

usually more or less soda, sometimes as much as 10 per cent., and (2) the Triclinic or Plagioclase feldspars (with oblique cleavage angles, or less than 90°), including a soda group with 8 to 12 per cent. of soda, and a lime group with 6 to 20 per cent. of lime. The feldspars form a large part of most igneous rocks. By their decay they form clay, and in that condition enter largely into the composition of the argillaceous stratified rocks, such as shale, mudstone, slate, &c.

Hornblende is a meta-silicate of magnesium, with lime, iron, or manganese, and frequently alumina. The white non-aluminous varieties (tremolite, actinolite, anthophyllite, asbestos) chiefly occur as constituents of such metamorphic rocks as crystalline limestone, gneiss, &c. The black or dark green aluminous varieties enter as essential constituents into the composition of many rocks, as diorite and hornblende slate.

Augite (resembling hornblende in composition) is divisible into two groups. The pale non-aluminous varieties (diopside, sahlite, coccinite, &c.) occur under conditions like those of the pale hornblendes. The dark aluminous or common augite is abundant as an ingredient of some igneous rocks, as basalt. Allied to augite are diallage (important as a constituent of diallage-rock or gabbro), hypersthene, and bronzite. Uralite is the name of a mineral of frequent occurrence among Palæozoic rocks, having the external form of augite and the cleavage of hornblende.

Olivine (an ortho-silicate of magnesium, with part of the magnesium replaced by iron or manganese) is a conspicuous ingredient among the basalt rocks. It appears also to have been the original magnesium constituent of many rocks now altered into serpentine.

Nepheline (a silicate of alumina and soda with a little potash) takes the place of feldspar in some lavas. It likewise occurs among the ejected blocks of Somma, and, in the form of cleolite, among the ancient crystalline rocks of Norway.

Leucite ($K_2Al_2Si_2O_{12}$) is a characteristic ingredient of many Tertiary and recent lavas. It has not been met with among any of the Palæozoic or Secondary igneous rocks, nor ever in association with quartz.

Häuyne and *Nosean* are two minerals allied to garnet, found in some Tertiary lavas.

Mica.—Under this general term are included several species of minerals distinguished by their basal cleavage into thin laminae and by their splendid or silvery lustre. The non-magnesian micas include muscovite or potash-mica, the most abundant of all, and lepidolite or lithia-mica; of the magnesian micas the most important is biotite. Muscovite enters into the composition of granite, gneiss, mica-schist, micaceous sandstone, and many other rocks. Biotite is likewise abundantly distributed among the older crystalline rocks. Lepidomelane is a black mica often found in fine-grained granites. Other species are margarodite—an abundant constituent of many unctuous schists formerly called talc-schists, and haughtonite—which, according to Heddle, is the common mica of the granites in the Scottish Highlands.

Garnet (an aluminous ortho-silicate with lime, magnesia, iron, or manganese) occurs in rhombic dodecahedrons or allied forms, and also massive in many metamorphic rocks, as mica-schist, eclogite, &c.

Epidote (a variable silicate of lime, alumina, iron, or manganese) occurs in yellow or greenish translucent crystals or crystalline masses in many of the older crystalline rocks, though seldom as an abundant constituent. It is probably always an alteration-product.

Tourmaline, in its common black variety, *schorl*, forms with quartz the rock known as schorl-rock, and occurs in some granites, gneisses, schists, and other crystalline rocks.

Zircon (silicate of zirconium) is found as a constituent of zircon-syenite, and more sparingly in other crystalline rocks.

The hydrous silicates have resulted from the alteration of the anhydrous forms. As constituents of rocks they may be grouped into two series:—(1) the aluminous, including the zeolites, and (2) the magnesian, embracing talc, chlorite, serpentine, and their allies.

Zeolites form a numerous genus of minerals distinguished usually by their boiling up before the blowpipe, owing to the escape of their water of crystallization, by their frequent pearly lustre, inferior hardness, and their occurrence in cavities and veins where they have been deposited from solution. They are found as abundant secondary products in many amygdaloids, also in altered limestones and other metamorphic rocks.

Serpentine ($SiO_2, 44.14$; $MgO, 42.97$; $H_2O, 12.89$) is a dull impure, usually green, granular to compact, more rarely foliated, mineral, with a hardness of 3 to 4 or even sometimes 5. Like the other hydrous magnesian silicates it has a soapy or greasy feel. It occurs abundantly in many altered rocks as a pseudomorph after some of the anhydrous magnesian silicates, also as a massive rock forming huge beds often associated with metamorphosed limestones.

Chlorite is a general term including several minerals which agree in possessing a greenish colour, soapy feel, hardness of only 2 to 2.5, and specific gravity of 2.65 to 2.85. It occurs in chlorite slate and in many rocks as an alteration-product.

Talc ($SiO_2, 59$ to 63; $MgO, 30$ to 33; H_2O , from a trace up to 7 per cent.) occurs in hexagonal plates or scales, cleaving readily into flexible non-elastic laminae, but most commonly granular and

massive, white to pale leek or apple-green, with marked pearly lustre on cleavage-planes. It is met with in talc-slate, also frequently in crystalline rocks as a result of the alteration of hornblende, augite, or other anhydrous magnesian silicate.

Dolomite and *Saponite* are soft green hydrous magnesian silicates found as products of alteration in asalt-rocks.

Carbon occurs chiefly as beds in the form of coal, lignite, peat, &c. Graphite, however, is often met with in black or steel-grey splendent scales and granular masses in metamorphosed rocks. Anthracite also takes sometimes the form of black glancing grains or of a diffused fine black dust through certain palæozoic formations.

