

1. During their growth they deoxidize carbon dioxide and water, and reduce to the solid state in their tissues, carbon and the permanent gases oxygen, hydrogen, and nitrogen; and after death, through the accumulation of the half-decayed tissues in favorable localities, — marshes, etc., — these elements are added to the solid crust of the earth in the forms of coal and bitumen.

2. During the decomposition, *i. e.*, oxidation, of the organic tissues, the iron existing everywhere in the soil is partially deoxidized, and, being thus rendered soluble, is removed by rain-water and concentrated in low places, forming beds of iron ore.

3. Through the agency of aquatic organisms, certain mineral substances are being constantly removed from the water and deposited upon the ocean-floor, forming various calcareous and siliceous rocks.

We now bring the review of the aqueous or superficial agencies to a conclusion by noting once more that the great geological results accomplished by *air, water, and organic matter or life* are: (1) *Erosion*, or the wearing away of the surface of the land; and (2) *Deposition*, or the formation from the debris of the eroded land of two great classes of stratified rocks, — the mechanically-formed or fragmental rocks, and the chemically and organically-formed rocks.

STRUCTURAL GEOLOGY.

Structural Geology treats of the different kinds of minerals and rocks, and rock-structures; and, in its broadest aspect, takes account of the constitution and contours of the entire crust of the earth. This department of geology embraces two distinct sciences: Mineralogy, which treats of the composition, structure, and physical properties of homogeneous chemical compounds or minerals: and Petrography, which treats of the composition, structure, and distribution of rocks, or the massive, impure aggregates of minerals.

The mineralogical collections are in Room A and the Petrographical collections in Room B. The Guide to Mineralogy has been published as a separate volume, and this volume embraces the second division, only, of Structural Geology, — Petrography.

Petrography, the science of rocks, is conveniently divided into two subordinate sciences, Lithology and Petrology. Lithology is an in-door science; we use the microscope largely, and work with hand specimens or thin sections of the rocks, observing the composition and those small structural features which go under the general name of texture. In Petrology, on the other hand, we consider the larger kinds of rock-structure, such as stratification, jointing, folds, faults, cleavage, etc.; and it is essentially an out-door science, since to study it to the

best advantage we must have, not hand specimens, but ledges, cliffs, railway-cuttings, gorges, and mountains.

The lithological collections occupy the wall-cases (sections 1—23) in Room B and the petrological collections the two large central or floor-cases.

LITHOLOGY.

A *rock* is any mineral or mixture of minerals occurring in masses of considerable size. This distinction of size is almost the only one that can be made between rocks and minerals, and that is very indefinite. A rock, however, whether composed of one mineral or several, is always an aggregate; and therefore no single crystal or mineral-grain can be properly called a rock.

Still, the study of minerals is not the same, by any means, as the study of rocks. In mineralogy each mineral species is regarded as a definite chemical compound—the composition being expressible by a chemical formula—and the aim is to study each mineral separately and to observe its chemical and physical characters in the purest state in which it occurs in nature. The mineralogist likes to find minerals separate and pure, and seeks to avoid mixtures.

In lithology, on the other hand, we deal mainly with mixtures of minerals, and the notion of definite composition has to be almost entirely given up; for there are only a very few minerals, such as quartz and calcite, which by themselves form masses large enough to be called rocks (*simple rocks*, such as limestone, quartzite, etc.), most rocks being composed of several minerals more or less intimately mixed in small particles (*mixed rocks*, such as granite, mica schist, etc.). We seldom find anything quite pure in lithology, but nature mixes the minerals in ever varying proportions.

Since rocks are mixtures or aggregates of minerals, it follows that they must be usually more complex compounds than minerals; for the various chemical elements are first combined to make minerals, and then the minerals are combined to form rocks. The combination of the elements in minerals is chemical and definite; while the combination of the minerals in rocks is mechanical and indefinite.

Rocks are composed of solid matter, but the particles are not necessarily consolidated or cemented together. Thus, the loose sand and gravel on the beach are as truly rocks, in the geological sense, as sandstone and conglomerate. Clay is a rock as much as slate or granite.

Lithology, like mineralogy, is either comparative or systematic, according as we make the properties of rocks, or the individual kinds or species, families, and classes of rocks, the special subject of investigation; and in a complete educational arrangement *Comparative Lithology* properly precedes *Systematic Lithology*.

