MINERALS AND ROCKS

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CHAPTER 2

INTRODUCTION AND DEFINITION

Below a thin, ragged mantle of soil and superficial material, the Earth's outermost shell is made up of rocks Most of these rocks are in turn made up of minerals. As the rocks are the chief documents in which the geologic history of the Earth is written, they be- come deeply interesting when regarded from this point of view. In order to penetrate their meaning and to understand them as historical records we must be able to recognize the minerals that make up the rocks. A mineral is a substance the product of inorganic nature, that is characterized by distinctive physical properties and a composition expressible by a chemical formula. Minerals are composed of chemical elements. A few consist of single elements, such as native gold and silver, as these metals are termed when they occur in elementary state in nature, or diamond and graphite, both of which are crystalline forms of the element carbon. Diamond and graphite illustrate in the most striking way possible what is meant by a mineral. Although both are identical in chemical composition, yet each is a distinct mineral because each has its own characteristic physical properties: diamond is transparent and is the hardest substance known, whereas graphite is opaque and is nearly the softest substance known. Most minerals, however, are made up of two or more chemical elements united in such a way that the product of the union differs greatly in its properties from those of the elements composing it.

CHARACTER OF MINERALS

CHEMICAL COMPOSITION

A few minerals have an invariable chemical composition; but most of them have a variable composition which, however, can be expressed by a chemical formula. Quartz, one of the most abundant minerals, has a fixed composition, expressed by the chemical formula SiO2 2 which is a sort of shorthand saying that one atom of silicon is united with two atoms of oxygen; in short, quartz, regardless of where obtained or how formed, is essentially 100 per cent (silica). Sphalerite from which most of the world's zinc is obtained, is a minera1 of variable composition, which is indicated by writing its formula thus: Zn,FeS thereby indicates g that in this mineral an atom of iron can proxy for an atom of zinc, The various minerals react differently to chemical reagents, and these reactions are one of the means used in identifying minerals. It is beyond the scope of this book to explain how minerals are identified by their chemical behavior, but, many textbooks of mineralogy treat the subject fully.

PHYSICAL CHARACTERS

Nearly all minerals are crystalline that is to say, they are built up of atoms that are organized in definite geometric arrangements. A few minerals are amorphous (non-crystalline). Under favorable conditions of growth most minerals form crystals A crystal is a solid that is bounded by smooth plane surfaces called faces whose arrangement is governed by the internal structure of the mineral. The crystals of any particular mineral have forms that are more or less characteristic. For instance, the mineral pyrite frequently crystallizes in cubes (Fig. 4). Garnet commonly occur as twelve-sided crystals known 88 dodecahedrons (Fig. 5). The recognition of these crystal forms helps in identifying minerals.

Structure of Minerals. The structure of minerals generally refers to their outward shape and form. The following descriptive terms are used, some of which are self-explanatory: crystallized occurring as crystals or showing crystal faces; massive not bounded by crystal faces: the antithesis of crystallized; columnar; fibrous (Fig. 6); botryoidal (Fig. 7), consisting of small rounded forms like closely bunched grapes; micaceous, occurring in thin sheets that can readily be split into thinner sheets; granular, in aggregates of coarse to fine grains; com- pact; earthy; oolitic, formed of small spheres resembling fish roe.

Cleavage and Fracture. The manner in which many minerals break or split is so characteristic that it helps greatly in identifying them. If they break so that smooth plane surfaces are produced, they are said to have a cleavage. Although this cleavage invariably occurs along planes, these planes are not necessarily parallel to the surface faces that bound the crystal. Some minerals have but one cleavage; other have two, three, or even six different cleavage directions. The number of cleavage directions that a mineral has serves as an aid in determining the mineral. A fine example is the cubic cleavage of galena, which causes the galena to cleave in three planes at right angles to one another, so that it breaks up into small perfect cubes which can in turn be split into still smaller cubes, and so on (Fig. 8). Other ex- ample are the rhombohedral cleavage of calcite three planes not at right angles, so that the resulting cleavage fragments are rhombohedrons (Fig. 9); and the cleavage of mica in one direction only, the most remarkable cleavage in the whole mineral king dom, by virtue of which the mica can be split into sheets of indefinite thinness. If a mineral has no cleavage, then the nature of its broken surface its fracture is more or less distinctive The fracture of a mineral is conchoidal, if the surface of a fracture is curved like the interior of a clam shell; fibrous or splintery if it is like that of wood; uneven or irregular, if the surface is rough.

Color. The color of a mineral is one of its most conspicuous features. A few minerals have a distinctive color that serves as a ready mean s of identification. For example, the golden-yellow of chalcopyrite the lead-gray of galena, the black of magnetite, are striking properties of these minerals. The golden-yellow color of chalcopyrite, together with a test for soft brittle character, practically surfaces to identify chalcopyrite, but unhappily few minerals can be identified so easily. Surface alterations are likely to change the color of a mineral, as shown by the golden-yellow tarnish frequently seen on pyrite. To observe the true, intrinsic color of a mineral a fresh surface must be examined. Moreover, many minerals vary in color in the different specimens. This is due to a difference in composition such as an increased amount of iron in Sphalerite, with the consequent darkening in color of the mineral: or to impurities such as the red color given to quartz by admixed hematite. Other minerals, such as fluorite (colorless, green, blue, violet), although having no perceptible variation in composition, show a wide range in color, the result of containing some foreign constituent in infinitesimal amount in a state of extremely minute subdivision evenly distributed through them.

Color of Powder or Streak. The color of the streak is an important aid in identifying minerals. The streak is a thin layer of the powder of the mineral obtained by rubbing the mineral on an unglazed porcelain place know n as a streak plate The color of the streak may be like that of the mineral, but surprisingly enough the color of the streak of many minerals differs greatly from their body color. For example, some varieties of hematite are brilliantly black, but they give a red- brown streak, which positively identifies them as hematite. Luster. The luster of a mineral is the appearance of its surfaces as determined by its inherent reflecting quality. Luster must not be confused with color, for two minerals of the same color can have totally different luster's, just as a black paint with a shiny finish, such as an enamel, differs in appearance from a black paint with a dull finish because it reflects light differently. The different kinds of luster are the following:

Metallic. Having the luster of a metal. Example: pyrite. Most minerals that give a dark or black streak have metallic luster.

Glassy Having the luster of glass. Example: quartz.

Resinous. Having the luster of yellow resin. Example: Sphalerite.

Pearly. Having the iridescence of pearl. Example: some varieties of feldspar.

Greasy. Looking as if covered with a thin layer of oil. Example: some varieties of massive quartz.

Silky. Like silk, as the result of a finely fibrous structure Example fibrous

Adamantine. Having a brilliant luster like that of a diamond.

Hardness of minerals. Minerals differ greatly in hardness, and the determination of this property is an important aid in identifying them. The reactive hardness of a mineral is determined by comparing it with the hardness of a series of minerals that has been chosen as a standard scale The scale consists of the following minerals, each mineral being harder than those that precede it in the scale.

