DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 150

WASHINGTON
GOVERNMENT PRINTING OFFICE
1898

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

THE EDUCATIONAL SERIES OF ROCK SPECIMENS

COLLECTED AND DISTRIBUTED

BY THE

UNITED STATES GEOLOGICAL SURVEY

BY

JOSEPH SILAS DILLER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1898

CONTENTS.

ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., November 9, 1897.

SIR: I have the honor to submit herewith the manuscript and illustrations for a bulletin to accompany the Educational Series of Rock Specimens.

Very respectfully,

J. S. DILLER,
Geologist.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

PREFACE.

It was early perceived that the field parties of the Geological Survey occasionally had favorable opportunities for the collection of important rock types not readily accessible to others, and that, by systematic cooperation, these parties, without much additional expense, could in the course of years gather a large collection of duplicate type specimens of rocks which would be valuable to educational institutions for the purposes of teaching.

This collection was started in 1882, under the directorship of Maj. J. W. Powell, and at first contemplated 200 suites containing only 100 specimens each of typical rocks belonging about equally to the two great groups, sedimentary and igneous.

To Messrs. Becker, Hague, and Emmons was assigned the collecting of the crystalline rocks, while the others were to be obtained by Messrs. Gilbert, Powell, Chamberlin, Hague, and Kerr. The work progressed steadily for several years, but, in order that important types not met by any of the field parties in their regular work might be obtained, it was found necessary to assign more definitely the task of completing the series and preparing it for distribution.

Although the responsibility for the selection, numbering, and arrangement of the series rests almost wholly with the present writer, these were determined after much correspondence and conference with his colleagues and were controlled largely by circumstances. Although most of the specimens in this collection are intended to illustrate rock types, there are a number—such as concretions (33–36), dike (57), jointing (103, 123), and others—intended to illustrate special features, and it has been thought best to treat each with its kind among the classified rocks rather than under a separate heading.

Acknowledgments are due to nearly all the geologists of the Survey and to many persons outside who have generously aided in collecting specimens within their reach. Special acknowledgment should be made to Prof. C. H. Hitchcock, who collected all the specimens from New Hampshire.

In the preparation of this bulletin, 29 specimens have been described by Prof. J. P. Iddings, of the University of Chicago; 16 by Prof. W. S. Bayley, of Colby University, Waterville, Maine; 9 by Mr. Whitman Cross, of the United States Geological Survey; 5 by Mr. George P. Merrill, of the United States National Museum; 5 by Prof. J. E. Wolff, of

Harvard University, Cambridge, Massachusetts; 4 by Mr. George Otis Smith, of the United States Geological Survey; 3 by Mr. G. K. Gilbert, of the United States Geological Survey; 3 by Mr. Waldemar Lindgren, of the United States Geological Survey; 3 by Prof. C. R. Van Hise, of the State University, Madison, Wisconsin; 2 by Mr. Bailey Willis, of the United States Geological Survey; 2 by Mr. H. W. Turner, of the United States Geological Survey; 2 by Mr. Walter Harvey Weed, of the United States Geological Survey; 1 by Prof. E. B. Matthews, of the Johns Hopkins University, Baltimore, Maryland; 1 by Prof. Florence Bascom, of Bryn Mawr College, Bryn Mawr, Pennsylvania; 1 by Prof. L. V. Pirsson, of the the Sheffield Scientific School in Yale University, New Haven, Connecticut; and 1 by Mr. S. Weidman, of the University of Chicago; in all of which cases the descriptions are duly accredited in the text. All of the descriptions not thus accredited and the other portions of the bulletin have been prepared by the present writer, who desires to acknowledge the aid he has received from Microscopical Physiography of Rock-making Minerals, by J. P. Iddings (translation of Rosenbusch); the excellent Handbook of Rocks, by J. F. Kemp; Petrology for Students, by Alfred Harker; Stones for Building and Decoration, by G. P. Merrill; Rocks, Rock-weathering, and Soils, by the same author, as well as to the more complete works on petrography, especially those of Rosenbusch and Zirkel.

J. S. DILLER.

JUNE 9, 1897.

THE EDUCATIONAL SERIES OF ROCK SPECIMENS.

By J. S. Diller.

THE STUDY OF ROCKS.

INTRODUCTION.