Carbonates play an important part both as individual minerals and as rock-masses. The three most important are calcite, dolomite, and siderite.

Calcite (carbonate of lime) is one of the most abundant minerals. It occurs crystallized as a secondary product in most rocks which have undergone decomposition, especially where they contain silicates into the composition of which lime enters. It is also found massive as limestone, forming beds having sometimes an aggregate thickness of many hundred feet and an extent of thousands of square miles.

Dolomite (carbonate of lime and magnesia) is likewise both a product of alteration and an original formation. In the former condition it is met with crystallized as bitter-spar in many metamorphic rocks as well as in veins and cavities of unaltered formations. It occurs also as an amorphous granular substance, sometimes replacing calcite, and sometimes in vast beds or masses of original deposit.

Siderite, *Chalybite*, or *Spathic Iron* (carbonate of iron) occurs both crystallized and massive. In the crystallized form it is comparatively unimportant as a constituent of rocks, being then found chiefly in veins and cavities where other alteration-products have been deposited. But in its massive condition it is found mixed with clay and other impurities, and forming beds and nodules which are among the most important ores of iron.

Sulphur, though seldom occurring in large masses, is widely diffused as an accessory ingredient of rocks. It occurs crystallized or finely granular in mineral veins, in nodules of limestone, and other concretions, and in beds of limestone and marl. It also takes the form of a crust in the sublimations of volcanic vents. Its frequent association in Tertiary strata with the remains of lacustrine shells, insects, and plants shows that it has in these cases been formed at ordinary temperatures from aqueous solutions.

Sulphides, combinations of sulphur with the metals, iron, copper, lead, zinc, and a few others, have a wide distribution among rocks. Where aggregated into masses they form mineral veins. It is the iron sulphides which deserve chiefly the attention of the petrographer. They occur in two varieties—*pyrite*, crystallizing in isometric forms, and *marcasite*, in rhombic forms. The former has a remarkably extensive diffusion throughout rocks of all ages, usually as minute crystals and thin streaks, but often in concretions and more massive veins. Marcasite also is abundantly distributed though less so than pyrite. From its greater liability to oxidation the strata through which it is diffused are apt to yield rapidly to the action of the weather, sulphuric acid and different alum compounds being produced.

Sulphates.—The most generally occurring sulphates in rocks are gypsum and barytes. *Gypsum* (hydrous sulphate of lime) in minute monoclinic prisms and needles may be obtained by the evaporation of sea-water, and in larger crystals of the same form it is found in many stratified formations. It likewise occurs as a secondary product in laminar or fibrous veins through rocks of igneous origin. Beds of gypsum, resulting from aqueous deposition, frequently appear interstratified with rock-salt and the associated products of evaporation. The anhydrous sulphate, anhydrite, likewise occurs among rock-salt deposits, but has a much more limited diffusion than gypsum. *Barytes* (sulphate of baryta) almost always occurs in veins or threads running through rocks. It is a common vein-stone in association with metallic ores.

Halite or *Rock-salt* (chloride of sodium) is more widely diffused than was formerly supposed. Microscopic research has shown its presence in the form of cubes in the minute cavities in the quartz of granite and other rocks. It occurs as scattered crystals, generally replaced by clay or some other substance, in many stratified formations. Its chief habitat, however, is in the various saliferous deposits where it takes the form of solid beds of salt.

Fluorite or *Fluor-spar* (fluoride of lime) is essentially a vein-stone, associated with metallic ores, especially with sulphides of lead and zinc. It occurs also in scattered cubes through various crystalline rocks, such as granite, gneiss, porphyrite.

Apatite (phosphate of lime, with fluorine and often chlorine) has been shown by microscopic investigation to have a very wide distribution among crystalline rocks. It occurs in fine needles or stouter hexagonal prisms in a large number of crystalline rocks, as granite, quartz-trachyte, syenite, diorite, basalt, and many others. It also occurs massive as beds among the more ancient geological formations.

Iron oxides.—These are abundantly distributed through rocks of

all ages. *Hæmatite* (peroxide of iron) occurs crystallized in veins through crystalline rocks, also massive and earthy in beds, and sometimes in minute scales (rubin-glimmer) disseminated through the minerals of many crystalline rocks. *Magnetite* (Fe_3O_4) has an extensive diffusion in the form of minute octohedra or grains through crystalline rocks. In some of these rocks indeed, as in basalt, it plays the part of a chief constituent. It also occurs in many metamorphic rocks both scattered in detached crystals and segregated into veins or beds. Titaniferous iron is likewise found as a plentiful ingredient in many crystalline rocks, particularly among the older basalts and dolerites. Hydrous iron oxide or limonite is diffused through almost all rocks. It is the usual brown or yellow colouring substance of minerals, and may be looked for wherever rocks containing iron have been exposed to the weather. It occurs also mixed with clay and other impurities in beds, as in the bog-iron-ore of lakes and marshes.

2. Rocks.

I. General Characters.

A rock may be defined as a mass of mineral matter, composed of one, more usually of several, kinds of minerals,—having, as a rule, no definite external form, and liable to vary considerably in chemical composition. The crust of the earth is built up of rocks, including under this term, not only hard solid masses like granite and limestone, but even all loose incoherent deposits such as mud, soil, peat, and blown sand.

Rocks may be distinguished by external and internal characters.

i. External Characters.