Scale of Hardness

1. Talc

2. Gypsum

3. Calcite

4. Fluorite

5. Apatite

6. Orthoclase

7. Quartz

8. Topaz

9. Corundum

10. Diamond

The relative hardness of a mineral in terms of this scale is deter- mined by finding which of these minerals it can scratch and which it can not scratch. In determining hardness the following precautions must be observed. A mineral that is softer than another may leave a mark on the harder one which can be mistaken for a scratch. The mark can be rubbed off. however, whereas a true scratch is permanent. Some minerals are commonly altered on the surface to material much softer than the original mineral The physical structure of a mineral may prevent the correct determination of its hardness. For instance, if a mineral is powdery, finely granular, or splintery in structure it can apparently be scratched by a mineral much softer than itself. It is always advisable when making the hardness test to confirm the test by reversing the procedure, that is, by rubbing the mineral of unknown hardness on the material of known hardness. The following materials serve as additions to the above scale. The finger nail is a little over 2 in hardness, as it can scratch gypsum but not calcite. A copper coin is slightly above 3 in hardness, as it can scratch calcite but not fluorite The steel of an ordinary pocket knife just exceeds 5, and ordinary glass has a hardness of 5.5. Specific Gravity. The specific -gravity of a substance is expressed as a number that indicates how many times heavier a given volume of the substance is than an equal volume of water. Minerals range in specific gravity between 1.5 and 20.0. The great majority range between 2.0 and 4.0. There are various instruments by which the specific gravity of a mineral can be determined accurately, but ordinarily it is sufficient to judge the weight of a fair-sized piece in the hand. After some experience rather small differences in specific gravity can be detected in this way, and the specific gravity of a mineral can be roughly estimated.

COMMON MINERALS

A few of the more common minerals are described on the following pages. The student should compare these descriptions with as many different specimens of the minerals as possible, and should note the form, color, and luster of each specimen and make the simple tests for hardness, streak, and specific gravity.

Magnetite. An oxide of iron, Fe304. Physical Characters. Black; metallic luster. Streak black. Hardness 6. Specific gravity 5.17. Strongly magnetic, hence its name. Granular or massive; fairly common it octahedral crystals (Fig. 10). Occurrence. Is a valuable iron-ore mineral, containing 72 per cent of iron. It is mined in the Adirondacks, New Jersey, Pennsylvania, and many other parts of the world. It is common as a minor constituent in rocks, particularly in the darker-colored igneous rocks. The black sand of the seashore is largely magnetite.-

Hematite. The ferric oxide of iron, Fe_2O_3. Physical Character Dark steel-gray to iron-black; brilliant metallic luster (except in earthy specimens). Streak light to dark red-brown (Indian red); color of streak distinguishes it from limonite. Hardness 5.5 to 6.5. Specific gravity about 5. Granular micaceous; earthy (in this form it is red). Rarely in crystals. Occurrence: Hematite is widely distributed in rocks and is the most abundant ore mineral of iron; it contains 70 per cent of iron. More than nine-tenths of the iron produced in the United States comes from this mineral. The chief districts are near the shores of Lake Superior in Michigan, Wisconsin, and Minnesota. Other important districts are in northern Alabama and eastern Tennessee. Earthy hematite is the pigment that gives many sandstone's their red color. It is used also in red paints and as a polishing material.

Limonite. Hydrous ferric oxide, Fe2O3-H2O. Physical Character Dark brown to nearly black Streak yellowish-brown, which distinguishes it from hematite. Hardness 5 to 5.5.. Specific gravity about 4. Common as masses that resemble compact bunched of grapes (botryoidal structure [Fig. l]); if broken open, these masses generally have a radiating fibrous structure; occurs also in stalactitic forms resembling icicles earthy. The term limonite is restricted to the amorphous and earthy forms, and the crystalline forms are called goethite. Occurrence. Limonite is a valuable source of iron, but contains less iron than magnetite and hematite. It is a common mineral formed by the alteration of previously existing minerals that contain iron. Ordinary iron rust is limonite. It gives brown, orange, and yellow colors to many weathered rocks, to some non- weathered sedimentary strata, and to many soils.

Pyrite. Iron sulphide, FeS2 Physical Characters. Pale brass-ye1low, but some specimens are tarnished to deeper shades of yellow. Streak black Hardness 6 to 6.5 unusually hard for a sulphide Specific gravity about 5. Generally granular Common as crystals, especially as cubes whose faces are marked with fine parallel lines, or striae (Fig. 4). Occurrence. The most common sulphide mineral. Occurs in many rocks and is an important vein mineral. May carry small amounts of gold or copper and so become an ore of both these metals. Is not used as an ore of iron, but as a source of sulfur in the manufacture of sulfuric acid. Its presence in building stones detracts from their value, as its oxidation produces not only iron-oxide stains but also sulfuric acid, which causes the stones to disintegrate.

Chalcopyrite (Copper Pyrite). Copper-iron sulphide, CuFeS2. Physical Characters Golden-yellow; generally tarnished to bronze or iridescent colors. Streak greenish-black. Hardness 3.5, hence much softer than pyrite. Specific gravity 42. As a rule massive, rarely in crystals Occurrence. An abundant and valuable ore-mineral of copper, containing 34 per event of the metal. Occurs intimately distributed in vein deposits with many other sulphide minerals.

Sphalerite. Zinc sulphide, ZnS, when ideally pure; generally contains some iron, as indicated by the formula ZnFeS. Physical Character Commonly yellow-brown to dark-brown, being darker in the varieties containing more iron. Resinous to submetallic luster Hardness 3.5 to 4. Specific gravity about 4. White to yellow and brown streak, of lighter shade than the mineral itself. Has brilliantly Bashing cleavage planes sloping in six different directions. As a rule massive. Occurrence. The most important source of zinc. Widely distributed, but generally in veins or irregular bodies in limestone. Associated generally with galena, pyrite, and chalcopyrite.

Galena Lead sulphide PbS. Physical Characters. Lead-gray. Bright metallic luster. Streak grayish-black Hardness 2.5 (soft). Specific gravity about 7.5 (" very heavy "). Perfect cleavage in three planes at right angles to each other, forming cubes Fig. 8 (not visible, however, in finely granular specimens). Occurs in natural cubic crystals, but massive and granular aggregates are more common. Occurrence. Is the chief source of lead; contains 87 per cent of the metal. Some contains silver and serves as an ore of that metal. Commonly occurs with zinc minerals.

Calcite. Calcium carbonate, CaCO3. Physical Characters. Generally white or colorless. Also variously tinted gray, red, green, and blue. Commonly opaque or translucent; rarely transparent Hardness 3. Specific gravity 2.7. Perfect cleavage in three planes at oblique angles to each other (rhombohedral cleavage [Fig. 9]), giving rhombic-shaped faces. well-formed crystals are common. Effervesces freely on application of cold acid, because of the copious liberation of the gas carbon dioxide. This test serves to distinguish calcite from dolomite, another common carbonate, which does not effervesce under these conditions. Occurrence. A very common mineral. Is the chief constituent of limestone's and marbles; also common in veins. Used in the manufacture of lime, plasters, and cement as a metallurgic flux, and in chemical industries.