COMPARATIVE LITHOLOGY.

The natural characteristics or properties of rocks are nearly all comprised under the two general heads of *composition* and *texture*.

COMPOSITION OF ROCKS.

Rocks are properly defined as large masses or aggregates of mineral matter, consisting in some cases of one and in other cases of several mineral species. Hence it is clear that the composition of rocks is of two kinds: chemical and mineralogical.

Chemical Composition of Rocks.

The elementary substances of which rocks are chiefly composed, which make up the main mass of the earth so far as we are acquainted with it, number only fourteen:—

Non-Metallic or Acidic Elements.—Oxygen, silicon, carbon, sulphur, chlorine, phosphorus, and fluorine.

Metallic or Basic Elements.—Aluminum, magnesium, calcium, iron, sodium, potassium, and hydrogen.

The elements are named in each group in about the order of their relative abundance; and to give some idea of the enormous differences in this respect it may be stated that two of the elements—oxygen and silicon—form more than half of the earth's crust.

It is also noteworthy that, with the exception of iron, all the metallic elements named are light and light-colored. Iron is the great coloring agent in rocks, and all the heavier rocks contain a large proportion of iron. Examples of all these rock-forming elements will be found in the complete series of the chemical elements in the first or north floor-case in the mineralogical room (A).

Mineralogical Composition of Rocks.

The fourteen elements named above are combined to form about fifty minerals with which the student of lithology should be acquainted, although not more

¹ These two sections are to be regarded as one, although each has a separate series of numbers. The specimens on each shelf are continuous from section 1 to section 2.

than one half of these are of the first importance. Typical specimens of the principal species are arranged in sections 1 and 2. These rock-forming minerals may, for lithological purposes, be classified in several ways:

1. Lithologists, when considering chiefly the definitions of rocks, distinguish their constituents as *essential* and *accessory*.

The essential constituents of a rock are those minerals which are essential to the definition of the rock. For example, we cannot properly define granite without naming quartz and orthoclase; hence these are essential constituents of granite; and if either of these minerals were removed from granite it would not be granite any longer, but some other rock. But other minerals, like tourmaline and garnet, may be indifferently present or absent; it is granite still. Hence they are merely accidental or accessory constituents. They determine the different *varieties* of granite, while the essential minerals make the *species*. This classification, of course, is not absolute, for in many cases the same mineral forms an essential constituent of one rock and an accessory constituent of another. Thus, quartz is essential in granite, but accessory in diorite.

2. When considering chiefly the origin and subsequent history of rocks, it is more important to distinguish their constituents as *original* and *secondary*.

The original constituents of a rock are those minerals of which it was composed when first formed; while the secondary constituents are those species which have resulted from the decomposition or alteration of the original constituents. With the eruptive rocks, especially, this distinction is often an important one, since the present composition is, with the older eruptives at least, often widely different from the original composition. This classification, like the preceding, holds only in

a general way, the same mineral, in many cases, occurring as an original constituent of certain rocks and as a secondary constituent of other or even of the same rocks. It would manifestly be impossible to fully illustrate these classifications without duplicating the series of minerals; the labels, however, state distinctly for each species whether, in its usual mode of occurrence, it is chiefly essential or accessory, and whether it is chiefly original or secondary. These distinctions will also receive due attention in the following descriptions of the rock-forming minerals; and in the systematic collection of rocks both the original and secondary constituents of each group of rocks, as well as the essential and accessory constituents, will be fully illustrated.

The actual arrangement of the minerals is essentially mineralogical, but with special reference to their occurrence in rock masses, the object being to keep together species that are naturally associated in the rocks and are hence closely related as rock constituents.

Besides the chemical composition of the minerals, which it is impracticable to illustrate in a satisfactory way, and the more obvious morphologic and physical properties, such as form, color, luster, etc., which may be readily appreciated in the specimens themselves, and are fully explained in the mineralogical collection and guide, there are in most of the species important optical or structural features which are essentially microscopic. In fact these features, although throwing much light upon the origin and history of rocks, usually require polarized light as well as the compound microscope for their exhibition. The only resource, therefore, is either to wholly omit them, which their importance forbids, or to illustrate them as far as practicable pictorially. This is the object of the diagrams and colored drawings interspersed through the collection.