A rock is a large mass of mineral matter forming an essential part of the earth. Granite and sandstone are rocks made up of a number of minerals, but in other rocks, as, for example, limestone and serpentine when pure, the mass is composed wholly of one mineral. In still other exceptional cases, like obsidian, the mineral matter may be in a wholly amorphous condition, like glass—not made up of any definite mineral or minerals. The material of which the rock is composed may be loose, as sand and gravel, or cemented (lithified), as sandstone and conglomerate.

Rocks may be studied (1) in the field, as large masses, where their greater structural features and relations to other rocks are discovered; and (2) in the laboratory, where only hand specimens (stones) are available for investigation. The science of rocks is *petrology*. It is the branch of geology that treats of the origin, mode of occurrence, structure, composition, and alteration of rocks. The branch of petrology that embraces a knowledge of the structural (megascopic and microscopic), mineralogic, and chemical characters of rocks is *petrography*, The knowledge of rocks especially as masses of minerals, acquired largely by microscopic and other laboratory methods, is called by some *lithology*.

It is hoped that the lithology and petrography to be learned in studying this educational series of rock specimens may arouse an interest in the study of petrology, and also in that of geology, of which the former is a part.

STRUCTURAL FEATURES OF ROCKS.

Among the first features of rocks noted by an observer are those arising from structure. They may be *megascopic*—that is, large enough to be seen by the unaided eye—or *microscopic*, visible only with the aid of a microscope.

Fragmental or clastic, *brecciated*, *agglomerated*, *conglomerated*, *pebbly*, *granular*, *cryptoclastic or compact*, *horny*.—Specimens 10, 11, and 12 are all made of fragments and illustrate a kind of structure characteristic of such rocks, viz, *clastic*. Clastic rocks composed of fragments of igneous rocks are said to be *pyroclastic*. Specimens 79 and 99 are pyroclastic. Clastic or *fragmental* structure, as it is sometimes called, may be *coarse* or *fine*, according to the size of the component parts, and other designations may be applied to it on account of variation in the shape of the fragments. When the fragments are angular the structure is *brecciated* (11). If they are coarse, with occasional large blocks of many shapes and sizes irregularly intermingled with finer material, the structure is *agglomerated*. When the fragments are distinctly rounded pebbles the structure is *conglomerated* (10). Such pebbles intermingled with sand produce *pebbly* structure (12). Rock composed of sand, either angular or well rounded, has *psammitic* or *sandstone-like* structure (12–19). It is also called *granular* (fragmental granular); but this term has a wider application than the others, for granites (67), diorites (94), gabbros (109), and similar igneous rocks, whose mineral constituents form distinct, angular, often interlocking grains, are also granular (crystalline granular), but their fundamental structure is *crystalline* and not *fragmental*, as is the case with sandstone.

In specimens 21 and 22, whose fragments, although visible in thin sections under the microscope, are so small that they can not be seen by the unaided eye, the structure is *cryptoclastic* or *compact*. The structure of specimen 134 is more than compact; it is especially fine and close, with the great hardness and conchoidal fracture of flint, due to the induration it has experienced in contact with an igneous rock. Its structure is *horny* or *flinty*.

Stratified, banded, cross bedded, laminated.—Most fragmental rocks are formed in water, and the material of which they are composed is *stratified*, i. e., arranged in layers and beds (strata), as illustrated in the accompanying Pl. I, which represents a series of parallel horizontal strata consisting chiefly of sandstones. A stratum may be thick or thin, and may contain one or more layers. In specimen 16 an indistinct *banded* structure is due to the presence of differently colored layers in a larger stratum of sandstone. A similar structure is produced in igneous rocks by flowing (see below). The layers are usually parallel to the stratification, but in some cases, as in the lower beds of Pl. I, the layers run diagonally across the stratum and produce *cross bedding*. The bedding may be thick and without layers or it may be thin, as in Pl. I, and also in specimen 17, where the fine material is arranged in sheets so thin that it is called *laminated*. This structure is often well illustrated in deposits of sedimentary clay.

Unstratified or massive.—Successive flows of lava, where they spread over a flat country, arrange themselves in sheets so as to show a bedded structure similar to that of stratified rocks, but igneous rocks generally, such as gabbros, diorites (Pl. II), granites, etc., show no such arrangement. They are *unstratified*—that is, *massive*.

