association was often designated by Haüy's term, diorite. The term was revived by Hausmann in 1842, who applied it to rocks composed of labradorite, pyroxene and chlorite.

<sup>2</sup> Haüy (1822).

<sup>3</sup> De la Beche, in his report on the geology of Cornwall, Devon and West Somerset, defines (p. 27) "greenstone" as a combination of hornblende and felspar. Microscopic exam-



The plagioclase (labradorite or anorthite) may be quite fresh or it may be much decomposed, altering then into an aggregate of minute granules of epidote, calcite and, occasionally, quartz. In thin section the augite is usually of a pale violet-brown tint. It mostly occurs in large ophitic masses, enclosing lath-shaped crystals and microlites of felspar. In the diabases the augite is partially, sometimes even completely, replaced by a scaly and fibrous aggregate of some chloritic mineral.

The original hornblende of the hornblende-diabases<sup>1</sup> is usually the common brown variety. In the epidiorites, however, it is of a pale green colour (uralite, actinolite, smaragdite), and is produced by paramorphism of the augite.

The olivine of the olivine-bearing dolerites and diabases is rarely quite fresh, being stained brown with limonite, blackened with magnetite-dust, or completely replaced by serpentine or calcite.

Among other accessory minerals the iron-ores, magnetite and ilmenite, are always more or less abundantly present, the latter giving rise, when altered, to leucoxene (an amorphous variety of sphene). Pyrites

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ination, however, has shown that the ferro-magnesian constituent of these rocks is essentially augite, the hornblende being mainly of secondary origin.

<sup>1</sup> Also known as proterobases.

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is sometimes present in disseminated granules, and apatite in six-sided needles. Quartz, calcite, epidote, chlorite and serpentine are common secondary minerals; and these minerals are often distributed in veins and nests through the rocks.

The structure of the diabases is characteristically ophitic; but, in some cases, a granular, in others, a porphyritic structure prevails. Interstitial glassy matter, or its devitrified equivalent, is rarely present, the rocks being usually holocrystalline. Very close-grained and compact diabases are known as **aphanites**.<sup>1</sup>

The intrusive character of the greenstones is especially shown by their contact phenomena: baking or "porcellanization" of shales: formation of banded and spotted rocks (desmoisites and spilosites) and of hornstone-like rocks rich in alkalis (adinole). The relation of these rocks to the volcanic representatives is shown by the fact that the more deeply-seated parts of massive basalt-flows often have a doleritic texture, and among Continental geologists the word dolerite is restricted to the coarse-grained varieties of Tertiary and modern basalts, the word diabase being used for the Pre-Tertiary "greenstones."

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<sup>1</sup> Haüy (1822)

## ANALYSES OF SOME DOLERITES.

	<i>Whin Sill, Cauldron Snout. (Teall.)</i>	<i>Rowley Rag. (J. H. Player.)</i>	<i>Clee Hill. (J. H. Player.)</i>
SiO <sub>2</sub> - -	51.22	49.0	48.4
TiO <sub>2</sub> - -	2.42	2.8	3.1
Al <sub>2</sub> O <sub>3</sub> - -	14.06	15.3	13.4
Fe <sub>2</sub> O <sub>3</sub> - -	4.32	2.6	4.0
FeO - -	8.73	8.2	8.5
MnO - -	0.16	—	—
CaO - -	8.33	8.2	8.6
MgO - -	4.42	4.9	6.5
K <sub>2</sub> O - -	1.25	2.6	2.1
Na <sub>2</sub> O - -	2.55	2.5	3.1
P <sub>2</sub> O <sub>5</sub> - -	.25	—	—
FeS <sub>2</sub> - -	.49	—	—
Loss on ignition	1.47	3.3	2.2
	99.67	99.4	99.9

*DISTRIBUTION IN THE BRITISH ISLES.*

Intrusive masses of "greenstone" (diabase) form a characteristic feature of some of the most important volcanic areas of Great Britain. Thus they are abundantly associated with the Ordovician lavas of N. Wales and the S.E. of Ireland, and, though to a less extent, of the Lake District. Again in the Carboniferous and Tertiary volcanic periods they played an important rôle.

ENGLAND AND WALES. *N. Wales.* The diabases of Caernarvonshire and Merionethshire occur usually in the form of sheets (sills) following the bedding plane, but occasionally they swell out to irregular or lenticular masses (bosses and laccolites), which are clearly intrusive.

In composition they are chiefly ophitic plagioclase-augite rocks, containing no olivine, but much impregnated with secondary chlorite, calcite and epidote.

A good representative of the Caernarvonshire diabases is the "Gimlet Rock," which is quarried at Pwllheli in the Lleyrn peninsula for paving-sets and road-metal. In Merionethshire the diabase intrusions are especially developed in the neighbourhood of Dolgelly. Thus the mass forming the ridge of Mynydd-y-gader, N. of Cader Idris, consists of a medium-grained ophitic diabase. A similar rock occurs at Bwlchau-yr-Figen, 3 miles N.W. of Dinas Mawddwy. A more gabbro-like type is developed at Bwlch-yr-Hendref, near Capel Arthog, 6 miles S.W. of Dolgelly.

A hornblendic type is represented in the Lleyrn peninsula, and at Rhobell-fawr in Merionethshire. These hornblende-diabases are composed of brown hornblende in ophitic plates moulding plagioclase felspar, together with a pale augite and iron ores. Olivine, partially altered to serpentine, occurs as an accessory constituent. In the Lleyrn they constitute

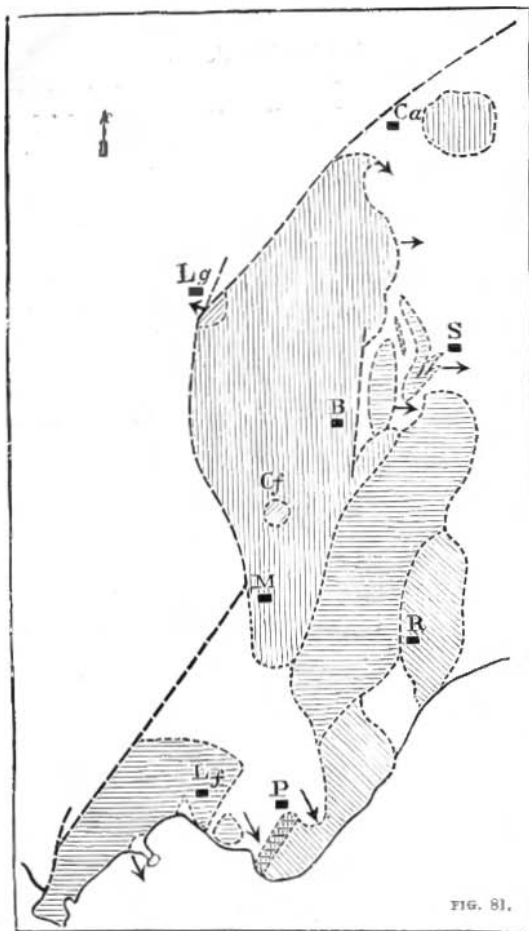
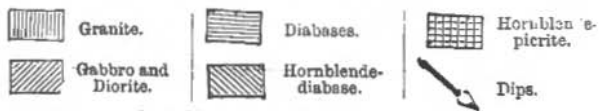


FIG. 81.