SILICA AND SILICATES.—This is by far the most important class of rock-forming minerals. It includes

free silicic acid or silica in the forms of quartz and opal, and the principal silicates, or the minerals formed by the union of silica with various metals. The silicates embrace more than one fourth of the known species of minerals and, omitting quartz and calcite, all of the really important constituents of rocks. They may be naturally divided into two great groups, the *basic* and *acidic*.

These groups are not sharply defined, on the contrary there is a perfectly gradual passage from one to the other; and yet this is, for geological purposes at least, a very natural classification. The dividing line falls in the neighborhood of 60 per cent. of silica: *i. e.*, all species containing this proportion of silica or less are classed as basic, since in them the basic elements predominate; while those containing more than 60 per cent. of silica are classed as acidic, because their characteristics are determined chiefly by the acid element or silica. The principal bases occurring in the silicates, named in the order of their relative importance, are aluminum, magnesium, calcium, iron, sodium, and potassium; and of these, magnesium, calcium, iron, and usually sodium, are especially characteristic of basic species. Iron is the heaviest base and consequently the basic must be, as a rule, heavier as well as darker colored than the acidic silicates. All this is of especial importance because in the rocks nature keeps the basic and acidic silicates separate in a great degree.

A more convenient division, and the one chiefly observed in the arrangement of the specimens, is that distinguishing the anhydrous from the hydrous silicates. These two classes are rarely mingled in the rocks; and this distinction is only second in importance to, and more practicable than, that between the basic and acidic silicates.

Silica.—This extraordinarily abundant and protean substance occurs in crystalline forms, as quartz, tridymite, etc., and amorphous, as opal.

Quartz.—The varieties of quartz are very numerous, but they are naturally divided into two groups, as follows, only the most abundant, rock-forming varieties in each group being included in this collection:—

1. *Phenocrystalline* or *vitreous* varieties, including the distinctly crystallized quartz or rock-crystal (1), vitreous quartz (6), granular quartz (2), milky quartz (7), etc. These varieties best represent quartz in its occurrence as an original and essential constituent of such abundant rocks as granite, mica schist, sandstone, etc.

2. *Cryptocrystalline* or *compact* varieties, including chalcedony (4), agate (8), flint (11), chert (12), etc. These varieties are, to a large extent, secondary and accessory constituents of the rocks in which they occur.

Phenocrystalline quartz occurs chiefly in hexagonal crystals, or in irregular vitreous masses or grains, devoid of cleavage; while the cryptocrystalline varieties are commonly characterized by botryoidal, concretionary, geoditic, and banded forms, all of which as well as the physical properties are fully explained in the mineralogical guide.

The figures (3), represent on a highly magnified scale, the numerous liquid inclusions which are the most important and constant microscopic feature of crystalline, rock-forming quartz. The right hand figure shows the usual arrangement of the inclusions in rows or bands; while the other figure, which is more highly magnified, shows the forms of the individual inclusions more accurately and the inclosed bubbles and crystals.

The enclosed liquids are usually either liquid carbon dioxide, water, or aqueous solutions, the nature of the dissolved salt being often indicated by a small crystal of it which separates from the solution under diminished temperature or pressure. The liquid usually fails to fill the cavity, the vacant space appearing like the bubble in a spirit-level and indicating that the quartz probably crystallized at a high temperature, the liquid which became enclosed in the growing crystal shrinking on subsequent cooling.

Quartz is, next to common feldspar, the most important constituent of the earth's crust; and it is also the hardest and most durable of all common minerals. It is not decomposed by the action of the elements; and, being very hard and devoid of cleavage, the same mechanical wear which, assisted by more or less chemical decomposition, reduces softer minerals to an impalpable powder or clay, leaves quartz chiefly in the form of sand and gravel.

Opal.—This species is like quartz in composition, except that it contains from 3 to 20 per cent. of water. It is absolutely devoid of crystalline structure, but presents a series of varieties similar to those of cryptocrystalline quartz. It is softer, lighter, and more soluble than quartz; and usually shows a tendency to slowly lose its water and change into quartz. The more beautiful and interesting varieties, such as precious opal, are very rare and of little geological importance. The semi-opal (5) resembles jasper and chalcedony and is found under similar conditions. But the specially important geological varieties of opal are *geyserite* or *siliceous tufa* (9), which is hydrated silica or opal deposited by hot springs and geysers; and *tripolite* or *diatomaceous earth* (10), which

is opal in the form of the microscopic siliceous shells of some of the lowest types of animals and plants.