Dolomite. Carbonate of calcium and magnesium, $CaMg(CO_3)_2$. Physical Characters. Generally white or gray; rarely flesh-colored. Opaque to translucent. Hardness 8.5 to 4 (harder than calcite). Perfect cleavage in three planes not at right angles to each other (rhombohedral cleavage). Specific gravity 2.9. Glassy to pearly luster. Does not effervesce on application of a drop of cold acid unless the acid is placed on a scratched or powdered surface. In this respect it differs from calcite. Occurrence. Composes the common rock known as dolomite; also dolomite marble. Occurs also as a vein mineral. In the rock form, it is used as a building and ornamental stone, for the manufacture of some cements, as s source of magnesia for refractory substances and as agricultural lime.

Gypsum. Hydrous calcium sulfate, $CaSO_4\ 2H_2O$. Physical Characters. Usually white or colorless. Hardness 2 easily scratched with the finger nail). Specific gravity about 2.8. Has one perfect cleavage; another imperfect cleavage is visible in some specimens. Occurrence. Is widely distributed in sedimentary rocks. In place forma thick beds, commonly interstratified with limestone and shale. Generally occurs in association with salt beds. Is chiefly used for the production of plaster of Paris.

Halite (Common Salt). Sodium chloride, NaCl Physical Characters. White or colorless. Hardness 2.5. Specific gravity 2.1. Perfect cleavage in three planes at right angles to one another (cubic cleavage). Transparent to translucent. Salty taste. Generally in cubic crystals or in masses showing cubic cleavage. Occurrence. In thick beds interstratified with sedimentary rocks and associated with gypsum. Used for cooking and preservative purposes; also extensively in chemical industry.

Quartz. Silicon dioxide, SiO_2. Physical Characters. Colorless or white; but many varieties are colored by impurities, yellow, red, pink, amethyst, green, blue, brown, black. Glassy luster. Transparent to opaque. Hardness 7. Specific gravity 2.65. In contrast to most common minerals, quartz shows no cleavage; has conchoidal fracture. Commonly in hexagonal crystals similar to Fig. 11. The triangular faces at the ends of the crystals are usually smooth, whereas the rectangular faces between the ends are horizontally striated. Also massive. Varieties. There are many varieties of quartz to which different names are given. A few are as follows. rock crystal which is colorless quartz, commonly in distinct crystals; amethyst quartz colored purple or violet; rose quartz, usually massive with a pink color; smoky quartz, quartz of a smoky yellow, brown, or almost black color; chalcedony, finely fibrous variety, translucent with a waxy luster; agate, a variegated chalcedony delicately banded in different colors; jasper, extremely fine-grained quartz colored red by admixed hematite. Occurrence. Quartz is one of the most common minerals. It is most abundant as a constituent of granite, in which it resembles bits of window glass. It is also the most common vein mineral. It makes up the largest part of most sands and sandstone's.

Garnet. There are several garnets, which differ from one another in the elements they contain. They are all silicates with analogous chemical formulas. The most common garnet is a red variety (almandine), containing ferrous iron and aluminum, FesAl2(Si04) g. Other garnets contain magnesium, calcium, manganese, and ferric iron. Physical Characters. Color depends somewhat on the composition, but is an unsafe criterion; most commonly red (almandine) or brown. Also yellow, green, and black. Transparent to almost opaque. Hardness 7. Specific gravity 32 to 43 (varies with the chemical composition Generally well crystallized, either in a form showing 12 rhombic-shaped faces (dodecahedron, Fig. 5) or 24 trapezium-shaped faces (trapezohedron). Occurrence. Garnet is a widely distributed mineral, occurring most commonly in metamorphic rocks. Used as a semi-precious gem stone and, because of its hardness, as an abrasive material.

Orthoclase (Potassium Feldspar). Potassium-aluminum silicate, KAlSi2O4. Physical Characters. Colorless, white, gray, pink, and red; rarely green. Streak white, in spite of the diversity of colors. Hardness 6. Specific gravity 2.56. Has two good cleavages that make right angles with each other (whence the name of the mineral). Occurrence. The most common silicate. Widely distributed as a prominent rock constituent, occurring in rocks of many kinds, but most abundantly in granite and allied rocks. Also in large crystals and cleavage masses in what are known as pegmatite dikes. From these dikes it is quarried in large amounts for use in the manufacture of porcelain.

Plagioclase Feldspars. Sodium-calcium-aluminum silicates. Physical Characters. Various shades of gray, less commonly white. Tans- parent to opaque. Hardness 6. Specific gravity 2.6 to 2.76. Have two cleavages making nearly a right angle with each other, one of them (the basal cleavage being better than the other. Some specimens are distinguishable from orthoclase by having on their basal cleavage planes a series of stria (fine parallel lines, which resemble rulings made by a fine diamond point). Some cleavage surfaces, especially of the dark-gray variety, give a beautiful play of colors when specimen is rotated in good light. The white variety commonly occurs in thin-bladed crystals with curved surfaces and a pearly luster. Occurrence. In much the same manner as orthoclase. The plagioclase in gabbros is likely to be dark colored or black and therefore not easily distinguishable from the associated pyroxene.

Muscovite (White Mica). A complex silicate containing potassium and aluminum. Physical Characters Has a perfect cleavage in one direction, which allows the mineral to be split into exceedingly thin sheets or flakes. These sheets are flexible and elastic, ie., on release of pressure a bent sheet- has the power of resuming its original shape. Transparent and almost colorless in thin sheets. In thicker blocks, opaque with light shades of brown and green. Hardness 2 to 2.5. Specific gravity 2.76 to 3. Occurrence. A common rock-making mineral. It occurs in granite together with quartz and feldspar, and with the same minerals in pegmatite dikes It is characteristic of a series of rocks made up of abundant mica, in which it is arranged in parallel orientation, with the result that the rocks split in flakes and slabs parallel to the cleavage of the mica. These rocks are known as mica schists. Is used chiefly as an insulating materials l in the manufacture of electrical apparatus. There are many minor uses.

Biotite (Black Mica). A complex silicate containing potassium, magnesium, iron, and aluminum. Physical Characters. Perfect micaceous cleavage. Cleavage sheets and flakes are flexible and elastic. Generally dark-green, brown, or black. Thin sheets generally have a smoky color differing from the almost colorless muscovite). Hardness 2.5 to 3. Specific gravity 3. Occurrence. An abundant rock-making mineral, common in granites and many gneisses and schists.