Flow structure, streaked.—Rhyolites and other acid lavas are usually

BEDDED STRUCTURE, BEDDING, AND CROSS BEDDING, OAK CANYON, ARIZONA.

viscous at the time of their eruption, and occasionally preserve lines produced by flowing. Specimen 80 shows a *streaked* arrangement of its black glass, due to this cause. The elongated parts may be drawn out so as to form bands and produce *banded* structure. All structures of this kind are included under the general synonyms *fluxion* structure, *fluidal* structure, and *flow* structure. When not visible to the unaided eye it may frequently be seen under the microscope in the stream-like arrangement of the small crystals and other material variously colored.

Porous, cavernous, cellular, pumiceous, vesicular—Specimens 23 and 29 are full of small irregular cavities, and their structure is *porous*. Both are hot-spring deposits, and the porous structure originated at the time the rock was formed. In specimen 153 the cavities are larger. It is *cavernous*. Similar structures occur in acid volcanic rocks. The special form illustrated by specimen 100 occurs most frequently in basic lavas. The cavities are nearly round cells or vesicles, produced by expanding vapor contained in the molten rock material at the time of its eruption. This structure is *cellular*. Sometimes the lava is so inflated by expanding vapors as to be froth-like, *pumiceous*, as in specimen 59. Pumice is usually a product of highly explosive volcanic eruptions. Vast quantities of it were thrown into the air by the great eruption of Krakatoa in 1883. When there are but few cells, so that they appear as separate vesicles, the rock is *vesicular*. The cells and vesicles of lava are formed while it is yet viscous, and if the lava afterward moves, the cells will be elongated in the direction of motion.

Amygdaloidal.—After vesicular lavas solidify, percolating waters frequently deposit mineral matter of various kinds in their cavities. Quartz, calcite, zeolite, etc., are deposited in the cells, producing, as in specimen 139, an *amygdaloidal* structure. The almond-shaped kernels filling the cells are known as *amygdules*.

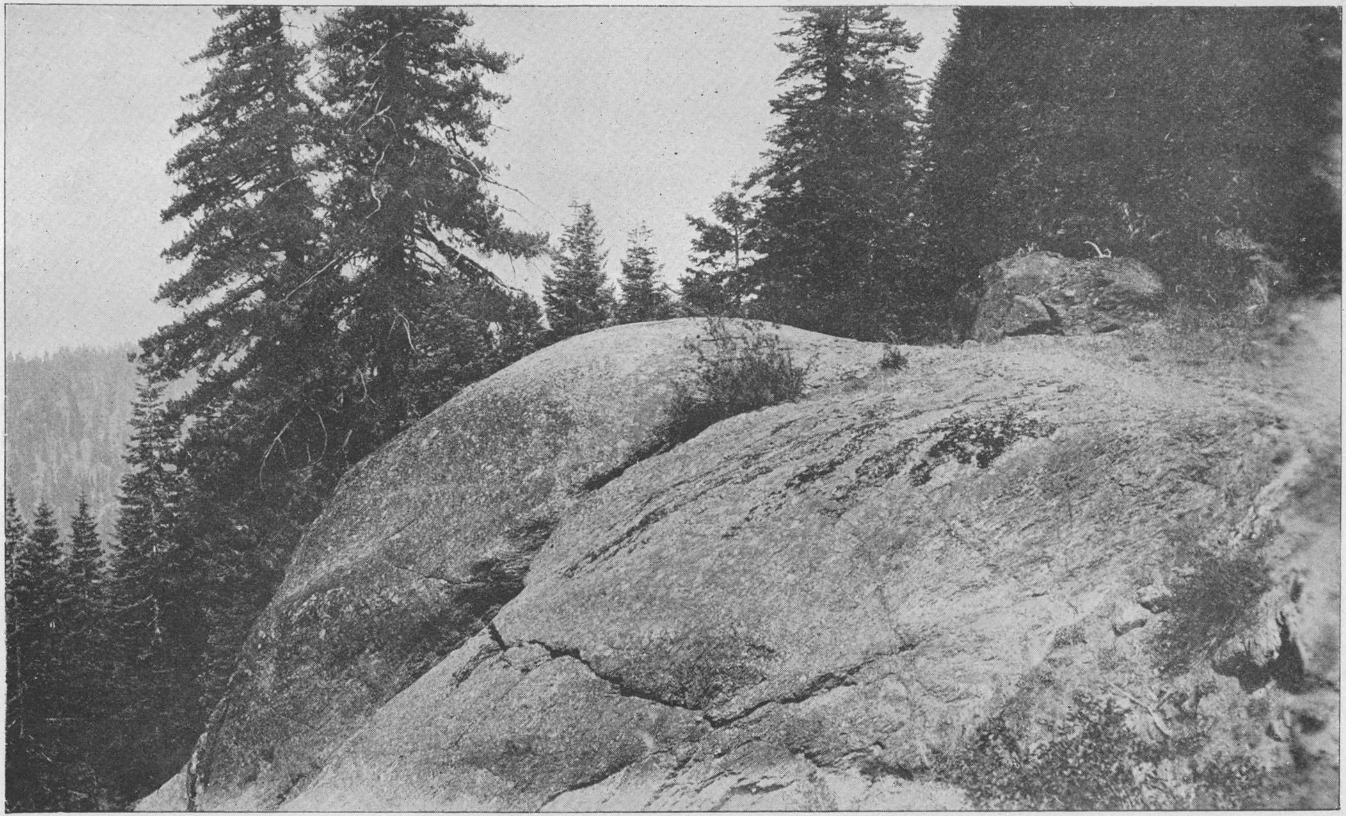
Vitreous or glassy, perlitic, devitrified.—Specimen 60 illustrates *vitreous* or *glassy* structure, so named on account of similarity to artificial glass. It is limited to igneous rocks, and results from the chilling of molten rock material (*magma*) so suddenly as not to permit an appreciable amount of crystallization before it becomes solid. Specimen 61 is almost wholly glass, and is divided by sets of more or less concentric fissures, so as to give it the globular (*perlitic*) structure characteristic of perlite. Some very ancient acid volcanic rocks which were originally glassy have by slow crystallization gradually lost their glassy character and become *devitrified*. Specimen 136 illustrates this feature. The minerals developed are chiefly quartz and feldspar.