1. *Structure*, or the manner in which the component particles have been built up into the mineral masses called rocks, is the fundamental character. Viewed broadly, there are two leading types of structure among rocks—crystalline or massive, and fragmental.

(a) *Crystalline*—consisting of a network of interlaced crystals and crystalline particles. Sometimes those crystals are large (half an inch or more in length), as in many granites, when the texture is called coarse or macro-crystalline; in other cases they are so minute as not to be discernible with the naked eye, when the texture is micro-crystalline or compact. While the crystalline structure is particularly characteristic of rocks which have crystallized from igneous fusion, it is not altogether peculiar to them. It may be produced by chemical deposit from aqueous solutions, or it may be developed in rocks previously granular by chemical infiltration and metamorphism.

Under the head of crystalline it is usual to include the *glassy* or *vitreous* structure. Rocks possessing this character are natural glasses produced by igneous fusion, such as obsidian and pitchstone. In most of these rocks, however, the process of devitrification may be observed; the glass has evidently become more and more stony as it cooled, by the appearance in it of small spherules, or hairs, or crystals, until in some cases it has become entirely lithoid. These stages are best studied with the microscope, and belong to the internal rather than the external characters.

When larger crystals than those of the compact base are scattered through a rock, the texture is said to be *porphyritic*. Many rocks, when in a melted condition, have had a cellular texture given to them by their imprisoned steam, like the open, cavernous texture of ill-baked bread. Several varieties of this texture are distinguished,—as *vesicular*, when there are comparatively few and small holes; *scoriaceous*, when the cavities occupy about as much space as the solid part, and are of very unequal sizes and forms; *pumiceous*, when the cells are much more numerous than the solid portion, and when, consequently, a piece of the rock may even float in water; *amygdaloidal*, when by subsequent infiltration the cells have been filled up with concretions of calcite, calcedony, zeolite, &c., which, from the elongated flattened form of the cells, are frequently almond-shaped.

Foliated rocks have their crystalline ingredients arranged in more or less defined layers, which usually inosculate. *Schistose* rocks are those where the foliated arrangement has been so produced that the rock splits into rude rough laminae or plates.

Most of the crystalline rocks have resulted from igneous fusion. Some, like limestone, have been formed as deposits in water. The foliated rocks are generally believed to have acquired their peculiar character from the re-crystallization of their ingredients along original divisional planes, such as the lines of deposit.

(b) *Fragmental* or *Clastic*.—These are all derivative from previously formed masses. They vary in texture from coarse masses consisting of accumulated blocks, several feet or even yards in length, to such fine aggregates as only show their secondary origin by microscopic investigation. They are said to be *conglomeratic* when they consist of beds of rounded water-worn pebbles like compacted gravel; *agglomeratic*, when the blocks are large, rounded, or sub-angular, and tumultuously thrown together; *brecciated*, when the fragments are angular and not water-worn. Most clastic rocks are *bedded*, that is, arranged in beds or layers. Each bed may consist of many thin layers or laminae, which, when they enable the rock to split up into thin leaves, give what is called a *shaly* or *fissile* structure. Many fragmental rocks show a *concretionary* structure. When the concretions are like the roe of a fish, and of a calcareous nature, they form the *oolitic* structure; when of larger size, like peas, they give the *pisolitic* structure. There is often also a crystalline structure developed in rocks originally quite fragmental; many limestones, for example, made up originally of water-worn fragments of shells, corals, &c., slowly acquire a crystalline character from the action of percolating and slightly acidulous water. The action of rain on the exposed parts of a recent coral reef produces this change in the dead coral.

2. *Colour*.—This character varies so much even in the same rock, according to the freshness of the surface examined, that it possesses but a subordinate value as a means of discriminating rocks. Nevertheless, when cautiously used, it may be made to afford valuable indications as to the probable nature and composition of rocks. It is in this respect always desirable to compare a freshly-broken with a weathered piece of the rock. *White* indicates usually the absence or comparatively small amount of the metallic oxides, especially iron. It may either be the original colour of the rock, as in chalk and calc-sinter, or may be developed by weathering, as the white crust on flints and on many porphyries. *Black* seldom occurs on a weathered surface of rock. Its existence may be due either to the presence of carbon, when weathering will not change it much, or to some iron-oxide (magnetite chiefly), or some silicate rich in iron (as hornblende and augite). Many rocks (basalts and dolerites particularly) which look quite black on a fresh surface, become red, brown, or yellow on exposure. *Yellow*, as a dull earthy colouring matter, almost always indicates the presence of hydrated peroxide of iron. Bright, metallic, gold-like yellow is usually that of iron-sulphide. *Brown* occurs as the original colour in some carbonaceous rocks (lignite), and ferruginous beds (bog-iron-ore, clay-ironstone, &c.). It very generally, on weathered surfaces, points to the oxidation and hydration of minerals containing iron. *Red*, in the vast majority of cases, is due to the presence of granular peroxide of iron. This mineral gives dark blood-red to pale flesh-red tints. As it is liable, however, to hydration, these hues are often mixed with brown and yellow. *Green*, as the prevailing tint of rocks, occurs among metamorphic schists, when its presence is usually due to some of the hydrous magnesian silicates (chlorite, talc, serpentine). It occurs also among the igneous rocks, especially those of older

geological formations, where some of the hornblende, olivine, or other similar silicates have been altered. Among the sedimentary rocks it is principally due to the proto-silicate of iron in glauconite. Carbonate of copper colours some rocks a bright emerald or verdigris green. The mottled character so common among many stratified rocks is frequently traceable to unequal weathering, some portions being more oxidized than others; while some, on the other hand, become deoxidized from the reducing action of decaying organic matter. To the latter cause may be attributed the circular green spots so often found among red strata.