Anhydrous Silicates.—This division of the silicates is made up, so far as the rock-forming kinds are concerned, of four important and natural groups of species which occur chiefly as essential constituents of rocks: *feldspars*, *feldspathides*, *micas*, and *hornblende* and *augite*; and one large group of accessory constituents. These groups are named here in approximately their order of importance or abundance; and in this order they exhibit a gradation in the proportions of alkalies (potash and soda) which the species contain, the feldspars being richest in alkalies, while the accessory species contain little or no alkalies.

Feldspars.—Feldspar is the name, not of a single species, but of a family of minerals. There are six principal feldspars, all of which are important constituents of rocks. The enormous abundance of the feldspars is expressed in the name, which is the German for *field-spar*. The name is sometimes spelled *felspar*, which is the German for *rock-spar*, implying that these are the common spars or minerals of the rocks and fields. The feldspars, with the kaolin or clay which results from their decomposition, undoubtedly form more than one half of the entire crust of the earth.

The feldspars may be classified chemically as follows:

Orthoclase (2-8), silicate of aluminum and potassium, or potash feldspar.

Albite (9-10), " " " " sodium, or soda feldspar.

Anorthite (15), " " " " calcium, or lime feldspar.

Oligoclase (12), " " " " sodium and calcium, or soda-lime feldspar.

Andesite (13), " " " " and equal parts of sodium and calcium.

Labradorite (14, 16), " " " " calcium and sodium, or lime-soda feldspar.

This complex arrangement can be greatly simplified for geological purposes. Orthoclase crystallizes in the monoclinic system and all the other feldspars in the triclinic system. With the exception of albite, which is a comparatively rare species, the triclinic feldspars all contain less silica than orthoclase, *i. e.*, are more basic. This is shown by the subjoined table giving the average composition of each of the feldspars.

	SiO ₂	Al ₂ O ₃	K ₂ O	Na ₂ O	CaO	Total.
Orthoclase,	65	18	17	—	—	100
Albite,	68	20	—	12	—	100
Oligoclase,	62	24	—	9	5	100
Andesite,	58	27	—	7	8	100
Labradorite,	53	30	—	4	13	100
Anorthite,	43	37	—	—	20	100

The triclinic or basic feldspars are commonly associated with each other and with other basic minerals, but are rarely important constituents of rocks containing much orthoclase. In other words, the distinction of orthoclase from the basic feldspars is important and comparatively easy; while the distinction of the different basic feldspars from each other is both unimportant and difficult. Hence, in lithology it is convenient and nat-

ural to class all the basic feldspars together, as if they were one species, under the name *Plagioclase*, which refers to the oblique cleavage of these feldspars, and contrasts with *Orthoclase*, which refers to the right-angled cleavage of that species.

Orthoclase, or the common feldspar, is probably equal in abundance to *plagioclase*, i. e., to all the basic feldspars, taken together. Its principal rock-forming varieties are well shown in the specimens (2-8). The crystals (2, 4) are usually simple monoclinic forms; but the double crystals or Carlsbad twins (3) are almost equally characteristic, and afford a ready and certain means of distinguishing orthoclase from plagioclase. The rectangular cleavage of orthoclase (5) is, perhaps, its most important feature. The specimen of trachyte (6) shows large Carlsbad twins of *sanidin*, a clear variety of orthoclase which is a very important constituent of volcanic rocks. The compact form of orthoclase is best represented by felsite (7), and the glassy or perfectly amorphous form by obsidian (8). Felsite and obsidian are volcanic rocks chiefly composed of orthoclase, which have solidified too suddenly to permit distinct crystallization. The most characteristic microscopic features of orthoclase are represented in the figures (1). The one on the left hand shows a peculiar striping supposed to be due to the interlamination of orthoclase and albite, and the other a curious cross-hatching or reticulation with brilliant colors, often observed in orthoclase in polarized light.