SKETCH-MAP OF THE SARN DISTRICT.



Probable faults marked - - - - -

NAMES OF PLACES.

B. Bryn-croes.

M. Meillionydd.

P. Penarfynydd.

S. Sarn.

R. Rhiw.

Cf. Craig-y-fael.

three oval masses (laccolites?), two of which build the hills Mynydd Penarfynydd,<sup>1</sup> Careg-llefain and Mynydd-y-graig, the third lying to the east of Rhiw. The Penarfynydd rock has the coarse-grained aspect of a gabbro; but we follow Mr. Harker in putting it with the diabases, as it presents a marked ophitic structure. Besides the Ordovician intrusions, certain dolerite dykes occurring in the Lleyn and in Anglesey (Menai) are referred by Mr. Harker to the Carboniferous period.

*S. Wales.* Numerous sills and bosses of greenstone (chiefly diabase) occur in Pembrokeshire, intrusive into Ordovician rocks as in N. Wales. Along the coast, from St. David's Head to Strumble Head, a great number of sills run out to sea, in many cases forming the headlands and promontories. A large mass of typical ophitic dolerite, without olivine, occurs near Llanwnda, 2 miles N.W. of Fishguard. This rock takes a high polish, and has been found suitable for ornamental work and sculpture. Between Fishguard and Newport the sills are greatly developed. They run N.E. and S.W., parallel to the strike of the rocks into which they are intrusive, and are continued in a southerly direction into the heart of Pembrokeshire.

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<sup>1</sup> Underlying the hornblende-diabase is the beautiful hornblende-picrite of Mynydd Penarfynydd.

*Radnorshire, Herefordshire, and Shropshire.* Diabasic intrusions are associated with Ordovician areas of these counties (e.g., in the range of the Carneddau near Builth, and near Chirbury). Enstatite-diabases are stated to occur in the Breidden Hills (Rodney's Pillar) and at Corndon and Shelve; and mica-diabases have been described from Stanner and Hanter Hill, near Old Radnor.

*Lake District.* Greenstones are not present quite so abundantly in the Cumbrian as in the Cambrian volcanic districts. The sills are best developed S. of the Borrowdale Fells (in Longstrath, on Stonethwaite Fells and crossing Greenup Gill to Ullscarf). A well-marked boss (a volcanic neck?) is formed by the diabase of Castle Head, near Keswick. Other occurrences are Wythop Fells, and Swirrel Edge near the summit of Helvellyn.

*Devonshire and Cornwall.* Numerous bosses, laccolites and sills of greenstone protrude through the Devonian slates and Culm-measures of these counties. Thus they occur abundantly on the margin of the Dartmoor granite; in the Teign Valley, N. of Chudleigh, and in the neighbourhood of Tavistock, where they swell out into large irregular and lenticular masses. Again, numerous sills are developed around Padstow Harbour; in the neighbourhood of Endellion; between Davidstow and St. Clether, N.E. of Camelford; and between Liskeard and Saltash. In texture these

rocks vary from very compact *aphanites* (e.g., Gurnards Head, Zennor; and Harlyn, near Padstow) to coarser, more gabbro-like rocks (e.g., Templeton, Cornwall; Yarner Beacon, Dartington; Ashton and Crocombe, near Chudleigh; the Botter Rock, near Hennock; Smear Ridge, near Tavistock). Mica-diabase occurs at Saltash, near Plymouth.

*The Midland Counties.* Olivine-dolerites are intrusive in the Carboniferous rocks of Gloucestershire, Worcestershire, Shropshire, Leicestershire, and Staffordshire. They are granular to ophitic rocks, composed of plagioclase felspar, strongly coloured augite, ferruginous olivine, and iron-ores. Some of the chief localities are the following: Rowley Hills, near Birmingham; Barrow Hill, W. of Dudley; Pouk Hill, near Walsall; Tansley Hill, near Dudley; Swinnerton Park, 8 miles N.E. of Stafford; Whitwick Colliery, Leicestershire; Clee Hills, near Ludlow, Shropshire; Kinlet in Wyre Forest, Shropshire. Olivine-dolerites occur as intrusive masses in the Old Red Sandstone at Bartestree, near Hereford; and at Brock Hill, near Shelsley Beauchamp, Worcestershire.

*N. of England.* Many of the dykes which traverse the northern counties are dolerites (without olivine). The Whin Sill, which runs from Cross Fell to Dunstanburgh Head, a distance of about 70 miles, is a sub-ophitic dolerite, containing enstatite in places.



In Teesdale (Tyne Head and Cauldron Snout) it forms a rather coarse crystalline variety, with long-bladed crystals of augite. The Cleveland Dyke, which cuts Secondary strata (Lias at Grossmount, Yorkshire) and appears at the surface for a distance of 90 miles, is also a dolerite. It consists of a ground-mass of lath-shaped feldspars, granular augite, iron-ore, and interstitial matter, containing porphyritic crystals of labradorite. The Acklington Dyke, which runs from Bondicar, on the coast of Northumberland, into the Cheviot district, is a rock of the same type. Other well-known dykes occur in Durham and Northumberland—Tudhoe and Hett; Hebburn; Tyne-mouth and Coley Hill (with large porphyritic crystals of anorthite); High Green, Seaton, and Hartley. These may all be classed as dolerites without olivine. A dyke of olivine-dolerite occurs, however, near Morpeth.<sup>1</sup>

SCOTLAND. Diabasic rocks—partly altered to epidiorites and to hornblende or chlorite schists—are abundantly associated with the gneisses and crystalline schists of the *North-west Highlands* (Sutherlandshire, Argyleshire, etc.).