Chlorite. A complex silicate containing magnesium and aluminum. Chlorite is a name given to a group of minerals that are prevailingly of green color and of broadly similar characters. Physical Characters. Perfect micaceous cleavage. Flakes are flexible but not elastic differing in this lack of elasticity from the micas). Green of various shades. Hardness 2 to 2.5. Specific gravity 2.65 to 2.96. Occurrence. A common rock-making mineral. The green color of many rocks is due to the presence of this mineral. This is particularly true of many schists and slates (green roofing slates). Serpentine. Magnesium silicate , $H_4Mg_3Si_2O_3$. Physical Characters. Green of various shades: olive-green, yellow-green. ranging to blackish-green. Luster greasy or wax-like; silky when fibrous. Hardness 2.5 to 5, generally 4. Specific gravity 2.5 to 2.65. Usually massive but also fibrous or felted. The name serpentine is given also to the common rock com- posed largely of the mineral serpentine. Occurrence. A common mineral, widely distributed. Invariably an alteration product of some magnesia n silicate, chiefly olivine. It is the chief constituent of the rock called serpentine, some varieties of which are used as ornamental stone. The fibrous variety known as chrysotile is the principal source of asbestos.

Olivine. Silicate of magnesium and iron, (Mg,Fe) 2Si04. Physical Characters. Olive-green to yellowish-green; rarely brownish. Trans- parent to opaque. Hardness 6.5 to 7. Specific gravity 327 to 3.37. Glassy luster Conchoidal fracture, causing it to resemble yellowish-green quarts. Occurrence. Common as irregular grains in the dark, heavy granular igneous rocks gabbros and peridotites, and as distinct crystals in many basalts.

Pyroxene and Amphibole

These two abundant rock making minerals are similar in some respects, and their identification is based on crystal form. Consequently, it is difficult to discriminate them in most rocks, because good crystal forms are rare in rocks. However, it is well to study them separately under favorable conditions, in order to appreciate their differences as well as their points of similarity. Pyroxene. A silicate containing chiefly calcium and magnesium; also varying amounts of aluminum, iron, and sodium. Physical Characters. Light- to dark-green to black, varying with the amount of iron; white in iron-free variety. Commonly opaque. Hardness 5 to 6. Specific gravity 3.1 to 3.6. In prismatic crystals with eight sides (Fig. 12a); in reality square prisms whose corners are truncated. The angle between alternate faces is therefore nearly 90'. These faces will fit into the corner of a box or tray. By means of these angles pyroxene can best be told from amphibole. Some specimens show a fair cleavage parallel to the faces lettered m in the figure, the angle between the cleavage faces being also nearly 90'. This cleavage is not visible in all specimens used for demonstration purposes. Occurrence. Pyroxene is a highly abundant rock-making mineral, occurring chiefly in the dark-colored igneous rocks. Rare in rocks that contain much quartz. Amphibole. Silicate of calcium and magnesium with varying amounts of aluminum, iron, and sodium. Chemical composition is much like that of pyroxene. Physical Characters. Light- to dark-green to black, varying with amount of iron. Commonly opaque, Hardness 5 to 6. Specific gravity 2.93 to 3.8. Commonly in prismatic crystals with six sides. Figure 12b shows that the angles between the faces lettered m are 124 and 56' (very different from the corresponding angles in pyroxene). Has a good cleavage parallel to the faces lettered m. The difference in the form of the crystals and in cleavage angles and the fact that amphibole has the better cleavage are the chief outward distinctions between amphibole and pyroxene. Amphibole as a rule has a higher luster and yields smoother more continuous cleavage surfaces than does pyroxene. Some varieties of amphibole have long, needle-like crystals resulting in a fibrous structure. Pyroxene does not occur in this form. It should be remembered that the 56' and 124' with each other. The presence of well-formed crystal faces or cleavage surfaces is essential in order to distinguish between pyroxene and amphibole in hand specimens. Occurrence. Amphibole is an abundant rock-making mineral, occurring in biotite rich igneous and metamorphic rocks. Hornblende is a common dark variety of amphibole. Pyroxene and amphibole together with biotite are the dark minerals commonly occurring in many rocks. The first two can be distinguished from biotite by the fact that they occur in prismatic crystals that can not be divided into thin elastic Hakes; that is, they lack the perfect cleavage of the micas. If present as small grains in a rock, they lack the high luster characteristic of flakes of biotite. They can be distinguished from chlorite by their much greater hardness as well as by their form and lack of micaceous cleavage.

ROCKS

Most rocks are aggregates of minerals. Therefore they differ greatly in appearance and other properties, depending on what minerals are present, the number of minerals present and their relative abundance, the size of the mineral grains, and the way in which the minerals are associated. The kinds of rocks are many and the varieties endless, but, if classified according to their modes of origin, they fall into three major classes:

I. Igneous rocks formed by the solidification of molten rock-matter, as exemplified by the rocks formed on the cooling of lava discharged from a volcano. II. Sedimentary rocks, most of which were formed by the settling of their substance as sediment from bodies of water such as streams lakes, and the sea. III. Metamorphic rocks, formed from pre-existing rocks by the development of new characters as the results of pressure, heat, or other geologic agents acting on them within the Earth's crust.

CHARACTERS USED IN IDENTIFYING ROCKS

The properties most useful in identifying rocks are structure, texture, hardness, and fracture. Color is sometimes useful, but is often misleading. Structure is a term used in describing the larger features of rocks. A layered or laminated structure generally indicates sedimentary origin. If a rock contains spherical or almond-shaped cavities or vesicles (" blowholes" formed by the liberated and expanding gases that were dissolved in molten rock-matter), it has s vesicular structure and is of igneous origin. If the vesicles become filled with minerals, the resulting structure is termed amygdaloidal (Fig. 18). Texture is the appearance of a rock as determined by the size, shape, and arrangement of the mineral grains of which it is built. The size of the grains determines the grain-size of the rock. If its grains are as large as peas, a rock is said to be coarse grained, or coarsely granular; if as small as the grains in granulated sugar, the rock is termed fine grained; and if so small that they can not be distinguished as separate entities, the rock will seem to be a homogeneous substance and is said to be aphanitic. The shape and arrangement of the mineral grains with respect to one another produce s distinct pattern the fabric of a rock. If, for example, the grains are roughly of one size, the rock has an equigranular fabric; but if the grains are very unequal in size, the fabric is termed inequigranular. There are many fabrics, some of which are characteristic of the rocks in which they occur. Inasmuch as texture (" appearance of the rock ") is the conjoint effect of grain-size and fabric, texture is customarily (and loosely) used for grain-size, for fabric, or for their conjoint effect Certain textures help in the megascopic identification of rocks, i.e., without the aid of the microscope, which is ill that is attempted here. The texture of a granite, so distinctive that it is termed the granitic texture, proves not only that the rock is of igneous origin, but also that it was formed under conditions of slow undisturbed cooling. A glassy texture proves that a rock having this texture is also of igneous origin, but that, unlike granite, it was formed by molten rock-matter suddenly solidifying, for glasses are the results of extremely rapid cooling. The clastic texture (clastic, from the greek meaning broken) occurs in rocks that are made up of angular or more or less rounded fragments of minerals and rocks, and is characteristic of many sedimentary rocks. Other textures are described in connection with particular rocks. Hardness aids in identifying some rocks. any rocks resemble limestone, but the test for hardness with the knife-point serves at once to distinguish a limestone, the hardness of which is 3, from the much harder rocks that resemble it. Fracture is a less useful property. However, perfect conchoidal fracture characterizes the volcanic glasses (Fig. 14); and a semi-conchoidal fracture yielding shell-like fragments characterizes shales. The tendency of most metamorphic rocks to split into slabs or thin flakes is a valuable aid to their identification.