Crystalline, porphyritic, holocrystalline, hypocrystalline, amorphous, lithoidal, even-crystalline granular.—In specimen 90 the prominent white portions are feldspar crystals, the dark blade-shaped crystals are hornblende, and the hexagonal ones are mica. These forms result from crystallization. The rock structure produced by crystallization is *crystalline*, a feature which is common to many igneous and metamorphic rocks.

Specimen 90 is a good example of one type of crystalline rock. The feldspar, hornblende, and mica each has its own peculiar form, i. e., is *idiomorphic*. The gray portion of the rock appears uniform to the unaided eye. It is the *groundmass*, in which the prominent crystals (*phenocrysts*) are embedded, producing the *porphyritic* structure. In a thin section of 90, it may be seen under the microscope that all the gray matter of the groundmass is crystallized. There is no amorphous matter (*base*) present; the rock is completely crystalline, i. e., *holocrystalline*. Granites, syenites, diorites, and similar igneous rocks, as well as gneiss, mica-schist, and others among the metamorphics, are holocrystalline. The other extreme is represented by obsidian (60), in which there may be no visible crystallization, its structure being *amorphous*. Many lavas, such as 62, 63, 82, 86, 101, etc., contain various proportions of both crystalline and amorphous material, and their structure is said to be *hypocrystalline*. Specimen 62 is an acid lava having a low degree of crystallization. On account of its compact, stony character the structure is called *lithoidal*. In granite the minerals crystallized under circumstances that made them interfere with one another and prevented the development of perfect crystals, such as produce porphyritic structure. On the other hand, the mineral grains are angular, interlocking, and of approximately equal dimensions, so that the rock is *even-crystalline granular*. Even-crystalline granular structure is so well illustrated by granite (66–69) that it is often called *granitic* or *granitoid*. The various minerals, instead of being bounded each by its own peculiar form (idiomorphic), as are the phenocrysts in porphyritic rocks, have irregular angular forms determined by interfering crystallization; each takes the form imposed on it by its growing neighbors, and is *allotriomorphic*. In specimen 90, among the phenocrysts of feldspar, hornblende, and mica there are occasional prominent round grains of quartz embedded in the gray groundmass. These grains of quartz differ from the other phenocrysts in not being idiomorphic. They lack the crystalline form peculiar to quartz and are said to be *anhedral*.