Numerous intrusive bosses, sills, and dykes of Carboniferous age occur in the *Basin of the Forth*; e.g.,

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<sup>1</sup> See Teall on "Some North of England Dykes," Q.J.G.S. Vol. XL. (1884), p. 209.

Ratho, 8 miles W. of Edinburgh (coarse hypersthene-dolerite)—largely used for paving the streets of Edinburgh; Dalmahoy Hill, 8 miles S.W. of Edinburgh (olivine-dolerite); Corstorphine Hill, 3 miles S.W. of Edinburgh (ophitic olivine-dolerite); Heriot Mount, the Dasses, and Salisbury Crags, Arthur's Seat; numerous localities in Fifeshire (Burntisland, Cleish Hills, etc.); Linlithgowshire (West Broadlaw, Cramond and Carmel Hill); south of the Kilsyth Hills (hypersthene-dolerite of Croy and Over-Croy); south of Glamis in Forfarshire (olivine-dolerite).

Good ophitic dolerites of Tertiary age are intrusive mainly as sills into the bedded basalts of the *Western Isles of Scotland* (Mull, Skye, Arran) and Ardnamurchan in Argyleshire.

IRELAND. *S.E. of Ireland.* Diabases passing into epidiorites are intrusive in the Ordovician rocks of Counties Wicklow and Waterford (*e.g.*, Arklow Head and in the Aughrim Valley).

*N.E. of Ireland.* Tertiary dolerites occur in the basalt plateau of Antrim (*e.g.*, at Portrush; Scawt Hill, 4 miles S.S.E. of Glenarm; and at Fairhead).

## 9. THE BASALT<sup>1</sup> FAMILY.

The basalts are dark-coloured lavas of basic composition and high specific gravity, representing the extrusive or volcanic type of the gabbros and dolerites. When fresh, they are characterized by their black



FIG. 82.—Crystal of Fused Hornblende.

colour and minutely crystalline, to compact, texture and high density. When altered or decomposed by the action of the weather, they assume a reddish or

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<sup>1</sup> The word "basalt" is one of the oldest in petrography. It is said to be derived from the Ethiopian word "basal," signifying an iron-bearing stone. According to Pliny, basalt was first brought from the country of the Ethiopians.

greenish hue, and are much veined by decomposition products. Such altered basalts are known as *metaphyres*.<sup>1</sup> A further stage of decomposition converts the basalt into a loose crumbling material known as



FIG. 83.—Olivine-Basalt, under the microscope.

Porphyritic crystals of Olivine (*o*) and smaller ones of Augite (*a*) imbedded in a microlitic ground-mass. The clear spaces (*c*) are cavities.

(After Fouqué and Lévy.)

*wacke*, which is but little removed from clay in composition. Microscopic examination of a fresh basalt

<sup>1</sup> Word introduced by A. Brongniart, and since used with various significations. Rosenbusch applied it to pre-Tertiary basalts. It is here applied to all altered basalts, without regard to their age.

shows it to be composed essentially of plagioclase (labradorite or anorthite) and augite. When olivine is present, the rock is termed olivine-basalt. (See Fig. 83.) In addition to the augite there are often present larger crystals, or partially fused fragments of brown augite and hornblende. (See Fig. 82.) Replacing the felspar, or in addition to it, some basalts contain members of the nepheline group (nepheline, leucite, melinite, haüyne, nosean).

Adopting a mineralogical classification, the different types of basalt may be summarized thus:—

### 1. Felspar-basalts:—

- a. **Basalt** proper = plagioclase + augite.  
 b. **Olivine-basalt** = „ + „ + olivine.  
 c. **Hornblende**  
 (or **mica**)-**basalt** = „ + „ + horn-  
 blende (or  
 mica).

### 2. Felspar {<sup>-nepheline</sup> -leucite} basalts:—

- a. **Tephrite**<sup>1</sup> = plagioclase + {nepheline  
or leucite} + augite.  
 b. **Basanite** = plagioclase + {nepheline  
or leucite} + augite +  
 olivine.

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<sup>1</sup> Rosenbusch (*Physiographie*, p. 248) proposes the name **thermalite** for the plutonic representatives of the plagioclase-nepheline rocks; the **teschenites**, which were formerly supposed to consist of these minerals, having been shown to contain no nepheline.

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 3. Basalts without felspar:—

- a. **Nepheline-basalt**<sup>1</sup> = nepheline + augite.  
 b. **Leucite-basalt** = leucite + augite.  
 c. **Melilite-basalt**<sup>2</sup> = melilite + augite.

Accessory minerals present in the basalts are magnetic iron-ore, in black opaque grains; apatite, in colourless needles; zircon, in conspicuous red grains; and h a yne and nosean (in the nepheline and leucite-bearing varieties). Isolated and much-corroded quartz grains occur; but it is an open question whether they are indigenous to the basalt or have been caught up during its eruption. Chlorite, calcite and epidote, either disseminated or filling amygdaloidal cavities, occur abundantly in the melaphyres, or altered basalts. The chlorite is derived mainly from the decomposition of the augite; the calcite and epidote, from the felspar; while the olivines are mostly entirely replaced by serpentine, limonite, magnetite, or carbonates of lime and magnesia. Zeolites (natrolite, phillipsite, scolecite) and agates are frequently the infilling material of the amygdules of the melaphyres and basalts.

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<sup>1</sup> Rosenbusch (*Ibid.*, p. 290) calls these rocks **nephelinite** and **leucitite** when they are free from olivine, but nepheline-basalt and leucite-basalt when they contain that mineral.

<sup>2</sup> Rosenbusch uses the word **aln ite** for a subdivision of the melilite-basalts (*Ibid.*, p. 805).

The average chemical composition of the basalts is as follows:—

$\text{SiO}_2 = 43\%$ ;  $\text{Al}_2\text{O}_3 = 14\%$ ;  $\text{Fe}_2\text{O}_3, \text{FeO} = 15.3\%$ ;  $\text{CaO} = 12.1\%$ ;  $\text{MgO} = 9.1\%$ ;  $\text{K}_2\text{O} = 1.3\%$ ;  $\text{Na}_2\text{O} = 3.9\%$ ;  $\text{H}_2\text{O} = 1.3\%$ . Sp. G. = 2.8–3.0 [von Lasaulx].