Albite, although triclinic in crystallization, is the most acidic of all the feldspars; and it is so generally associated with orthoclase in the rocks, that it may be fairly classed with that

species. The specimens represent both the coarsely crystalline (9) and the massive (10) forms of albite, the former showing the parallel lines or twinning striae which indicate, without farther examination, that it is a triclinic species.

Plagioclase is represented in the collection by all of its component species, but the two specimens of *Labradorite* (14, 16) are decidedly the most typical examples. They show that plagioclase is contrasted with orthoclase and albite by its darker color. The coarsely crystalline or cleavable specimen (14) shows the beautiful play of colors, which is sometimes observed in other feldspars, but is especially characteristic of this species, and the straight, parallel lines or bands due to repeated twinning. These twinning striae are exceedingly characteristic of plagioclase; and, although often so fine as to be invisible to the unassisted eye, they are strongly contrasted under the microscope in polarized light, and afford the best means of distinguishing orthoclase and plagioclase.

The figure (11) represents typical sections of plagioclase magnified in polarized light. The extremely important fact that plagioclase is decomposed or kaolinized when exposed to the weather much more rapidly than orthoclase is illustrated by the weathered specimens of granite (17) and diabase (18), from this vicinity, for orthoclase is the principal constituent of the former rock and plagioclase of the latter. These specimens have probably been exposed to the weather for equal times; and yet the granite shows but little change, while the diabase, which was also once a firm, hard rock has been thoroughly rotted and reduced to a fine soil.

Feldspathides.—The minerals of this group are called feldspathides for the reason that, while strikingly

unlike the true feldspars in crystallization, they are almost identical with them in composition and physical characters, and, furthermore, they commonly appear as substitutes for the feldspars in the rocks. They are far less abundant than the feldspars, and are, on the average, more basic in composition and association, occurring chiefly in the more basic eruptive rocks. Only the more abundant, rock-forming feldspathides are represented in the collection (21-26).

Nephelite, which is similar to albite in composition, except that it contains much less silica, crystallizes in hexagonal prisms, and presents two distinct varieties. The typical nephelite (25) forms small glassy crystals in volcanic rocks; while the variety *elaeolite* (23) is coarsely crystalline or cleavable, translucent, has a greasy luster and is found chiefly in the older plutonic rocks. Typical nephelite stands in the same relation to *elaeolite* that *sanidin* does to *orthoclase*.

Sodalite (26) and *Hauynite* (24), the latter being represented by the single blue crystal in the dark colored lava, are rarer, isometric species occurring under much the same conditions as nephelite.

Leucite (21), which contains the same elements as *orthoclase*, but with only 55 per cent. of silica, is especially interesting on account of its very perfect isometric form.

The crystals are tetragonal trisoctahedrons; but the shaded figure (22), which represents the appearance of a thin section in polarized light, shows in the double refraction that the optical characters are inconsistent with this form, since all crystals in this system should, theoretically, be strictly singly-refracting. When the *leucite* crystals are heated, however, the isometric

symmetry is developed internally as well as externally, indicating that the abnormal optical characters are the consequence of strains due to cooling from the high temperatures at which the crystals were formed. The other figure shows the concentric arrangement of the enclosed crystallites.

Micas. Mica, like feldspar, is not the name of a single mineral, but of a group or family of minerals, including some half-dozen species (27-32). Four of these are represented in the collection, although only two—*muscovite* and *biotite*—are of the first importance as constituents of rocks. All the micas are basic silicates of alumina and potash; and certain kinds are also rich in magnesia and iron. The crystallization is monoclinic; but all the species occur commonly in flat rhombic or hexagonal forms (27). Undoubtedly the most important and striking characteristic of the whole mica family is the remarkably perfect cleavage parallel with the basal planes of the crystals (28-29), and the wonderful thinness and elasticity of the cleavage lamellae. The cleavage contrasts the micas with all other common minerals, and makes their certain identification one of the easiest things in lithology.

Muscovite is distinctly more acidic than *biotite*, both in composition and in associated minerals. It contains little or no iron and magnesium as against 20 per cent. of oxide of iron and 17 per cent. of magnesia in *biotite*. The large proportion of iron in *biotite* fully explains the difference in color, which is usually so marked that *muscovite* is known as the *white* mica and *biotite* as the *black* mica.