IGNEOUS ROCKS

As their name implies, igneous rocks were formed at high Temperatures, and they are defined as those rocks made by the cooling of molten matter that originated within the Earth. This molten matter when rising from the depths is more or less highly charged with gases; and these gases begin to escape as soon as the pressure on the liquid is reduced, and they are entirely eliminated when the liquid solidifies. The liquid rock-matter plus its content of dissolved gas is called magma. There are many kinds of magma at least forty and they have a wide range in composition.

Extrusive and Intrusive Rocks. Magma extruded at the Earth's surface solidifies on cooling to form extrusive rocks. Vastly greater quantities of magma than ever reached the surface have remained within the crust, however, and have solidified there under a cover consisting of the rocks of the upper part of the Earth's crust. This magma moved upward from the place where it originated : it is an intruder in the place it now occupies, hence the resulting rocks are termed intrusive Manifestly, such bodies of intrusive rock have become accessible to view only after they have been uncovered by erosion. Intrusive rocks were formed in a geologic environment that differs greatly from that in which extrusive rocks have formed. In an intrusive mass the magma cools under an insulating cover of rocks; hence its dissolved gases tend to be held until a late stage of solidification and it loses heat sIowly, and therefore it solidifies slowly. In extrusive bodies, such as a lava flow the magma, becomes drastically chilled by exposure to the atmosphere even more so, by flowing into water and solidifies rapidly. As a result, most intrusive rocks differ greatly in appearance from extrusive rocks.

TEXTURE AND COMPOSITION OF IGNEOUS ROCKS

Texture. The most obvious thing about an igneous rock, except perhaps its color, is its texture. By texture, as already explained, is meant the appearance of a rock as determined by the size, shape, and arrangement of its constituents. Most igneous rocks are made up of mineral grains, but some consist of glass, and some of glass and mineral grains. The grain-size is coarser the more slowly the magma cooled When the magma is extremely hot, the minerals dissolved in it can not crystallize out; that is, the atoms and atomic groups in the magma can not arrange Themselves to form organized solid compounds (the minerals). After the temperature has fallen far enough the minerals begin to separate from the magma, and, if the cooling is slow, they have time to grow to large size, thus forming a coarse-grained rock. But if cooling is rapid, more and more nuclei centers of crystallization form spontaneously, and, instead of a few such nuclei growing to large crystals, many begin to grow simultaneously; therefore none of them can attain large size, and consequently the resulting rock is fine grained. If cooling is still more rapid, the crystals remain so minute that they are not visible to the unaided eye, and the resulting rock is aphanitic Under conditions of extremely rapid cooling the magma solidifies into a homogeneous substance before any crystallization can occur. In this event the product is a glass sometimes called a natural glass. Porphyry: Porphyritic Texture. So far all the mineral grains in a given rock have been tacitly assumed to be of uniform size, i.e., That the rock is equigranular (Fig. 15). Not all igneous rocks, however, are equigranular. Many of the consist of grains of two markedly contrasting sizes: in part of large conspicuous crystals and in part of much smaller grains, which form a matrix inclosing the large crystals. An igneous rock of this texture is said to be porphyritic (Fig. 16) . The matrix is called the ground- mass, and the large crystals imbedded in the groundmass are the phenocrysts, the easily discernible crystals. Porphyritic rocks are abundant and of many kinds. Some have medium- grained groundmasses; others have fine-grained, aphanitic, or glassy ground-masses as exemplified by the lavas, which as a rule are porphyritic rocks having aphanitic groundmasses. The phenocrysts also range greatIy in size from those several in the s in diameter to those so small as to be barely visible to the unaided eye, and they range from sparse to abundant. In all porphyritic rocks, however, the phenocrysts contrast conspicuously in size with the grains that make up the groundmass; and this contrast in size is the essential feature of a porphyry. The porphyritic texture is not a contrast of colors; thus a rock made of grains of light-colored quartz and feldspar and containing a few crystals of black mica in marked color contrast, the grains of all three minerals being of about the same size, is not a porphyry. Factors Determining grain-size. Reduced to its fundamentals, grain-size is determined (1) by the viscosity of the magma during the time the minerals are growing and (2) by the time available for them to grow. Low viscosity increases the mobility of the atoms while they are getting together to build up the growing crystals, and adequate time is necessary for them to travel to the growing crystals. Viscosity is enormously affected by the mica composition of the magma. Silicic magma (those high in silica) are several hundred thousand times as viscous as are the subsilicic magmas (those low in silica) . The effect of this great difference in viscosity is impressively Illustrated by the strongly contrasting behavior of these magmas when erupted at the Earth's surface. Subsilicic magmas require such drastic chilling to form glasses that subsilicic glasses are rare, whereas silicic magmas, because of their great viscosity and consequently feeble tendency to crystallize, commonly produce silicic glasses. No subsilicic counterpart of the large, thick flow of silicic glass (obsidian) at Obsidian Cliff, Yellowstone National Park, occurs anywhere in the world. The presence of gases especially the water contained in magmas , decreases the viscosity of the magma and thereby promotes a coarser crystallization to an astonishing degree. An intrusive body of mag- ma, cooling and solidifying under a cover of rocks, is likely to retain its gases to a late stage and consequently to develop a coarsely crystalline texture. Depth in the crust and especially gas-tightness of the surrounding rocks are therefore important factors in determining the texture of igneous rocks. A silicic magma increases enormously in viscosity when its gas content escapes; hence the very great contrast in appearance between the rocks formed in a gas-tight environment within the crust and the rocks formed from the same kind of magma erupted at the Earth's surface, where of course the gas content escapes freely. However, if the subterranean magma solidifies surrounded by confining rocks that are fissured or otherwise allow the gases to escape, it takes on a texture like that of surface rocks. For example, in the Rocky Mountains of Colorado, certain intrusive masses are coarse grained, whereas others formed at the same time, but deeper in the crust, are porphyritic; evidently depth was not the controlling factor here in developing coarsely granular texture. The importance of depth in determining a coarse-grained texture in igneous rocks has in the past been greatly exaggerated. Minerals Common in Igneous Rocks. The minerals that make up most of the igneous rocks are the following:

Light-colored Group

(Feldspar Group)

Orthoclase feldspar Plagioclase feldspars

Quartz

Dark-colored Group

(Ferromagnesian Group)

Biotite (black mica)

Pyroxene

Hornblende

Olivine

Magnetite

The rocks in which the light-colored minerals predominate are light in color and light in weight, i.e., they are of low specific gravity. The rocks predominantly composed of dark ferromagnesian minerals are dark in color and heavy in weight. The range in specific gravity from 2.67 for the average granite to 3.0 for gabbro is not large, but surfaces after some experience to serve as an aid in identification. Although each rock has been placed in the table in a separate compartment, in nature no rock variety is as sharply delimited from its neighbors as it seems to be in the table. For example, there are transitional varieties between granite and diorite and between granite and granite porphyry. In more detailed classifications these intermediate rocks receive special names. No hard and fast boundaries set off any of the so-called rock species. These facts often make it difficult to classify a given rock. Great difficulties are presented by the finer- grained rocks. When the accurate identification of a rock becomes a matter of high importance, recourse must be had to expert microscopic examination.