## ANALYSES OF BASALT.

	<i>Olivine-Basalt of Kippie Law, Garlton Hills. (J. S. Grant-Wilson.)</i>	<i>Olivine-Basalt of Hailes Castle, Garlton Hills. (J. S. Grant-Wilson.)</i>
$\text{SiO}_2$ - - -	46.01	49.07
$\text{Al}_2\text{O}_3$ - - -	19.19	19.43
$\text{Fe}_2\text{O}_3$ - - -	5.91	10.58
$\text{FeO}$ - - -	6.75	2.35
$\text{MnO}$ - - -	.19	.32
$\text{CaO}$ - - -	8.68	7.87
$\text{MgO}$ - - -	6.81	4.36
$\text{K}_2\text{O}$ - - -	1.20	.98
$\text{Na}_2\text{O}$ - - -	3.27	3.31
$\text{H}_2\text{O}$ - - -	3.07	2.26
	101.08	100.53
Sp. G. - -	2.8	2.76

The tephrites<sup>1</sup> and basanites<sup>2</sup> are the plagioclase-

<sup>1</sup> Name introduced by Delam  therie and Cordier for the olivine-free plagioclase-nepheline basalts.

<sup>2</sup> Name introduced by A. Brongniart for the olivine-bearing variety.

nepheline (and leucite) rocks corresponding to the phonolites (or orthoclase-nepheline rocks). In the nepheline-, leucite- and melilite-basalts, however, felspar is not present as an essential constituent.

The nepheline is sometimes present in recognis-

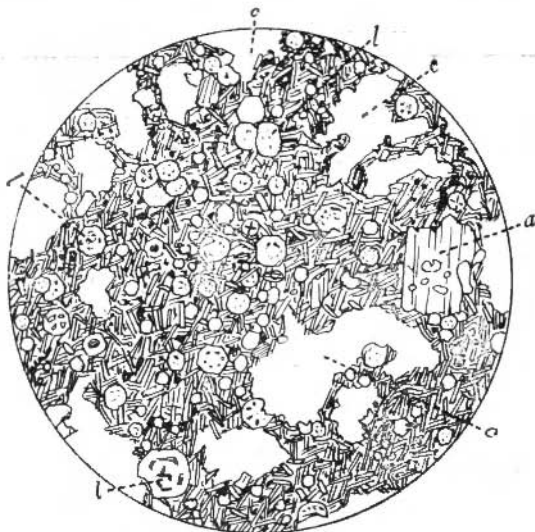


FIG. 84.

Leucite-tephrite of Veauvius, under the microscope. Crystals of Leucite (l) and Augite (a) imbedded in a microlitic ground-mass. The irregular clear spaces (c) are cavities. (After Fouqué and Lévy.)

able six-sided crystals; oftener, however, in small disseminated granules, then only to be detected by chemical tests. Leucite, on the other hand, is easily known by its characteristic polygonal shape, zonal inclusions and optical behaviour. Accessory to the



nepheline and leucite-bearing basalts are haüyne, nosean, melanite (black garnet), perowskite and melilite. (See Fig. 84.)

With regard to structure the basalts are very variable. They may contain no porphyritic ingredient or be crowded with large crystals of different minerals. They may be holocrystalline or semi-vitreous. They may be very felspathic, passing then into the andesites, or they may be nearly free from felspar, grading then into the limburgites and augitites.

In one common type porphyritic olivines and augites are imbedded in a ground-mass composed of lath-shaped felspars and microlitic or granular augite. Such rocks are characteristically developed on the right bank of the Rhine (Siebengebirge, etc.), and in the Midland Valley of Scotland.

In the British basalts of Tertiary age, however, an ophitic or "intersertal"<sup>1</sup> structure prevails; and in these rocks a gradual passage to the ophitic dolerites can be traced. The andesites, into which the basalts also pass by every gradation, differ in the fact that in them the felspars are porphyritic and more abundant, while augite occurs in smaller and less frequent crystals, and olivine only as a rare accessory.

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<sup>1</sup> Rosenbusch.

Basalt occurs in "flows" or beds of great extent and variable thickness, forming characteristic plateaux and terraced hills; also in dykes which, perhaps, represent, in some cases, the fissures through which the molten lava welled out.<sup>1</sup> The "bedded" basalt is slaggy and amygdaloidal on the outer surface. Internally it is characterized by a well-marked columnar structure, which has doubtless been developed by contraction during cooling. The columns are 3, 4, 6, and 8-sided, and are sometimes of great length and regularity, the long axes being perpendicular to the surfaces of cooling. A cross-jointing is sometimes superadded, producing a tabular structure. The spheroidal weathering of basalt is due to the presence of these intersecting joint-surfaces, along which permeating waters have access. Where basalt has been quickly cooled, by contact with cold rock, a thin layer or selvage of black opaque glass is invariably present. This basaltic glass is known as **tachylite**. It decomposes into a yellowish substance known as **palagonite**.

Basalt is very hard and tough, and constitutes an excellent material for paving and road-metalling. Olivine-basalt has been artificially produced by fusing the necessary ingredients, and allowing the

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<sup>1</sup> On the "fissure-eruption" theory, which has not met with universal acceptance.

fused mass to cool slowly. Fig. 85 shows the appearance under the microscope of a thin section of

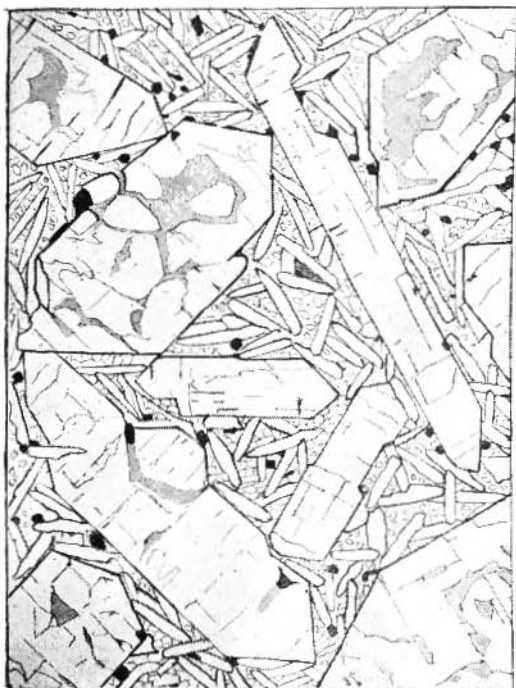


FIG. 85.

Synthetically prepared Olivine-basalt. (After Fouqué and Lévy.)

an olivine-basalt synthetically prepared by Messrs. Fouqué and Lévy.