3. *Lustre*, as an external character of rocks, does not possess the value which it has among minerals. In most rocks the granular texture prevents the appearance of any distinct lustre. Where a rock shows a completely vitreous lustre it will usually be found to consist of a volcanic glass. A splendid semi-metallic lustre may often be observed upon the foliation planes of schistose rocks and upon the laminae of micaceous sandstones. As this silvery lustre is almost invariably due to the presence of mica, it is commonly called distinctively micaceous. A metallic lustre is met with sometimes in beds of anthracite; more usually its occurrence among rocks indicates the presence of metallic oxides or sulphides.

4. *Hardness and Frangibility*.—A rock which can easily be scratched with the nail is almost always much decomposed, though some chloritic and talcose schists are soft enough to be thus affected. Compact rocks which can easily be scratched with the knife, and are apparently not decomposed, may be limestones, or other fragmental masses. Crystalline rocks, as a rule, cannot be scratched with the knife unless considerable force be used. The ease with which a rock may be broken is the measure of its frangibility. Most rocks break most easily in one direction; attention to this point will sometimes throw light upon their internal structure.

5. *Fracture* is the surface produced when a rock is split or broken, and depends for its character upon the texture of the mass. Finely granular compact rocks are apt to break with a *splintery* fracture where wedge-shaped plates adhere by their thicker ends to, and lie parallel with, the general surface. When the rock breaks off into concave and convex rounded shell-like surfaces, the fracture is said to be *conchoidal*, as may be seen in obsidian and other vitreous rocks, and in exceedingly compact limestones. The fracture may also be *foliated*, *slaty*, or *shaly*, according to the structure of the rock. Many black, opaque, compact rocks are translucent on the thin edges of fracture, and afford there, with the aid of a lens, a glimpse of their internal composition.

6. *Feel*.—Practice enables a geologist to discriminate some rocks by the feel of their weathered or fresh surfaces. The hydrous magnesian silicates, as already mentioned, have a marked soapy or greasy feeling under the fingers. Some micaceous schists, with margarodite or an allied mica, likewise exhibit the same character.

7. *Smell*.—Many rocks when freshly broken emit distinctive odours. Those containing volatile hydrocarbons give sometimes an appreciable *bituminous* odour, as is the case with some of the dolerites, which in central Scotland have been intruded through coal-seams and carbonaceous shales. Limestones have often a *fetid* odour; rocks full of decomposing sulphides are apt to give a *sulphurous* odour; those which are highly siliceous yield, on being struck, an *emphyreumatic* odour. It is very characteristic of argillaceous rocks to emit a strong earthy smell when breathed upon.

8. *Specific gravity* is an important character among rocks as among minerals. It varies from 0.6 among the hydrocarbon compounds to 3.1 among the basalts. As already stated, the average specific gravity of the rocks of the earth's crust may be taken to be about 2.5, or from that to 3.0.

9. *Magnetism* is a distinguishing feature of many igneous and some metamorphic rocks. In some cases it exists in such development as powerfully to affect the magnetic needle, so that observations with that instrument among rocks of this character are deceptive. But even when much more sparingly present, the existence of magnetic iron in a rock may be shown by reducing the rock to powder in an agate mortar, washing carefully the triturated powder, and drying the heavy residue, from which grains of magnetite may be extracted with a magnet. This may be done with any basalt.

ii. Internal Characters.

These are revealed chiefly by the microscope and chemical analysis. By the former we learn what are the component minerals of a rock, how they are built up into its mass, and what changes they have undergone. By the latter we are taught the chemical constitution of rocks, and are enabled to bring into close relations rocks which have externally no resemblance to each other, or, on the other hand, to show that rocks externally similar are chemically very distinct.

1. *Microscopic Examination*.—This method of inquiry has made great advances during the last 20 years, especially from the labours of German petrographers. Slices are cut from the rocks to be examined, and after being polished on one side with great care, are cemented by that side with Canada balsam to glass, and are then ground down until they attain the requisite transparency. In this way the minutest features in the structure of a rock can be leisurely studied. By the application of polarized light to these thin slices a marvellously delicate method of petrographical analysis is afforded.

Among the igneous rocks three leading types of microscopic structure have been established, chiefly through the researches of Professor Zirkel of Leipsic:—(1.) Purely-crystalline.—Granite (fig. 1) is a good example, consisting, as it does, entirely of crystals interlaced with each other. (2.) Half-crystalline.—In this division, which embraces most of the eruptive masses, the rocks consist of a non-crystalline amorphous matrix with crystals scattered through it. This matrix may be either (a) entirely glassy (figs. 2 and 3); (b) partly devitrified through separation of peculiar little granules and



FIG. 1.—Microscopic Structure of Rocks.—Purely crystalline.—Section of Granite (X 18 diameter). The white mineral is quartz; that with shading, orthoclase. Some flakes of mica are shown as striated forms.



FIG. 2.—Microscopic Structure of Obsidian.—A volcanic glass, with numerous microlites, which have been drawn out in a general direction during the flow of the melted rock (fluid-structure). (X 18 diameter.)

of the other two. In their most typical condition they

crystallized or amorphous (*nicht individualisirten*) substance, sometimes glassy and sometimes microfelsitic.