DESCRIPTION

EQUIGRANULAR ROCKS

The equigranular rocks are the results of slow cooling, combined with retention of the gas content in the magma until it has nearly solidified. Typically they occur in intrusive bodies, especially in those of great size. In such voluminous masses, cooling was necessarily slow, and the pressure was sufficient to keep the gases within the magma and to allow them to exercise their power of promoting coarse crystallization.
Granite. As can be seen from the scheme of classification (p. 31), granite consists largely of quartz and feldspar (mainly of the variety orthoclase) . It contains also as a rule some black mica (biotite); less commonly it contains hornblende, or hornblende and biotite together. All these component minerals are roughly of the same size, and hence granite is said to be equigranular. The minerals began to separate from the magma in a definite order: first the dark minerals, hornblende and biotite; then the feldspars; and last the quarts. The dark minerals, being the first to crystallize, were not hampered in their growth by the presence of any neighbors, and so are generally in the form of sharply defined crystals; and the feldspars, having begun to grow later are less well crystallized, for where they abutted upon the earlier- formed dark minerals their freedom to grow was hampered. As the quartz was the last mineral to separate from the magma, it had to take what space was left, and it is therefore molded around the earlier minerals and occupies the angular interspaces between them, This habit of the quartz produces an initimately

interpenetrating and interlocking arrangement. Diorite. Diorite is an equigranular igneous rock composed of feldspar and one or more dark minerals, in which the feldspar is more abundant than the dark minerals. The feldspar is mainly plagioclase, but unless the characteristic striae on the cleavage planes can be seen it is generally difficult to recognize the plagioclase with the unaided eye. The dark minerals are biotite, hornblende, or pyroxene, occurring either singly or together. Syenite is much like granite in composition, differing only in containing little or no quartz; hence it is classed here with diorite. It is not common, nor does it as a rule occur in large masses compared with the enormous bodies of granite. Gabbro. Gabbro differs from diorite in that the feldspar is sub- ordinate and the dark minerals predominate. Hornblende, pyroxene, and olivine are the common dark minerals, occurring singly or together; biotite, though present in some gabbros, is distinctly uncommon. Because the dark minerals predominate, gabbros are dark and of high specific gravity. Dolerite is a convenient term. for the basic rocks that in grain-size are intermediate between basalts and gabbros. Peridotite. Peridotite is composed wholly of ferromagnesian minerals, with olivine predominating. Pyroxenite, as its name implies, is composed wholly of pyroxene, and homblendite consists entirely of hornblende As a rule hornblendite and pyroxenite form bodies of small size; nevertheless, in places, as at the remarkable platinum deposits recently discovered in South Africa, pyroxenite occurs in vast volume.

PORPHYRITIC-GRANULAR ROCKS

Rocks of this class are distinguished by the fact that they contain phenocrysts imbedded in a groundmass so coarse grained that its component minerals can be recognized by the unaided eye. The phenocrysts in most of these porphyries are abundant making up half or more of the bulk of the rock. If the volume of the phenocrysts exceeds 75 per cent, the porphyry becomes to the unaided eye indistinguishable from the corresponding granular rock. Granite Porphyry; Diorite Porphyry etc. Typical granite porphyry contains conspicuous crystals of feldspar, quartz, and biotite set in a granitic groundmass. As its name implies, its composition is like that of granite it differs from granite in having phenocrysts and a groundmass whose grain-size on the average is finer than the grain- size of the average granite. Diorite porphyry differs from granite porphyry in the absence of quartz phenocrysts and the prevalence of phenocrysts of plagioclase feldspar.

PORPHYRITIC-APHANITIC ROCKS

The rocks of this class are generally of volcanic origin. Extruded upon the Earth's surface, the magmas from which they were formed have cooled rapidly. They are characterized by the occurrence of porphyritic crystals (Fig. 16) set in a groundmass that is either so fine grained as to be irresolvable by the unaided eye or else is partly or wholly glassy. Rhyolite. Rhyolite contains phenocrysts of feldspar, quartz, and biotite, and rarely of hornblende, set in an aphanitic groundmass. These phenocrysts range in number within the widest limits, so that there is a complete transition from nonporphyritic to highly porphyritic rhyolite. The colors typically are light, ranging from white to gray, pink, red, and purple. Rhyolites and andesites that have inconspicuous phenocrysts or few or no phenocrysts are termed felsites. Andesite. Andesites are of many colors, but in general they are darker than the rhyolites; dark gray is common. They are transitional on the one hand into rhyolites; on the other, into basalt. The average or typical andesite occupies the intermediate position. The darker andesites are like basalts in appearance, but unlike basalts their freshly broken thin edges are translucent when held in bright light. The phenocrysts in andesites commonly consist of striated feldspar and one or more dark minerals (hornblende, pyroxene, or biotite).

Quarts phenocrysts are absent (distinction from rhyolite). Andesite was named for the Andes Mountains, where it occurs in great quantity and in many varieties.

Felsite. The difficulty of discriminating between rhyolites and andesites that are devoid of phenocrysts makes it necessary to use an elastic noncommital name. For the light-colored rocks of this kind, namely those which are white, light to medium gray, light pink to dark red, pale yellow, brown, purple, or light green, the term felsite is convenient. Some felsites that in hand specimens are as dark as basalts should be examined on their @in edges, where the rock will be seen to be almost white in transmitted light. Basalt specimens are dark even on thin edges.

Basalt. Lavas that are dark gray, dark green, brown, or black are termed basalt, the common extrusive equivalent of the basic magmas. Basalts are either compact or vesicular. If the vesicles have become Filled with some mineral, such as calcite, chlorite, or quartz, the fillings are called amygdales and the rock is an amygdaloidal basalt. Many basalts have no phenocrysts but others contain abundant conspicuous phenocrysts, consisting of feldspar, olivine, or pyroxene, or some combination of these. Therefore, in the Table of Igneous Rocks, basalt is shown to fall in both Classes III and IV. The phenocrysts are hard and have straight clean-cut boundaries, whereas amygdales are generally soft and have irregular, roundish or elliptical boundaries (Fig. 13) . Dolerite is the name given to those coarser-grained basalts in which the grains are large enough so that the constituent minerals are nearly or quite recognizable. There is no hard and fast line between basalt and dolerite on the one hand and dolerite and gabbro on the other.