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*DISTRIBUTION IN THE BRITISH ISLES*

ENGLAND. *Devon and Cornwall.* Vesicular basic lavas associated with breccias and tuffs occur interbedded with the Devonian rocks of these counties. Thus in Cornwall, well-defined lavas occur at Endellion, St. Minver, St. Clether and near Padstow. In Devonshire there is the volcanic series of Ashprington and Totnes, described by Messrs. Champernowne and Ussher. These rocks are much chloritized and impregnated with calcite. They are often weathered to a red, rusty colour, and sheared into schistose rocks ("Schalstein") by earth movements. Scoriaceous basic lavas, together with tuffs and breccias, occur at Brent Tor, near Tavistock. They were probably erupted from a volcanic vent, of which Brent Tor itself represents the denuded stump (Rutley).<sup>1</sup> Olivine-basalts are also associated with the Permian (?) porphyrites occurring near Exeter (*e.g.*, at Raddon Court, at Pocombe, between Chiphele and Budlake, and at quarry near Crabtree, Kellerton).

*Gloucestershire, Somerset, etc.* Basalts are intruded into sandstones of Upper Llandovery age at Damary and near Charfield Green. They are black, compact rocks, sometimes vesicular, being spotted with amygdules of calcite coated with delessite. Similar

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<sup>1</sup> Memoirs of the Geological Survey: Brent Tor.

rocks, and of the same age, occur at Old Radnor Hill, Radnorshire. Small patches of Carboniferous basalt associated with tuffs and breccias, occur in the Mendips and near Weston-super-Mare. Basalt intruded in Old Red Sandstone occurs at Brock Hill in Worcestershire, and at Bartestree in Herefordshire.

*Derbyshire.* Contemporaneous flows of basaltic lava occur in the Carboniferous Limestone of this county. These rocks, locally known as "toadstone," are strongly amygdaloidal melaphyres; they are associated with volcanic ash, and are well exposed in Miller's Dale, Tideswell Dale and near Matlock.

*North of England.* Basaltic lavas of Carboniferous age occur in the Cheviots; for instance, on the E. side of Hungry Law, Ramshope Burn, and in Cottonshope Burn, Reedwater. Many of the dykes of the North of England consist of basalt, e.g., Tarret Burn, N. Tyne (a compact rock, with cavities filled with black glass). A compact black basalt dyke occurs at Shelwell, head of S. Tyne. A tachylitic basalt occurs at Lennell, near Coldstream, on the Scottish side of the Tweed.

WALES. Basic lavas consisting of altered olivine-basalts occur at St. David's in Pembrokeshire ("Pebidian formation of Dr. Hicks"). These rocks may be well seen at Penmaen Melyn, the S.W. point

of the St. David's district. Vesicular flows of basalt containing a little olivine occur in Skomer Island, off the coast of Pembrokeshire. Basic material was also erupted at Rhobell Fawr, 5 to 6 miles N.N.E. of Dolgelly; but these rocks consist mainly, if not altogether, of fragmentary material (tuffs and breccias). According to Messrs. Cole and Holland they are of Tremadoc age, and lie on the upturned edges of the Lingula Flags.

Vesicular basaltic lavas of Ordovician age occur in Ramsey Island (Porth Hagog).

SCOTLAND. The basalts of Scotland belong chiefly to two volcanic periods: (1) the Carboniferous, developed in the Midland Valley; (2) the Tertiary, developed in the Western Isles.

The Carboniferous basalts present many various types of structure and composition. They mostly contain olivine, some being very rich in this mineral, and then approximating to the composition of limburgites. A few of the commoner types of Carboniferous olivine-basalt are the following:—

1. Composed of large porphyritic olivine, granular augite, magnetic iron-ore, and a few felspar-micro-lites,—Hillhouse and Kirkton West quarry (Bathgate Hills), and among the basalts of Burntisland and Kinghorn.

2. Showing abundant small olivines, and grains of augite, imbedded in a mesh of slender lath-shaped

crystals of felspar, the interspaces being filled with microlitic augite and minutely granular magnetite. This type is developed at Dalmeny; in the Bathgate Hills, Linlithgowshire; and between Burntisland and Kirkcaldy in Fife.

3. Containing large porphyritic olivine, augite and felspar in a ground-mass composed of lath-shaped felspars, granular augite, magnetite and some glassy matter—Lion's Haunch, Arthur's Seat; Duddingstone Loch; and Calton Hill.

4. A rock similar to the Lion's Haunch type, but without the porphyritic felspars, occurs at Craiglockhart Hill, Edinburgh.

5. In another type (*e.g.*, Kippie Law, in the Garlton Hills of Haddingtonshire) the olivine alone is porphyritic, the augite appearing in the ground-mass in the form of microlites.

6. The very felspathic type of basalt is called "labradorite" by the French, on account of the nature of its felspar. A good example of this type occurs in the Garlton Hills (Markle Quarry).

Olivine-basalts of Carboniferous age also occur, near Jedburgh; and at Stitchill, N. of Kelso; in the Campbeltown district of Argyleshire; and in the southern part of Bute.

The Tertiary basalts have a more strongly marked ophitic structure than those of Carboniferous age. They occur abundantly in horizontal beds forming

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terraced hills in Mull, Skye, Arran, Rum, Raasay, etc. Dykes of the same rocks are abundant in Arran, Mull, Skye, Eigg and Raasay. In numerous cases the dykes are bordered by a narrow selvage of dark-coloured glass or tachylite.

IRELAND. Carboniferous olivine-basalts occur in the Limerick district of the S.W. of Ireland (Limerick Traps). Mr. Watts describes them as consisting of "granular augite and magnetite set in a more or less devitrified glass, with microlites of felspar and porphyritic plagioclase, serpentized olivine, and some well-marked augite."<sup>1</sup> The upper basalts on Nicker Hill are more basic, approaching limburgites in composition.

The Tertiary basalts of Antrim belong to the same petrographical province as the Western Isles of Scotland, and the rocks show no distinctive features. The volcanic sheets afford in places a magnificent example of columnar structure, as at the famous Giant's Causeway.

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<sup>1</sup> A. Geikie: "Anniversary Address to the Geological Society, 1892," p. 147.



TABLE SHOWING THE MUTUAL RELATIONS OF THE BASIC ROCKS.