Phanerocrystalline, cryptocrystalline, compact, aphanitic.—The series of terms already noted designate structures arising from varying amounts of crystalline and amorphous material. There is still another series (besides coarse and fine), to designate the size of the crystallized grains. When the particles are sufficiently large to be visible to the naked eye the structure is *phanerocrystalline*. When the particles are so fine as to be visible only with the aid of the microscope the structure is *microcrystalline* or *cryptocrystalline*. Very fine-grained igneous rocks, like fragmental ones, are said to be *compact*. In diabases and diorites compact structure has been called *aphanitic*.

Pegmatitic, granophyric, graphic.—In granite, quartz-porphyry, and rhyolite, quartz and feldspar sometimes intercrystallize in parallel positions so as to produce, in certain sections, a graphic appearance. The structure is *pegmatitic*, *granophyric*, or *graphic*, and is well illustrated



MASSIVE STRUCTURE IN DIORITE, SHASTA COUNTY, CALIFORNIA.

in graphic granite (fig. 1), of which there is no specimen in the collection. When the structure is so fine as to be visible only under the microscope, it is *micropegmatitic*, *microgranophyric*, or *micrographic*.

Spherulites and lithophysæ.—In some acid lavas there is a low grade of crystallization, illustrated by specimen 62, in which there is a more or less distinct radial arrangement of the crystalline particles and development of spheroidal bodies (*spherulites*). These are more distinct under the microscope between crossed nicols, when each is marked by a black cross. The hollow spherules (*lithophysæ*) contained in specimen 62 form its most conspicuous feature. The lithophysæ often show concentric shells, and are lined by a multitude of minute crystals. Like spherulites, they are found chiefly in acid lavas, especially in the lithoidal form of rhyolite.

Microlites or crystallites, and globulites.—Crystals vary in size, and may be so small as to be visible only under the microscope. Extremely minute crystals are called *microlites* or *crystallites*. Feldspar and augite occur as microlites. Generally microlites are acicular, or rod-shaped, and, although crystallized and doubly refracting, are not determinable mineralogically. Besides these there are other extremely minute bodies which do not possess crystallographic form and do not sensibly affect polarized light. The simplest of these are round and are termed *globulites*. They are common in hypocrystalline lavas, especially basalt and rhyolite. Branching hair-like forms are called *trichites* and straight ones *belonites*.

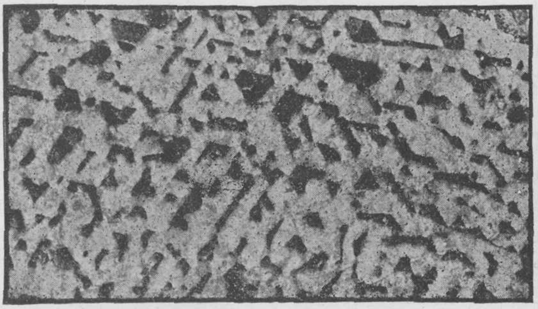


FIG. 1.—Pegmatitic structure of graphic granite. The dark areas are quartz; the light, feldspar. The figure was prepared from a specimen loaned by Mr. G. P. Merrill, of the National Museum.

Concretionary, oolitic.—The spheroidal forms lately noted are found in igneous rocks. Forms somewhat similar, but of different origin, are found in stratified rocks. Specimen 34 shows a piece of fern embedded in sand, which has been indurated in nodular form about the fern by the deposition of carbonate of iron collected from the surrounding rock. Such a structure, formed about a center by additions to the outside, is *concretionary*. Specimens 33 and 35 also are concretions; so is each of the many little round grains in specimen 30, as well as in 26 and 31. When, as in 26, they are abundant and so small that the mass resembles the roe of fish, the structure is *oolitic*.

Secretionary, geode.—A nodule that is hollow and lined with crystals, as specimen 36, is a *geode*. It is a *secretion*, and is formed in a cavity by coating its walls and then gradually making additions on the inside. Amygdules, as illustrated in specimen 139, are secretions and are of the same general character as the geode.