GLASSY ROCKS

Volcanic glasses occur as thin crusts on the surfaces of lava flows, or more rarely as lava flows that have cooled rapidly. Most glasses are the products of the chilling of silicic magmas (p. 28) . Brilliantly lustrous volcanic glass is called obsidian and the duller and more pitchy variety is pitchstone Pumice is frothed glass. Obsidians are generally dark colored to black, yet many of them have the same chemical composition as rhyolite and granite. Hence obsidians seem to contradict the rule that nearly all silicic rocks are light colored. However, if the thin edge of a piece of black obsidian is held to the light, it will be seen that the obsidian transmits light and has lost much of its dark appearance. The deep coloring is the result of the uniform distribution throughout the glass of a relatively small amount of dark material. Basalt glass is of rare occurrence. To form it requires extremely rapid chilling of basaltic magma. Summary of Igneous Rocks. There are three principal king of magma, termed, in the order of decreasing silica content: silicic, intermediate (mesosilicic), and subsilicic. Silicic magma forms, according to the environment in which it solidifies, granite, granite porphyry, and rhyolite; intermediate magma forms diorite, diorite porphyry, and andesite and subsilicic magma forms gabbro, dolerite, and basalt. These nine rock names constitute an irreducible minimum for the understanding of igneous geology, and can well serve as starting points for more detailed classification as the occasion may demand. The intrusive rocks are typically coarse grained: they are granite, diorite, and gabbro, comprising the so-called plutonic rocks. The extrusive equivalents of these plutonic rocks are rhyolite, andesite and basalt. Typically, there extrusive rocks are porphyritic, having conspicuous crystals that are set in a groundmass that is so fine grained as to be irremovable by the unaided eye. Basaltic magmas, however crystalline so readily, forming coarse-grained rocks, that the distinction between plutonic and extrusive equivalents is generally much less sharply marked than in the rocks formed from the more silicic magmas.

SEDIMENTARY ROCKS

Sedimentary rocks are formed principally in two ways. Some result from the accumulation of fragments derived from older rocks: detritus (pronounced detritus Latin deterere, detritus, to rub or wear away), consisting of particles of rocks and minerals is carried away from its source by water wind or ice, and is eventually dropped by the carrier as sediment, and later this sediment hardens into rock. Detrital rocks thus formed are classified according to the size of their constituent grains of detritus. The second principal class of sedimentary. rocks is made of material l that was formerly dissolved in the sea (less commonly in is lakes from which it has separated either as the shells of organisms or as chemical precipitates; rocks made in this way are classified according to composition. By far the most abundant sedimentary rocks are shale sandstone, limestone, dolomite, and conglomerate.

DESCRIPTION

Conglomerate consists of gravel that has become 6rmly cemented The stones in it are more or less round (Fig. 17), having become water worn by abrasion during stream transport or by buffeting by waves in the shore zone. They may consist of rocks of any kind or of mixtures of many kinds, but durable material l, such as quarts and quartzite, is more common. In sine, the detritus ranges from coarsest sand grains up to pebbles, cobbles, and boulders many feet in diameter. The interspaces between the stones are filled with sand grains and a cement, which may be silica, clay, calcium carbonate, or iron oxide. Breccias is like conglomerate, except that most of the stones, instead of being round, are angular, with sharp edges and unworn corners. There are varieties intermediate between Breccias and conglomerate, in which the stones are poorly rounded or subangular, blurring the distinction between the well-defined end members. Breccias s, in brief, are coarse angular detrital rocks. those that are firmly cemented alluvia l-fan material l are termed fanglomerates (p. 188), and those of glacial l origin till changed into rock are tillites (p. 195).

Sandstone. Sandstones are widely distributed detrital rocks of finer grain-size than conglomerates. They are of many colors; gray, yellow buff and tawny), red, and brown are most common, but green and other tints occur. Sandstones consist of sand grains held together by a cement. Coarse sandstones grade by increasing grain-size into conglomerates; on the other hand, fine sandstones by decreasing grain-size grade into siltstones, the lower limit for sandstone being that at which the individual grains can not be distinguished by the unaided eye. Most sandstones are made up of grains of quartz or other materials not easily destroyed by weathering and transport. A sandstone is strong and dur- able if its cement is abundant and durable If the pore spaces remain more or less incompletely filled with cement the sandstone is proportionally porous. As is true of conglomerates, sandstones may have very different cements A siliceous cement produces the strongest and most durable sandstone, hence those most desirable as building stones. Sandstones when fractured break around the grains instead of through them, because the grains are stronger than the cement; consequently the broken surfaces have a gritty feel. If, however, the cement is so strong that fracturing takes place across the grains instead of around them, the rock is termed quartzite. Arkose is a sandstone containing abundant feldspar (more than 25 per cent). The feldspar is recognisable by its cleavage planes which reflect flashes of light as the specimen is turned from side to side while being examined. If an arkose contains much coarse feldspar, it closely resembles a granite. The arkose can be distinguished from granite, however, by the fact that its quartz is in angular or subangular particles, instead of being molded around the feldspar as it is in granite. Some arkoses contain leaf remains or other fossils, an impossibility in a granite.

Siltstone . Siltstone is a silt that has been converted into rock. It is intermediate in grain-size between sandstone and shale.

Shale. Gray in various shades is probably the prevalent color of shale. Red and pink in many shades, black, brown, buff, and green are also common. Shale is a consolidated clay and has a characteristic fiat-conchoidal or " shelly " fracture, which is parallel to the bedding. Shale is so fine grained as to seem homogeneous to the unaided eye. It is soft enough to be scratched with a knife; harder varieties are termed argillite Typically, shales have a smooth and almost greasy feel; but a little sand if present will make them feel somewhat gritty Between clays and shales there are all gradations, but typical shale unlike clay, is not plastic when mixed with water. Some consolidated clays lack the characteristic shaly fracture, and massive rocks of this kind are sometimes designated mudstones or, more logically, claystones All these rocks are much too fine grained for the component particles to be determined with the unaided eye, or even with the microscope. Their composition is now being determined by means of X-rays, and it is already established that the composition varies widely.

Limestone. Gray is the most common color of limestones, but many others are seen. Limestones to which plant or animal remains have contributed carbonaceous matter are almost or quite black. Limestones range from extremely fine-grained varieties, irresolvable by the unaided eye, to fragmental and granular varieties. The ultra fine grained are made up of chemically precipitated calcium carbonate, or of the shells of microscopic organisms, or of a mixture of the two. In many coarse-grained limestones, whole or fragmentary shells of megascopic organisms can readily be seen. If the shells predominate and are loosely cemented, the rock is termed Coquina The coarser- grained limestones show on their freshly broken surfaces distinct cleavage planes of calcite. Since limestones are composed chiefly or wholly of calcite, they have a hardness of 3, and hence can be scratched easily. Limestones are " soft " rocks. They effervesce vigorously on being moistened with dilute acid, owing to the copious liberation of carbon dioxide gas. Many limestones are impure, containing admixed clay or fine sand. As the amounts of these admixtures increase, the resulting varieties of limestone grade on the one hand into shale or mudstone, and on the other into sandstone. Chalk is a loosely coherent variety of limestone loosely coherent because weakly cemented. It is extremely fine grained and is white or creamy white. Dolomite. Dolomite resembles limestone closely, but is slightly harder and does not effervesce with cold acid, except on scratched or bruised surfaces, i.e., where the rock has been powdered. The grain- size ranges from aphanitic to megascopically crystalline. Some dolomites are coarsely porous. Dolomite, like limestone, is a carbonate rock. Whereas limestone is composed of calcite (calcium carbonate CaCO2 the rock dolomite is made up of grains of the mineral dolomite, which is calcium-magnesium carbonate CaMg (CO,),. Table of Sedimentary Rocks. The principal sedimentary rocks and the sediments from which they were derived are listed in the following table.