INTRUSIVE.		VOLCANIC.		
<i>Deep-seated (plutonic masses.)</i>	<i>Dykes and intrusive sheets.</i>	<i>Fresh.</i>	<i>Altered.</i>	
Gabbros {	Diallage-gabbro	Dolerite (diabase)	Basalt and Tachylite	Melaphyre and Palagonite
	Hornblende-gabbro	Hornblende } -dolerite or mica } (diabase)	Hornblende } -basalt or mica }	
	Hypersthene-gabbro or Norite	Enstatite-dolerite (diabase)	Enstatite-basalt	
	Pyroxene-granulite			
			Nepheline-bearing basalts, etc. {	Tephrite and Basanite
		Nepheline } -basalt Leucite }		
		Melilite }		

*All these varieties with or without olivine.*

## 10. THE MAGMA-BASALT FAMILY.

The **magma-basalts** of Bořický<sup>1</sup> are rocks consisting solely of ferro-magnesian minerals and iron-ore imbedded in an abundant glassy base. Augite of the common brown type is the most abundant constituent; it occurs in prismatic crystals, giving 8-sided cross-sections, and in microlites. Iron-ore



FIG. 86.

Magma-basalt, composed of crystals of Magnetite and Augite imbedded in a brown glassy base. In the centre is a patch of trichites

(magnetite) is always present, both in granules and trichites (see Fig. 86). Those rocks which, in addition to augite, contain olivine, are termed **limburgites**;<sup>2</sup> those without olivine, **augitites**.<sup>3</sup> Accord-

<sup>1</sup> 1873.

<sup>2</sup> Rosenbusch (1872).

<sup>3</sup> Dörlter (1882).

ing to Bořický, the magma-basalts contain 38·7-42·5% of SiO<sub>2</sub>, 3·6-6·3% of alkalies, and 3-6·5% of water.

## ANALYSES OF TYPICAL LIMBURGITES AND AUGITITES.

	<i>Kaiserstuhl, Baden. (Rosenbusch.)</i>	<i>Augitite, Madeiral, São Vicente. (Doelter.)</i>	<i>Whitelaw Hill, Garlton Hills. (J. H. Player.)</i>
SiO <sub>2</sub> -	42·8	41·0	40·2
TiO <sub>2</sub> -	—	—	2·9
Al <sub>2</sub> O <sub>3</sub> -	8·7	24·2	12·8
Fe <sub>2</sub> O <sub>3</sub> -	—	9·5	4·0
FeO -	18·9	—	10·4
CaO -	12·3	11·0	10·4
MgO -	10·1	5·1	11·9
K <sub>2</sub> O -	0·6	1·8	0·8
Na <sub>2</sub> O -	2·3	5·7	2·7
H <sub>2</sub> O -	4·0	} 1·6	3·4
Residue-	0·3		
	100·0	99·9	99·5

## DISTRIBUTION.

These rocks have a widespread occurrence abroad: *e.g.*, Kaiserstuhl, Rhön and Vogelsberg in Germany; further, in Bohemia, in the Cape Verd Isles, at Kili-manjaro and in Madagascar. In Britain they occur among the Lower Carboniferous volcanic rocks of the Midland Valley of Scotland. A good example

occurs at Whitelaw Hill (Chester's Quarry) in Haddingtonshire. It has been analysed and found to contain 40% of silica. Its specific gravity is 3.3. It is practically free from felspar, consisting of olivine, augite and glassy matter.

Other localities are Pitandrew, near Fordel Castle; and the Hill of Beath, in Fife.

## 11. THE PICRITE FAMILY.

The **picrites**<sup>1</sup> may be regarded as constituting a passage between the true peridotites and the basic olivine-gabbros. They are dark, heavy rocks, composed mainly of olivine and augite, with a variable but always small amount of felspar. In addition to these minerals, brown biotite is sometimes present; while bright green chloritic and serpentinous products, probably also a secondary hornblende (pilate), are usually developed at the expense of the ferromagnesian minerals.

**Hornblende-picrite**<sup>2</sup> is a similar rock in which brown hornblende is present instead of the usual augite. A colourless augite (malacolite) is, however, sometimes associated with the hornblende.

A characteristic feature of the picrites is the

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<sup>1</sup> Name given by Tschermak (in 1866) on account of the high percentage of magnesia (bitter-earth) in these rocks.

<sup>2</sup> Bonney (1881).

*lustre-mottling*, which is visible in hand-specimens. This phenomenon is produced by the interrupted reflection from the cleavage-surfaces of the augite or hornblende, as the case may be, the interruption being due to the inclusion of grains of olivine within the cleaved mineral.

Chemically these rocks contain about 40% of silica, a small proportion of alumina (10 per cent. or less), and a very large amount of magnesia, ranging from 15 to 30 per cent.; while the total alkalis are usually below 2 per cent. The specific gravity lies between 2.8 and 3.

## ANALYSES OF SOME ULTRABASIC ROCKS.

	<i>Picrite, Gümbelberg. (Tschermak.)</i>	<i>Hornblende-picrite, Anglesey. (J. A. Phillips.)</i>
SiO <sub>2</sub> - - -	40.79	42.94
Al <sub>2</sub> O <sub>3</sub> - - -	10.41	10.87
Fe <sub>2</sub> O <sub>3</sub> - - -	3.52	3.47
FeO - - -	6.39	10.14
CaO - - -	8.48	9.07
MgO - - -	23.34	16.32
K <sub>2</sub> O - - -	0.71	.15
Na <sub>2</sub> O - - -	1.71	.90
Loss on igni- tion- - -	4.04	6.09
	99.39	99.95

Sp. gr. = 2.96.

Sp. gr. = 2.88.

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*DISTRIBUTION.*

Picrites were first described by Tschermak, as olivine-augite rocks intrusive in the Cretaceous and Eocene formations of the highlands between Neutitschein, Teschen and Bielitz in Moravia and Silesia. Similar rocks have since been noticed by Gumbel in the Fichtelgebirge ("Palæopikrit"), and other observers have recorded their occurrence in the Lower Devonian slates of the Rhine Valley (Nassau, Ruhrthal, Wetzlar, etc.). The so-called "Schillerfels" of the Odenwald is a typical hornblende-picrite (Rosenbusch).

**BRITISH ISLES.** In *Scotland* picrites of well-marked character occur among the Carboniferous rocks of the Basin of the Forth (Blackburn, near Bathgate; and on the island of Inchcolm).<sup>1</sup> The Inchcolm rock is a singularly beautiful type: besides olivine, augite and felspar, it contains brown hornblende, biotite, iron-ore, apatite, and a vivid bluish-green serpentinous mineral derived from the alteration of the olivine. A fibrous green hornblende (pilitite) is also developed to some extent. A very similar rock has recently been discovered at Lethan Hill, Waterside, Ayrshire; another occurs at Turnberry Castle, 6 miles N. of Girvan, on the Ayrshire coast. In the Western

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<sup>1</sup> First described by Sir Archibald Geikie.