Rocks really formed of compacted sediment become sometimes so close-grained that their origin may not be apparent to the naked eye. Their truly derivative character is well brought out by the microscope. In fig. 4, for example, the structure of a piece of fine greywacke is shown. It will be observed that the component particles are not crystals, but broken and more or less rounded fragments of different minerals. The larger white pieces are quartz, the darker portions consist of granules of slate, felspar, and other substances, with a little siliceous ferruginous cement. Many exceedingly compact and even flinty argillaceous rocks are in this way shown by microscopic examination to be formed of water-worn particles.

Rocks which have been so affected by subsequent changes as to acquire a new crystalline character, and to receive the name Metamorphic, exhibit many characteristic features of structure under the microscope.

Limestones, for example, which have been altered into saccharoid marble are found to consist of crystalline grains of calcite, showing the characteristic cleavage of that mineral (fig. 5). The foliated rocks (schists) show a curious blending of the characters of igneous and sedimentary rocks. Thus they have often a distinctly granular structure, resembling that of sedimentary deposits, with, at the same time, an arrangement of the micaceous folia reminding us of the fluid structure of igneous rocks. In fig. 6, for instance, the quartz-grains are to be observed in layers separated by folia of mica which curve and twist like the microlites in an obsidian (compare fig. 2).

Much light has been cast on the origin and history of igneous rocks by microscopic investigation. It is easy, for example, to see in what order the several mineral components have crystallized out of the original glass. Thus in basalt the magnetite has appeared before the augite, in which it has been abundantly enclosed. Again, the movement of the still liquid or viscid rock, when many of its crystals had already been produced, is beautifully shown by the "fluid structure" (fig. 2), where minor crystals and particles are drawn into curving lines which bend round



FIG. 3.—Microscopic Structure of Pitchstone.—A glassy base, with numerous feathered and needle-shaped microlites, and a sanidine crystal.



FIG. 4.—Microscopic Structure of a fragmental rock. Greywacke.



FIG. 5.—Microscopic Structure of Saccharoid white Marble (Carrara).



FIG. 6.—Microscopic Structure of Mica-schist.

the large crystals, and also by the frequent fracture of the larger crystals and the insertion of portions of the general ground-mass of the rock between the separated pieces. That intensely saline water was present during the formation of many crystalline rocks is proved by the presence in their crystals of minute cavities filled with fluid and containing cubes of halite (common salt). Liquid carbonic acid has been observed in such cavities.

Most interesting and important information is likewise afforded by the microscope regarding the subsequent changes which rocks have undergone through the influence chiefly of percolating water. Every gradation of alteration from the fresh mineral to its complete pseudomorph may be observed. In this way many serpentines have been shown to have been originally olivine rocks. It can be seen, too, how certain minerals decay, and to what products their alteration gives rise, even when the general mass of the rock looks to the eye still tolerably fresh. There can be little doubt that the application of microscopic analysis is destined to throw much light upon both the formation and the subsequent history of the sedimentary rocks. These have not yet been so sedulously explored as the igneous groups. The obscure subject of metamorphism is especially open to elucidation by the microscopic method.¹

2. *Chemical Analysis*.—This method of investigation must supplement the work of the microscope. A mere chemical analysis gives the ultimate chemical constitution of a rock, but may afford little clue to its mineral structure, which can only be thoroughly examined by means of the microscopic method. On the other hand, many rocks do not allow of satisfactory determination of their constitution by means of the microscope. For these chemical analysis is, of course, indispensable. But our knowledge of no rock can be considered complete until the rock has been subjected to both processes of investigation.

II. Classification and Description.

A precise yet convenient classification of rocks is still required. We may adopt chemical characters as the basis of arrangement, and group rocks according as they may be sulphates, carbonates, silicates, &c.; but in so doing we place together rocks which, from a geological point of view, have no real affinity. Again, we may select mineralogical composition as the groundwork of the classification; but in this case also great violence may be done in the geological relationships of the rocks. In many respects the long established geological arrangement according to manner of production is a useful one—igneous, aqueous, and metamorphic rocks. There is, of course, the obvious objection to it that it starts upon a preconceived theory of the origin of the rocks, and this objection must be admitted to be serious. Every year, however, is diminishing its force by making us more certain of the mode of formation of different rocks; and, probably, some modification of it will in the end be very generally adopted. In the meantime the most eligible course seems to be to choose a scheme of arrangement which, confessedly imperfect and temporary, shall recognize at once the mineralogical, chemical, and geological relations of the rocks. With this object the following classification will be adopted here.

I. Crystalline and Glassy Non-Fragmental Rocks.

1. Simple Rocks (composed of one mineral substance),—chiefly of aqueous rocks formed from chemical precipitates.

¹ The reader will find this subject fully treated in Zirkel's *Mikroskopische Beschaffenheit der Mineralien und Gesteine* (1873), Rosenbusch's *Mikroskopische Physiographie der Mineralien und Gesteine* (1873-7), Vogelsang's *Krystalliten* (1874), and De la Vallée and Renard, *Sur les roches plutoniques de la Belgique* (Acad. Royale de Belgique, 1876).

2. Compound Rocks (composed of two or more minerals), including (a) Massive series, embracing the various igneous rocks, as granite and lava, and (b) Schistose series, including all the crystalline schists and most of the so-called metamorphic rocks.

II. *Fragmental or Clastic Rocks*, including (a) *Gravel and Sand Rocks*, (b) *Clay Rocks*, (c) *Plant-formed Rocks*, (d) *Rocks formed from animal remains*, (e) *Volcanic Agglomerates and Tuffs*.