METAMORPHIC ROCKS

A metamorphic rock is a previously existing rock that has acquired a new mineral composition or new structures, or commonly both. The change from the older rock to the new rock was affected by a process acting within the Earth's crust, termed metamorphism. Such metamorphism takes place in response to changes in the geologic environment to which the pre-existing rock was subjected. The resulting metamorphic rock may retain vestiges of the original characters of the rock from which it was derived, but commonly the changes have been so thorough that the original characters were obliterated and the product is to all appearance a new rock Most metamorphic rocks have a more or less parallel arrangement of their component minerals. If some of these minerals are of flaky habit, the parallel arrangement confers on the rock the capacity to split readily parallel with the direction in which the flakes are oriented. This tendency of a rock to split parallel to s plane is termed foliation (Latin folium, a leaf) because the rock breaks into Ieaves or thin slabs. All rocks having a foliation are grouped together as foliates The notable foliation-making minerals are the micas (muscovite and biotite), chlorite, and to a lesser extent amphibole which because of its needle-like habit makes a less well-defined foliation. Metamorphic rocks are abundant, are of extraordinary variety, and comprise some of the most remarkable rocks in the crust Only the simpler and more abundant kinds are described here.

DESCRIPTION

Gneiss. Gneiss (pronounced nice) has an imperfect foliation and is generally coarse grained. Many gneisses have a streaky, roughly layered aspect owing to the alternation of lenses or layers of unlike mineral composition, e.g., white lenses of quartz and feldspars may alternate with thin layers or streaks of black mica. Most kinds of gneiss contain mica, whose flakes are in parallel arrangement. The gneiss splits parallel to the direction marked by the mica flakes Probably the commonest kind is mica gneiss, containing abundant black mica. In some varieties both black and white mica occur together. Gneiss containing prisms of hornblende in more or less parallel alignment is called hornblende gneiss. Many gneisses are obviously granites that have had a foliation impressed on them; they are there- fore called granite gneisses.

Schist. Schist differs from gneiss in having closely spaced, better- developed foliation planes, and as a result it splits readily into thin flaky slabs or plates There is no demarcation between gneisses, which are imperfect foliates, and schists, which are well-developed foliates. In schists the minerals are large enough to be recognized by the unaided eye, a feature that distinguishes them from the finer-grained foliates termed phyllites Schists are generally named for the mineral whose parallel alignment produces the foliation. Thus mica schist contains much mica (biotite, Muscovite or both). Chlorite is the foliation-making mineral in chlorite schist and hornblende in horn- blende schist As schists split parallel to the plane in which the foliation-making minerals are oriented, these minerals seem to make up most of the rock; only by examining a schist on cross-fracture, i.e., at right angles to its foliation can it be seen that the schist contains other minerals, generally quartz. Many schists have scattered through them large, conspicuous, well-shaped crystals, simulating the phenocrysts of igneous rocks. A deep-red garnet commonly occurs in this fashion in mica schists, and such rocks are called garnet-mica schists (Fig. 5). Cruciform crystals of staurolite occur in this way; the well-known lucky stones of Virginia are such staurolite crystals that have weathered out of the inclosing schists.

Phyllite. A phyllite (pronounced fillite) is intermediate in appearance between a schist and a slate. It is finer grained than a schist, so that its constituent minerals are not discriminable by the unaided eye. It differs from a slate in having a higher, glossy luster. Some phyllites, otherwise much like slates in appearance, contain sporadic large well- shaped crystals of garnet and other minerals. Phyllites by increase of grain-size grade into schists on the one hand, and by decrease of grain-size grade into slates on the other.

Slate. Slate is so fine grained that no mineral grains can be seen. Most slates are blue-black, a shade so typical that it is called slate colored, but many are red, green, gray, or black. Slate splits with a foliation so well defined that it yields slabs having plane surfaces al- most as smooth as the cleavage planes of minerals; hence foliation of this kind is called slaty cleavage. In roofing slates this cleavage attains its acme and allows them to be split into plane-parallel slabs of any desired thinness. Slaty cleavage, most remarkably, is not related to the bedding of the slate in which it occurs; in places it is parallel to the bedding but in others it intersects the bedding at angles ranging up to 90" (p.263). Slates grade on the one hand into phyllites, and on the other into shales. The distinguishing differences from shales are as follows: Surfaces of shales are generally of dull luster, whereas slate has a considerable luster. Slate is on the average slightly harder than shale. Most slates ring when struck a light blow, and sonorousness is a time honored test indicating high quality in a roofing slate. Slates when split yield nearly plane surfaces, whereas shales have a semi-conchoidal or " shelly " fracture.

Marble. Marbles are commonly gray or nearly white, but have many other colors. Many are streaked or splotched irregularly Marble is the metamorphic equivalent of both limestone and dolomite. The ordinary variety is composed of calcite and therefore effervesces readily when touched with cold dilute acid, whereas dolomite marble effervesces only if the acid is applied to a fresh scratch. All varieties of marble are soft enough to be scratched easily (hardness about 8). The term marble is reserved in geologic usage for those metamorphosed limestones and dolomites that are visibly crystalline to the unaided eye. In commercial practice, however, any limestone or .marble that will take a polish is called a marble, and is generally endowed with an alluring trade name. Although marbles are metamorphic rocks, few of them are foliated.

Quartzite. Quartzite consists chiefly of quarts, and therefore has a hardness of 7. The grains of quartz of which it is composed are so firmly cemented that when the rock is fractured, the fractures pass through the grains not around them, as happens in sandstone. Most quartzites have been formed by the metamorphism of sand- stones, but some are sandstones that have become so firmly cemented by a quartz cement that they too fracture across the grains and hence they also are called quartzites. Quartzites of metamorphic origin no longer show the sand grains of which the sandstone was composed, and tend to have a glassy appearance. Like marbles, most quartzites are massive and do not have the foliation so characteristic of most metamorphic rocks.

Contact-Metamorphic Rocks. A rich and varied assemblage of metamorphic rocks occurs around the borders of igneous masses (p. 264). Limestones thus altered by heat are especially noteworthy for the handsome suites of well-crystallized minerals that occur in them garnet, vesuvianite, and many others and are favorite hunting grounds for those who enjoy collecting minerals.