The crystal of *muscovite* (27) represents equally well the form of *biotite*. The large plates (28-29), as well

as the distinct crystals of mica, are found only in veins, the mica in common rocks, such as granite, gneiss, mica schist (30), etc., occurring for the most part in thin scales of indefinite or irregular outlines. Muscovite is the mica of commerce, being colorless and clear in thin plates.

Phlogopite (31), and *lepidomelane* (32), are much rarer species, although they are occasionally important rock-forming minerals. *Phlogopite* is a highly magnesian mica, usually of a brownish color, and is found chiefly in crystalline magnesian limestone, dolomite, serpentine, and other magnesian rocks. *Lepidomelane* is only slightly magnesian, but it is distinctly a ferruginous mica, containing about 30 per cent. of iron oxide. It resembles biotite, and occurs in various granitic and metamorphic rocks.

Hornblende and Augite.—These two minerals are the common, rock-forming varieties of the species *Amphibole* and *Pyroxene*, which may be described as very similar complex silicates, similar in composition, crystallization and physical characters, and in their numerous varieties depending on variations in composition and structure. These varieties include, besides hornblende and augite, which are black, the green varieties, actinolite, sahlite, etc., and the white varieties, tremolite, diopside and asbestos. All these varieties are of interest to the mineralogist, but *hornblende*, the black, aluminous, and highly ferruginous variety of amphibole, and *augite*, the corresponding variety of pyroxene, are the only ones that are sufficiently abundant to be of special geological interest. Hence the geologist naturally substitutes the names of

these two important varieties for the names of the species to which they belong.

Hornblende and *Augite* rank in abundance with the black and white micas. But they are not so easily distinguished as the micas, for, as already indicated, they are essentially identical in composition and physical characters, and they farther agree in crystallizing in the monoclinic system.

It might appear at first that the distinction of minerals so nearly identical is not an important matter. But nature has decreed otherwise, for, as with the micas and feldspars, they are to a large extent kept separate in the rocks. In associated minerals, augite is distinctly more basic than hornblende. In proof of this we need only to know that it rarely occurs in the same rock with original quartz, while hornblende is found very commonly in that association. It is these differences of association, chiefly, that make the distinction of hornblende and augite essential to the proper recognition of rocks. The specimens have, therefore, been selected with special reference to showing how the two minerals are contrasted and may be distinguished.

The crystallized specimens are intended especially to show the angles of the monoclinic prisms, the prismatic angle which is $124^{\circ} 30'$, or distinctly oblique, in hornblende (21), is only $87^{\circ} 5'$, or nearly a right angle, in augite (28). In each mineral the principal cleavage is prismatic, and hence the cleavage fragments (26-29) yield the same angles. In both the crystals and the cleavage specimens the particular edges or angles referred to are designated by the small strips of paper which are bent over them. The importance of the cleavage angles in the

microscopic study of these minerals may be readily inferred from the drawings (22). The first figure, showing cleavage lines crossing obliquely, represents hornblende; and the second one, showing cleavage lines crossing nearly at right angles, represents augite. The massive specimen of hornblende (31) might be readily duplicated for augite; but not so with the specimen of bladed hornblende (27), since this slender, bladed crystallization, although very characteristic of hornblende, is rarely seen in augite. The principal optical feature distinguishing hornblende and augite is the dichroism (23), which is very strong in hornblende (the green and yellow crystals in the drawing) and wanting in augite.

The remaining specimen of hornblende (32) represents the very common pseudomorphs of hornblende after augite, or the variety *uralite*. The crystals of uralite are strictly *paramorphs*, since the conversion of augite to hornblende is a change of molecular structure only, and not of composition. Although the molecular structure of augite appears to be stable with the conditions under which the mineral usually crystallizes in eruptive rocks, it is relatively unstable under the existing conditions, in many cases, since we find that, while the crystals retain the external forms of augite, they gradually take on the molecular arrangement or cleavage of hornblende; and hornblende derived in this way is known as *uralite*. The next drawing (24), shows crystals of augite which have been partially changed to hornblende, the inner portion still showing the right-angled cleavage of augite.

Enstatite (25) and *Hypersthene* (30) are closely related to augite and hornblende both mineralogically and geologically, occurring very abundantly in some of the basic eruptive rocks with augite or as a substitute for augite.