I. *Crystalline and Glassy or Non-Fragmental Rocks.*

The great majority of these rocks are original formations; that is, they have not been palpably derived from the destruction of pre-existing rocks, as in the case of the fragmental series. They include all chemical precipitates, whether these possess a distinctly crystalline or a dull granular texture, all rocks which have consolidated from igneous fusion, and all the schistose and metamorphic rocks which, whatever may have been their original character, now possess a crystalline or foliated structure.

1. *Simple Rocks.*

Limestone is a mass of carbonate of lime, either nearly pure or mixed with clay or other impurity. Few rocks vary more in texture and composition. It may be a hard flinty close-grained mass, breaking with a splintery or conchoidal fracture; or a crystalline rock built up of fine crystals of calcite and resembling loaf sugar in colour and texture (fig. 5); or a dull earthy friable chalk-like deposit; or a compact massive finely-granular rock resembling a close-grained sandstone or freestone. The colours, too, vary extensively, the most common being shades of blue-grey and cream-colour passing into white. Some limestones are highly siliceous, the calcareous matter having been accompanied with silica in the act of deposition; others are argillaceous, sandy, ferruginous, dolomitic, or bituminous. To some of these varieties particular names have been assigned:—*Oolite*, a granular limestone built up of small roe-like grains, each of which consists of concentric coats of lime; *Pisolite*, an oolitic or pisolitic limestone where the grains are as large as peas; *Travertine* (*calcareous tufa*), the material deposited by calcareous springs, usually white or yellowish, varying in texture from a soft chalk-like substance or marl to a compact building-stone; *Stalactite*, the calcareous pendant deposit formed on the roofs of caverns, vaults, bridges, &c. The water from which the hanging lime-icicles are derived drips to the floor, and on further evaporation there gives rise to the crust-like deposit known as *stalagmite*. *Hydraulic limestone* contains sufficient silica (and usually alumina) that, when it is burnt and subsequently mixed with water, a compound containing silicate of calcium is formed, which has the property of "setting" or hardening under water. Limestones containing perhaps as much as 25 per cent. of silica, alumina, iron, &c., which in themselves would be unsuitable for many of the ordinary purposes for which limestones are used, can be used for making hydraulic mortar. These limestones occur sometimes in beds like those in the Lias of Lyme Regis, sometimes in nodules like those of Sheppey, from which Roman cement is made. *Cement-stone* is the name given to many pale dull ferruginous limestones, which contain an admixture of clay, and some of which can be profitably used for making hydraulic mortar or cement. *Fetid limestone* (*stinkstein*, *swinstone*) gives off a fetid smell, like that of sulphuretted hydrogen gas, when struck with a hammer. In some cases, as in that at North Berwick, the rock seems to have been deposited by volcanic springs containing decomposable sulphides as well as lime. In other instances the odour may be connected with the decomposition of organic matter. In some quarries in the Carboniferous Limestone of Ireland, as mentioned by Mr Jukes, the freshly broken rock may be smelt at a distance of a hundred yards when the men are at work, and occasionally the stench becomes so strong that the workmen are sickened by it and require to leave off work for a time. *Cornstone* is an arenaceous or siliceous limestone particularly characteristic of some of the Palaeozoic red sandstone formations. *Rottenstone* is a decomposed siliceous limestone from which most or all of the lime has been removed, leaving a siliceous skeleton of the rock. A similar decomposition takes place in some ferruginous limestones with the result of leaving a yellow skeleton of ochre.

Marble is limestone which has acquired a granular crystalline structure. Ordinary statuary marble is a familiar example of this rock. It is white, fine-grained, composed of minute crystalline granules of calcite, and resembles loaf-sugar, whence the term "saccharoid" often applied to it (fig. 5). Fine silvery scales of mica or talc may often be noticed even in the purest marble. Some limestones associated with gneiss and schist are peculiarly rich in

minerals,—tremolite, actinolite, anthophyllite, zoisite, and many other species occurring there, often in great abundance. Many varieties of colour and texture occur among these limestones, as may be seen in the numerous kinds of ornamental marble.

Dolomite (*Magnesian Limestone*) is a massive formation of the carbonates of lime and magnesia, commonly associated with gypsum, rock-salt, and other results of the evaporation of saturated saline waters. It is dull granular to finely crystalline in texture, sometimes full of cavities lined with crystals of dolomite, sometimes aggregated into botryoidal, mammillated, and other concretionary forms. Dolomite also occurs as the result of a chemical transformation of ordinary limestone, carbonate of magnesia replacing carbonate of lime. This process, known as *dolomitization*, was largely insisted on by Von Buch and has been discussed by Bischof. The metamorphic variety of the rock is generally quite crystalline, resembling saccharoid marble in texture, and sometimes even in colour, though yellowish tints are apt to predominate. As a proof of the dolomitization or conversion of limestone into dolomite the fact may be noticed that fossil shells, and other organisms consisting originally of calcite, have been altered into dolomite. On a small scale a similar change may be observed in a limestone where it is traversed by some igneous dyke. Even along the vertical joints of limestone where no igneous matter has penetrated, and where percolating water has probably been the only agent of change, the limestone is changed for some distance on either side into a dull yellow dolomite, locally termed "dunstone."

Gypsum occurs as a rock in the form of beds and concretions as well as in strings and veins. It is associated with red strata, often with dolomite, rock-salt, and anhydrite.

Rock-salt, massive chloride of sodium, occurs in seams sometimes 60 to 90 feet in thickness, rudely crystalline, usually stained red from an admixture of red sediment, like that of the red clays and sandstones among which the salt-beds occur.