Shaly structure, slaty cleavage, foliated or schistose, schist, gneiss.—Some fine-grained fragmental rocks, whether laminated (17) or not (21 and 22), may be much more easily split into irregular chips or plates parallel to the stratification than perpendicular to it, and the structure that renders them thus fissile, being characteristic of shales, is called *shaly* structure. Specimen 122 may be split readily into thin sheets, like roofing slate (122). The character that renders such splitting possible is called *slaty cleavage*, since it is a common feature of slate. Shaly structure is parallel to the stratification and is determined in the deposition of the material, but slaty cleavage may be parallel or inclined to the plane of stratification, and is induced by movements in the mass due to pressure in the process of mountain building. (See description of specimen 122.) Specimen 129 splits readily in one direction and yet it possesses neither shaly structure nor slaty cleavage, but has what is usually denominated *foliated* or *schistose* structure. This fissility is due to the parallel, more or less lenticular arrangement of foliated and other minerals. The plane of easiest splitting is through the sheets or lenses of the foliated mineral. Foliated structure is a common feature of metamorphic rocks, both sedimentary and igneous. When the foliated structure is coarse the rock is *gneiss*, and when fine the rock is *schist*. Formerly the term gneiss had a mineralogic significance, but here, following Gordon[1] and Kemp,[2] the writer uses it in a structural sense only. Gneiss is well illustrated in the collection by specimen 128, which may be called conglomerate-gneiss as well as metamorphic conglomerate. Specimens 137 and 138 also illustrate gneiss, and 129, 131, and 133 are good examples of schist.

Jointing, rhombohedral, columnar.—Rocks are frequently intersected by divisional planes called *joints*, which divide them into more or less regular bodies. Pl. III represents jointing in metamorphic rocks, in which the several systems of fissures divide the rock into *rhombohedral* bodies, illustrated by specimen 123. In igneous rocks the jointing gives rise to *columns* (Pl. IV), like those of the Giant's Causeway and Fingal's Cave. Specimen 103 is a small column.

METHODS OF PHYSICAL ANALYSIS.

Within the last thirty years great advances have been made in the study of rocks, especially in the appliances for their detailed chemical and physical investigation in the laboratory. Chemical analysis gives the sum total of the chemical elements they contain, but in most cases this does not disclose the mineral composition of the rocks analyzed,

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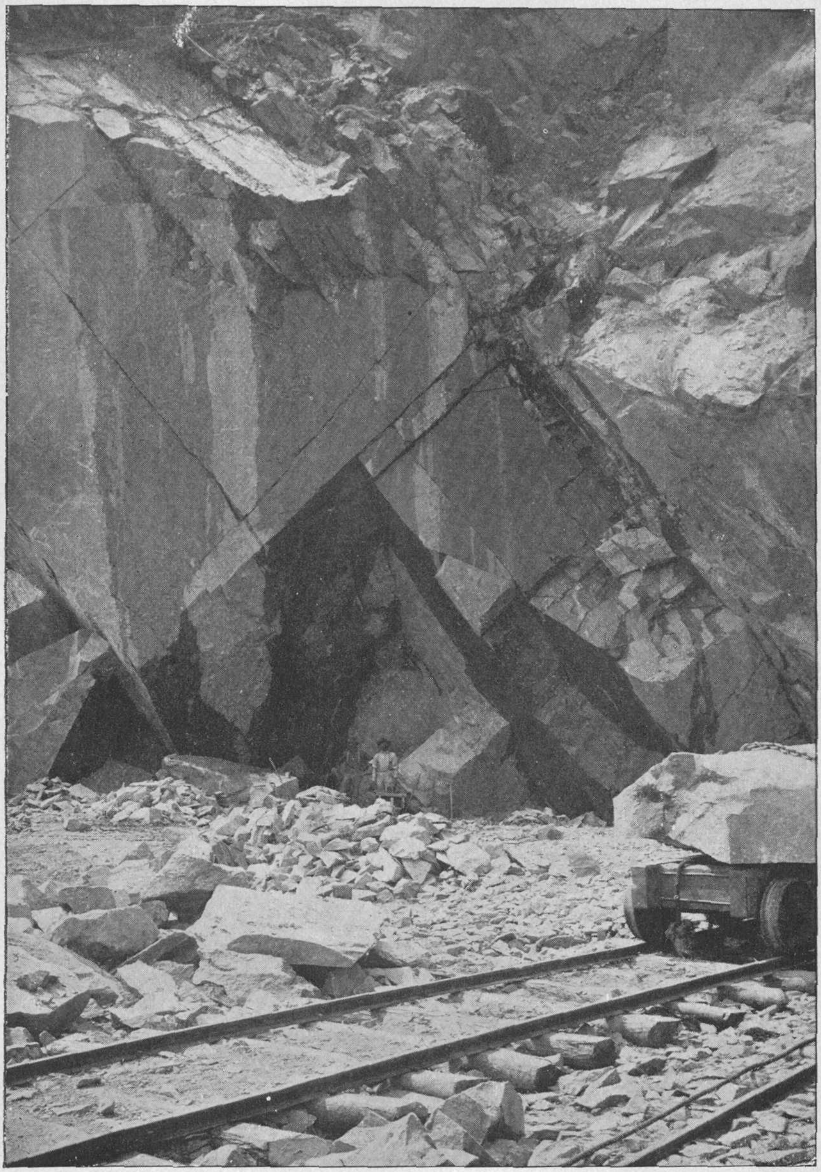
[1] C. H. Gordon, Bull. Geol. Soc. America, Vol. VII, p. 122.