They crystallize in the orthorhombic system, but with essentially the same prismatic angles as augite. This is seen most clearly in the specimen of enstatite, which is a nearly perfect crystal. The fibrous appearance and metalloidal luster of the specimen of hypersthene are also very characteristic. Chemically these species are silicates of magnesia and iron, differing from the preceding group chiefly in the absence of lime.

Accessory Silicates.—The species of this group, as already noted, are generally non-alkaline; and they are farther characterized, as a rule, by very distinct crystallization, and by great hardness. They may be conveniently divided, according to their modes of occurrence, into two sub-groups, the first three species in the following list being found chiefly in eruptive rocks and the remainder chiefly in the metamorphic sedimentary rocks, and especially in the schists. With the exception of epidote, they are all to be regarded as usually original constituents of the rocks in which they occur.

Chrysolite or *Olivine* (41, 51) is a very basic silicate of magnesium and iron, occurring chiefly in basalt and other highly basic eruptive rocks. It is a hard, green, glassy mineral, usually forming small, isolated crystals or grains in the dark-colored lavas.

The first specimen (41) shows grains of olivine that have been set free by the disintegration of the enclosing rock. Occasionally the grains are aggregated to form lumps or nodules in the lava, and sometimes they are the principal or even the sole constituent of the rocks, as in peridotite and dunite (51). Chrysolite changes very readily, by simple hydration, into serpentine; and it is the general belief of geologists that much of the serpentine in the rocks has had this origin.

Zircon (46) is a silicate of the rare metal zirconium (more probably, perhaps, a double oxide of silicon and zirconium), occurring quite commonly, but often microscopically, in syenite and allied rocks. The crystals, as the specimens plainly show, are simple tetragonal prisms and pyramids, of adamantine luster and great hardness.

Epidote (42, 47) is one of the most important of the secondary minerals in basic rocks, occurring usually as an alteration-product of augite, hornblende, and allied species. It is found chiefly in irregular veins and cavities in the rocks, in both distinctly crystallized (42) and massive (47) forms. It is a hard mineral and the yellowish green color is very characteristic.

Garnet (49, 52), in its numerous varieties, is the most abundant accessory in the schists and gneisses or metamorphic rocks, and is often found in granite and other eruptive kinds, sometimes as an essential constituent. Garnet varies widely in composition, but is exceedingly homogeneous in crystallization, occurring almost always in dodecahedrons and trisoctahedrons of the first system, so that it is readily recognized by its form. It is hard and heavy, and the color is usually reddish or brown.

Tourmaline (44, 53) is a highly complex and variable silicate. Its chief interest, chemically, lies in the fact that it contains from 4 to 10 per cent. of oxide of boron. It is hexagonal and usually hemihedral; occurring commonly in slender prisms having an approximately triangular cross section. It is hard, commonly black, strongly double refracting and dichroic. It is found for the most part in the same rocks as garnet, and especially in eruptive and vein granite and in quartz (53).

Andalusite (43, 48) is an important accessory of metamorphic states and schists. It is as simple in composition as tourmaline is complex, and its usual form is the simple orthorhombic prism. The most abundant and interesting variety is *chiastolite* (48). It contains a large proportion of dark impurities, and these are distributed in such a way as to give the appearance of a cross or square on the section, as shown in the figures (43).

Cyanite (54) and *Fibrolite* (55) are the same chemical substance as andalusite, occurring under similar conditions, but crystallizing in very slender triclinic and monoclinic forms, cyanite being especially characterized by its flattened or bladed crystallization.

Staurolite (45) resembles the preceding species in abundance and mode of occurrence. It crystallizes in simple orthorhombic forms; but undoubtedly its leading and specially distinguishing feature is the cruciform twinning, which is also well represented by the specimens.

Chondrodite (50) is an important accessory of the older crystalline limestones. Distinct crystals are uncommon, but it usually forms irregular grains of a yellowish or brownish color.

Hydrous Silicates. — All the rock-forming hydrous silicates belong to the section of Margarophyllites. These are, as a rule, imperfectly crystalline, foliated or compact, and soft, with, commonly, a greasy feel and greenish color. They are, with unimportant exceptions, original and essential (often the only essential) constituents of the various schists and other rocks in which they