Ironstone.—Besides the iron ores met with in veins associated with other accompaniments of metalliferous lodes, there are many which were doubtless formed as chemical precipitates on the floors of lakes and other sheets of water. Some of these deposits (either peroxide or carbonate of the protoxide of iron) arise from precipitation in water or on moist ground where organic matter, especially of vegetable origin, has decomposed. The hard crust of hydrous peroxide of iron which forms under wet or boggy soil (*moor-band pan*, *bog-iron-ore*) is an example of such a deposit now in course of formation. Where the peroxide has been reduced and become carbonate, it occurs in beds or nodules usually mixed with a variable proportion of clay (*clay ironstone*), and sometimes with a good deal of carbonaceous matter from associated vegetation (*black-band ironstone*). Clay iron-ore is one of the most valuable ores of the metal, and occurs largely in beds and nodules in the Carboniferous system, as well as in parts of the Jurassic series in Britain. In some of the oldest geological formations extensive beds occur of hæmatite and magnetite.

Serpentine.—This mineral occurs massive, forming large bands of rock. In some places it may have been an original deposit from oceanic water, comparable to the glauconite found filling the chambers of *Foraminifera*, and occurring extensively both in old geological formations and on the present ocean-floor. The serpentine associated with the gneisses and other crystalline rocks have had this origin assigned to them by Sterry Hunt. There can be no doubt, however, that many, probably most, serpentines are the results of the alteration of pre-existing rocks. Tschermak pointed out that much serpentine has been produced by the hydration and alteration of olivine, and this view has been confirmed by illustrations from all parts of the world. In many serpentines the forms of the original crystals of olivine may still be detected. Hence the difficulty in understanding how there could be intrusive masses of serpentine—a hydrated magnesian silicate—is now removed, for we see that the original olivine-rocks may have been intruded as molten masses which would preserve their external characters as eruptive rocks though undergoing an internal conversion into serpentine. With many Palaeozoic limestones, and more particularly with the crystalline beds which occur among the schistose rocks, serpentine is frequently associated. Some of this may represent the result of an alteration of dolomite, though, as above stated, it may with more probability be connected with some original oceanic deposit of a magnesian silicate.

2. *Compound Rocks.*

Nearly the whole of the rocks in this division consist of two or more minerals. A few examples occur, however, where, at least in some parts of their mass, the rocks are formed of only one mineral. Strictly speaking, these exceptions should be placed among the simple rocks. But they are so closely linked with the compound masses that to separate them would do much more violence to geological continuity than any harm likely to arise from the present

arrangement. Besides, a rock which, like obsidian, may appear quite simple at one place may, at a short distance, show the presence of other minerals entitling it to a place among the compound rocks.

(a) *Massive Rocks*.—This important division consists almost entirely of rocks which have resulted from igneous fusion. Considered from a chemical point of view, these rocks may be described as mixtures in different proportions of silicates of alumina, magnesia, lime, potash, and soda, usually with magnetic iron and phosphate of lime, and, in a great group of rocks, with an excess of silicic acid, existing as free quartz. Taking this last feature as a basis of arrangement, some petrographers have proposed to divide the igneous rocks into an acid group, including such rocks as granite, quartz-porphry, and quartz-trachyte, where the percentage of silica ranges from 60 to 75, and a basic group, typified by such rocks as leucite-lava and basalt, where the proportion of silica is only about 50 per cent.

In the vast majority of igneous rocks the chief silicate is a felspar,—the number of rocks where the felspar is represented by another silicate (as leucite or nepheline) being comparatively few and unimportant. As the felspars group themselves into two great series, the monoclinic or orthoclase, and the triclinic or plagioclase, the former with, on the whole, a preponderance of silica, and as the minerals occur under tolerably distinct and definite conditions, it has been proposed to divide the felspar-bearing massive rocks into two series,—(1) the orthoclase rocks, having orthoclase as their chief silicate, and often with free silica in excess, and (2) the plagioclase rocks, where the chief silicate is some species of triclinic felspar. The former series corresponds generally to the acid group above mentioned, while the plagioclase rocks are on the whole decidedly basic. It has been objected to this arrangement that the so-called plagioclase felspars are in reality very distinct minerals, with proportions of silica, ranging from 43 to 69 per cent.; soda from 0 to 12; and lime from 0 to 20. But in the state of minute subdivision in which the minerals occur in many igneous rocks, it is often scarcely possible to determine the species of felspar.

Without attempting here any formal classification, according either to relative proportion of silica or to the distinguishing felspar, it may be sufficient to arrange the following description of the massive rocks in a continuous series, with the most typical acid or orthoclase rocks at the beginning, and the basic felsparless rocks at the end.

Granite is a thoroughly crystalline-granular admixture of felspar, mica, and quartz. The felspar is chiefly orthoclase, but striated triclinic felspars (as oligoclase and albite) may often be observed in smaller quantity. The mica in most granites seems to be the potash or muscovite variety, usually of a white silvery aspect; sometimes it is dark brown or black, and belongs to biotite (magnesian mica) or lepidomelane. Dr Heddle finds the common mica of the granites in the Scottish Highlands to be a new variety, which he has called haughtonite. The quartz may be observed to form a kind of paste or magma wrapping round the other ingredients (see fig. 1). It is only in cavities of the granite that the component minerals occur as independent well-formed crystals, and there too the accessory minerals are chiefly found, such as beryl, topaz, tourmaline, &c.