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Isles, Professor Judd has recorded the association of picrites with the Tertiary gabbros and dolerites of Rum, the west of Skye and the Shiant Isles. A variety of hornblende-picrite, containing a peculiarly lustrous mica (*scyelite*), has been described by the same author from the western border of Caithness. Typical picrites occur as dykes in the Lewisian Gneiss of Sutherland; and hornblende-picrites occur in most of the igneous complexes of the Central Highlands.<sup>1</sup>

In *England* there are three recorded localities for picrite; viz., in Cornwall (Clicker Tor, near Liskeard), in Shropshire (Shelve Pool; and Cwmmawr, N.W. of Hyssington), and in the Lake District (the hornblende-picrite of Little Knott).

*North Wales.* A beautiful type of hornblende-picrite occurs at Mynydd Penarfynydd in the Lleyn peninsula in Caernarvonshire, where it is intrusive in rocks of Arenig age. It has been described by Professor Bonney and Mr. Harker as consisting of brown hornblende, olivine and felspar, together with a pale augite, brown mica, magnetite and secondary products. The lustrous cleavage-surfaces of the hornblende broken by spots of serpentinized olivine, produce a characteristic lustre-mottling. Another Caernarvonshire locality is Pen-

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<sup>1</sup> From information supplied by G. Barrow.

y-rhiwiau, near Clynog-fawr.<sup>1</sup> Similar rocks occur in Anglesey; viz., N.E. of the town of Llanerchymedd, Pengorhwysfa, near Amlwch, and at Ty-Croes. The Llanerchymedd rock is black and coarse-grained, with large lustrous crystals of hornblende, showing lustre-mottling. According to Mr. Harker, it forms laccolitic intrusions in Arenig rocks. The Pengorhwysfa occurrence is a large, irregularly-shaped mass on the western slope of Llaneilian Mountain.

## 12. THE PYROXENITE<sup>2</sup> AND HORNBLENDITE<sup>3</sup> FAMILY.

The **pyroxenites** are plutonic or deep-seated rocks, composed of one or more varieties of pyroxene and having a holocrystalline and granular structure. The pyroxenes usually present are a green monoclinic variety (omphacite or diallage) and a pleochroic rhombic variety (bronzite or hypersthene). These rocks have received various names—**diallagite**, **hyperstheneite**, **bronzitite**, **websterite**, etc.

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<sup>1</sup> Harker refers this rock and a similar one occurring near Tanrallt to the hornblende-diabases, on account of the variable proportions of olivine and felspar they contain. The same reasoning applies to the Anglesey occurrences.

<sup>2</sup> Name introduced by Sterry Hunt, in 1862.

<sup>3</sup> Name introduced by J. D. Dana, in 1880.



When typically developed, they contain neither felspar nor olivine; but by the addition of the former, however, they pass into norites and gabbros, and by the addition of the latter into peridotites.

The **hornblendites** are similar rocks, composed of varieties of hornblende.

The beautiful rock known as **eclogite**, which is composed of emerald-green hornblende (smaragdite), grass-green augite (omphacite) and red garnet, belongs to this family, lying midway between the pyroxenites and the hornblendites. By the addition of olivine, eclogite passes into eulysite (see under "peridotites").

#### DISTRIBUTION.

Various members of this family are represented as bands in the Lewisian Gneiss of Sutherland (*e.g.*, at Scourie), in Scotland; and in other areas where crystalline schists and their associated basic plutonic rocks are developed. Thus pyroxenites, composed of hypersthene and diallage, occur among the older crystalline rocks of Madagascar; and rocks of the same general type are associated with the gabbros, picrites, and peridotites of the Baltimore district of Maryland, U.S., and appear as a member of the corundum-bearing dunite series, which extends through North Carolina and Georgia (*e.g.*, at Webster N.C.). Hornblendites and pyroxenites are also im

portant members of the igneous complex of Peekskill in the N.W. corner of West Chester Co., N.Y.

The most famous eclogites are those of Eppenreuth and Silberbach in the Fichtelgebirge, Bavaria.

### 13. THE PERIDOTITE FAMILY.

The peridotites are ultrabasic rocks without feldspar and composed mainly of olivine, the remaining constituents being one or more ferro-magnesian minerals or members of the iron-ore, spinel and garnet groups. The rocks are plutonic in their geological relations, *i.e.*, they are deep-seated intrusive rocks; or they occur in dykes. They are especially remarkable for their excessively basic character and high specific gravity:  $\text{SiO}_2 = 35-45\%$ ;  $\text{Al}_2\text{O}_3 = 0-6\%$ ;  $\text{FeO} = 8-10\%$ ;  $\text{CaO} = 0-2\%$ ;  $\text{MgO} = 35-48\%$ . Alkalies, only in small quantities. Sp.G. 3.0-3.3. By decomposition they give rise to serpentinous rocks.

The following names have been applied to some of the combinations: **Dunite**, mainly composed of olivine, together with chromite and sometimes garnet (pyrope), so named from the Dun Mountains in New Zealand, where rocks of this type were discovered by Hochstetter in 1859. **Wehrlite**<sup>1</sup> = olivine + diallage. **Saxonite** or **Harzburgite**<sup>2</sup> = olivine + rhombic pyroxene, or bastite resulting from the

<sup>1</sup> Von Kobell (1838).

<sup>2</sup> "Schillerfels."

decomposition of the latter. The former name was proposed by Wadsworth in 1884, on account of the occurrence of these rocks in Saxony; the latter by Rosenbusch in 1885, in reference to the well-known Harzburg occurrence (Baste, near Harzburg). **Lherzolite** = olivine + diallage + bronzite, named after Lake Lherz in the Pyrenees by Delam  therie. **Cortlandtite** = olivine + hornblende + hypersthene; name suggested by G. H. Williams for a type occurring in the "Cortlandt Series" of Peekskill on the Hudson River, N.Y. **Eulysite**<sup>1</sup> = olivine + augite (diallage) + garnet, a type analogous to eclogite.