Microscopic examination of granite by Sorby and other later observers has shown that the quartz is full of cavities containing liquid, sometimes in such numbers as to amount to a thousand millions in a cubic inch. The liquid in these cavities appears usually to be water containing chlorides of soda and potash, with sulphates of potash, soda, and lime.

Granites vary in texture from extremely coarse crystalline masses, with crystals an inch or more in length, to fine granular rocks which pass into elvanite or felsite. They are sometimes porphyritic, with large scattered orthoclase crystals. The variety known as graphitic granite is distinguished by the way in which the quartz is crystallized through the felspar in imperfect or hemihedral shells arranged with their longer axes generally parallel, so as to produce on cross fracture the appearance of Hebrew characters.

The mean of eleven analyses of granites made by Dr Haughton

gave the following average composition:—Silica, 72.07; alumina, 14.81; peroxide of iron, 2.22; potash, 5.11; soda, 2.79; lime, 1.63; magnesia, 0.33; loss by ignition, 1.09; total, 100.05,—with a mean specific gravity of 2.66.

Granite occurs (1) as an eruptive rock, forming huge bosses, which rise through other formations both stratified and unstratified, and sending out veins into the surrounding and overlying rocks, which usually show evidence of much alteration as they approach the granite; (2) connected with true volcanic rocks, and forming probably the lower portions of masses which flowed out at the surface as lavas; and (3) in the heart of mountain chains and elsewhere, so intimately connected with metamorphic rocks as to suggest that it is itself a final stage of the metamorphism of rocks. Granite is thus a decidedly plutonic rock; that is, it has consolidated at some depth beneath the surface, and in this respect differs from the superficial volcanic rocks, such as lavas, which have flowed out above ground from volcanic orifices.

Quartz-porphry, Felsite-porphry, Felstone, Felsite.—These names are given to different conditions under which orthoclase and quartz unite to form a massive eruptive rock. When the quartz forms well-marked grains, blebs, or crystals, the rock is a quartz-porphry; when the felspar and quartz are so intimately mixed as to appear to the eye as a homogeneous matrix, the rock is called by one of the other epithets.

The base of the rock, whether in the form of quartz-porphry or felsite, is usually exceedingly compact or even flinty in texture. Under the microscope it shows the microfelsitic character, the true nature and origin of which is still the subject of much discussion among petrographers. When the quartz occurs in forms visible to the naked eye it usually appears as round or irregular grains, varying in size from mere specks up to pieces as large as a pea or larger. Less frequently it occurs definitely crystallized, and sometimes in perfect doubly terminated pyramids.

Besides the orthoclase of the diffused matrix, this mineral occurs in crystalline fragments and crystals, which sometimes reach to the length of an inch or more, so as to give a markedly porphyritic character to the rock. Triclinic felspars usually occur, though perhaps not so commonly as in granite. Mica and hornblende are among the most frequent of the minerals which accompany the two essential constituents, while apatite, magnetite, and pyrite are not infrequent accessories.

The colours of quartz-porphry and felstone depend chiefly upon those of the felspar,—flesh-red, reddish-brown, purple, yellow, bluish or slate-grey, and even white, being in different places characteristic. The presence of much mica or hornblende gives dark grey, brown, or greenish tints. It will be observed in this, as in other rocks containing much felspar, that the colour, besides depending on the hue of that mineral, is greatly regulated by the nature and stage of decomposition. A rock weathering externally with a pale yellow or white crust may be found to be quite dark in the central undecayed portion.

The flesh-red quartz-porphry of Dobritz, near Meissen, in Saxony, was found by Rentsch to have the following chemical composition:—Silica, 76.92; alumina, 12.89; potash, 4.27; soda, 0.68; lime, 0.68; magnesia, 0.98; oxide of iron, 1.15; water, 1.97; total, 99.54,—specific gravity, 2.49.

Besides the differences of colour already referred to, minor varieties in composition are produced by the relative abundance and size of the felspar crystals, and by the presence of mica (*micaceous quartz-porphry*, *micaceous felstone*, or *felsite*), hornblende (*hornblendic quartz-porphry* or *felstone*), or other accessory ingredient. The variety called *minette* consists of a felsite base with crystals of orthoclase and dark mica, and may be regarded as a micaceous felstone, bearing the same relation to the acid felspar-rocks (felstones) that mica-porphryite does to the more basic forms (porphyrites). When the base is very compact, and the felspar-crystals well defined and of a different colour from the base, the rock sometimes takes a good polish, and may be used with effect as an ornamental stone. In ordinary language such a stone is classed with the "marbles," under the name of "porphyry."

Closely related to the quartz-porphries and felstones, of which, indeed, it can be regarded only as a variety, comes the rock known as *elvan* or *elvanite*. This is a Cornish term for a crystalline-granular mixture of quartz and orthoclase, forming veins which proceed from granite, or occur only in its neighbourhood and are evidently associated with it. It forms an immediate stage between granite and quartz-porphry.

Quartz-porphry and the other varieties included under this species occur (1) with plutonic rocks, as eruptive bosses or veins, often associated with granite, from which, indeed, the elvanite, as just stated, may be seen to proceed directly; of frequent occurrence also as veins and irregularly intruded masses among highly convoluted rocks, especially when these have been more or less metamorphosed; (2) in the chimneys of old volcanic orifices, forming there the "neck" or plug by which the vent is filled up; and (3) as truly volcanic rocks which have been erupted at the surface in the form of flows of lava, either (a) submarine, as in the felstones of