## ANALYSES OF SOME ULTRABASIC ROCKS.

	<i>Dunite, Dun Mountains, New Zealand. (Reuter.)</i>	<i>Olivine-Diallage Rock, Loch Garabal. (J. H. Player.)</i>
SiO <sub>2</sub> - - -	42.8	38.6
Al <sub>2</sub> O <sub>3</sub> - - -	—	3.7
Fe <sub>2</sub> O <sub>3</sub> - - -	—	7.6
FeO - - -	9.4	7.8
CaO - - -	—	7.7
MgO - - -	47.4	27.7
K <sub>2</sub> O - - -	—	.2
Na <sub>2</sub> O - - -	—	—
Loss on ignition	.6	6.4
	100.2	99.7

Sp. gr. = 3.295.

<sup>1</sup> Name given by A. Erdmann (1849).

## DISTRIBUTION.

Peridotites occur as members of plutonic complexes of a basic character in association with picrites, pyroxenites, hornblendites, gabbros, etc., or as dykes in gneissose areas. Thus in the *British Isles* they appear as dykes in the Archæan gneiss of Sutherland (*e.g.*, S. of Loch Assynt), and of Connemara in Ireland. In the *United States* they are intruded into the gneiss-complex of the "Piedmont plateau" of Maryland<sup>1</sup> (saxonites, lherzolites, and cortlandtites) and N. Carolina (corundum-bearing dunite<sup>2</sup> of Mount Webster); they also form a part of the Peekskill complex in West Chester Co., N.Y. (Cortlandtite). Besides the typical occurrence in the Pyrenees, lherzolite occurs at numerous localities among the old crystalline rocks of Norway and Sweden. Wehrlite and eulysite are found in the Saxon granulite districts, and at Tunaberg in Sweden. A well-characterized cortlandtite has been described from the gneiss-platform underlying the volcanic pile of Kilimanjaro, in E. Africa.<sup>3</sup>

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<sup>1</sup> G. H. Williams.

<sup>2</sup> Julien.

<sup>3</sup> Hatch.

TABLE SHOWING THE RELATION OF THE ULTRABASIC ROCKS.

	<i>Olivine-free.</i>	<i>Olivine-bearing.</i>	<i>With a little Felspar.</i>
Hornblendite	Eclogite	Cortlandtite Eulysite	Hornblende- picrite
Pyroxenite	{ Diallagite Hyper- sthénite Bronzitite Websterite	Wehrlite	{ Picrite
		Saxonite (Harz- burgite)	
		Lherzolite	
		Dunite	

## SERPENTINES.

By alteration under the influence of surface agencies the peridotites give rise to **serpentinous rocks**; and there is no doubt that a great number of serpentines have originated in this way. On the other hand, some serpentines have been shown to be derived from augitic rocks, such as gabbro, diabase, etc., and from hornblendic rocks, as in the case of the Rauenthal serpentine, described by Weigand. In each case the structure of the serpentine generally serves to indicate the nature of the mineral components of the rock from which it is derived. Thus serpentine derived from olivine is found to have a characteristic reticulated or "mesh" structure (see Figs. 62 and 63); that resulting from the alteration of augitic rocks (in the so-called **anti-**

gorite-serpentines), a "netted"<sup>1</sup> or "bladed"<sup>2</sup> structure, due to the fact that the alteration proceeds along cleavage cracks which cross one another nearly at a right angle, thus producing a plexus of bladed forms, bearing a resemblance to network. Finally, the serpentine derived from hornblende-bearing rocks has a "lattice-structure," due to the alteration having taken place along cleavage-cracks intersecting at an angle of  $124^{\circ}$ . Fragments of unaltered olivine, diallage, and bastite (derived from a rhombic pyroxene) are often found imbedded in serpentine, thus furnishing further proof of the mode of origin of these rocks. Again, their mode of occurrence, in dykes and bosses, leads to the same conclusion.

Serpentines are dull green and red, often mottled rocks. They are so soft that they can be easily scratched, or even cut with the pen-knife. Veins of fibrous chrysotile and steatite frequently traverse them. In some cases the serpentinous mineral is disseminated through limestone, as in the rocks known as "ophicalcite." Serpentine is used as an ornamental building-stone, also for the preparation of ornamental objects, *e.g.*, tobacco-jars, vases and other receptacles.

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<sup>1</sup> Ger. *Gestrickte Structur*.

<sup>2</sup> Ger. *Balken-Structur*.

ANALYSES SHOWING THE COMPOSITION OF SERPENTINE, AND ITS MODE OF ORIGIN  
FROM OLIVINE AND PYROXENE.

	<i>Olivine, Snarum. (Helland.)</i>	<i>Serpentine derived from it. (Helland.)</i>	<i>Pyroxene, Montville, New Jersey.</i>	<i>Serpentine derived from it.</i>	<i>Theoretical Composition of Serpentine.</i>
SiO <sub>2</sub> - -	41.32	42.72	54.22	42.38	43.48
Al <sub>2</sub> O <sub>3</sub> - -	0.28	0.06	0.59	0.07	—
Fe <sub>2</sub> O <sub>3</sub> - -	—	—	0.20	0.97	—
FeO - -	2.39	2.25	0.27	0.17	—
CrO - -	0.05	tr.	—	—	—
CaO - -	—	—	24.71	—	—
MgO - -	54.69	42.52	19.82	42.14	43.48
H <sub>2</sub> O - -	0.20	13.39	0.14	14.12	13.04
	98.93	100.94	99.95	99.85	100.00

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*DISTRIBUTION.*

In the *British Isles* serpentines are abundant, occurring in many localities in Cornwall (Lizard district), Anglesey, Ayrshire (Lendalfoot, Ballantrae), Aberdeenshire, Portsoy in Banffshire. In Forfarshire and Perthshire, a great number of dykes<sup>1</sup> of serpentine occur. In the W. of Ireland they occupy a considerable area in Galway and Sligo. The famous green serpentine ("ophicalcite") of Connemara is chiefly from quarries near Clifden and at Lissoughter.

Many of them are probably derived from the alteration of olivine-bronzite rocks like saxonite, as they contain numerous crystals of bastite.

In the *United States* the chromite-bearing serpentines of Maryland and Pennsylvania have been probably produced by the alteration of peridotites and pyroxenites (dunite, etc.). A similar origin is ascribed to the perowskite-bearing serpentine of Syracuse, N. Y.<sup>2</sup>

Rosenbusch ascribes many of the serpentines of the Vosges, the Fichtelgebirge, and the Pyrenees to the alteration of dunites and lherzolites.

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<sup>1</sup> My colleague, Mr. G. Barrow, informs me that the Old Red Conglomerate in Forfar contains at intervals a great number of serpentine boulders. In many of these chrome iron-ore is very abundant.

<sup>2</sup> G. H. Williams.



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