[2] J. F. Kemp, Handbook of Rocks, p. 95.



RHOMBOHEDRAL JOINTING IN GNEISS, POTOMAC RIVER NEAR WASHINGTON, DISTRICT OF COLUMBIA.

nor does it throw any light on their structure, which is closely related to their origin and history. For these we must depend on physical analysis.

There are three important methods of partial or complete physical analysis of rocks: (1) By means of heavy solutions, (2) by means of an electro-magnet, the rock in both cases being used in the form of small particles, and (3) by means of a polarizing microscope, thin sections of rock being used.

The first method depends for its efficiency upon a difference in the specific gravity of the minerals composing the rocks, and is quantitative as well as qualitative; the second depends upon the relative magnetic susceptibility of the associated minerals; and the third depends upon their optical properties. The last is by far the most important and complete method, and when practicable should be employed first, as it will certainly furnish information of value in the application of the other methods. It is chiefly qualitative, determining the minerals and structural elements of rocks, but affords also a means of estimating approximately the quantitative relations of the minerals.

SPECIFIC-GRAVITY METHOD.

If a mixture of dry sawdust and iron filings be thrown into water the sawdust will float and the iron filings will sink, the two being separated by means of a liquid whose specific gravity is between those of the mixed substances. Minerals of which rocks are composed differ in specific gravity, and by employing heavy liquids of intermediate specific gravity the minerals may be separated. The best liquids for this purpose readily mix with water, so that their specific gravity can be conveniently changed by the addition or evaporation of water.

Preparation of the material.—The rock to be investigated should be pulverized by stamping (not grinding) in a mortar. To separate the grains and dust a series of sieves or bolting cloths may be used. Those found most generally useful are bolting cloths Nos. 10 and 16. The grains which go through No. 10 and not through No. 16 are usually of the best size for separation in the heavy liquid, and, having been rubbed, are clean and free from dust.

Solutions most commonly used.—Thoulet brought into general use a solution of potassium iodide and mercuric iodide mixed in the proportions of KI to HgI_2 as 1 to 1.24. With this solution a specific gravity of 3.196 may be obtained. It is readily miscible with water, and as easily evaporated, so that its specific gravity may be conveniently changed as desired.

Cadmium borotungstate, barium mercuric iodide, and methyl iodide have been used, but the separation of minerals having high specific gravity is most easily attained by means of a solution prepared by mixing nitrates of silver and thallium in the proportion of 1 to 1. For the methods of preparing the solutions and descriptions of the apparatus used, as well as its manipulation in making the separation, reference may be made to the following works:

Mikroskopische Physiographie der Mineralien und Gesteine, I. Band (die petrographisch wichtigen Mineralien), by H. Rosenbusch, third edition, pp. 226–250.

Translation of the above, Vol. I, by J. P. Iddings (third edition, 1893), pp. 98–107.

Lehrbuch der Petrographie, by F. Zirkel, second edition, Vol. I, pp. 94–108.

American Journal of Science, December, 1895, third series, Vol. L, p. 446.

To convey a more definite idea of this method of analysis, a description may be here inserted of the Smeeth separating apparatus, which is illustrated in fig. 2.

This consists of a wineglass-shaped base (*a*), with a hollow standard, a tube (*b*) to contain the heavy liquid in which the separation takes place, and stoppers (*c* and *d*) to close the upper and lower ends of the tube.

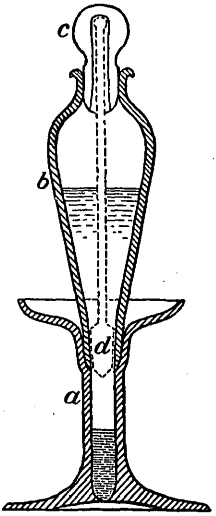


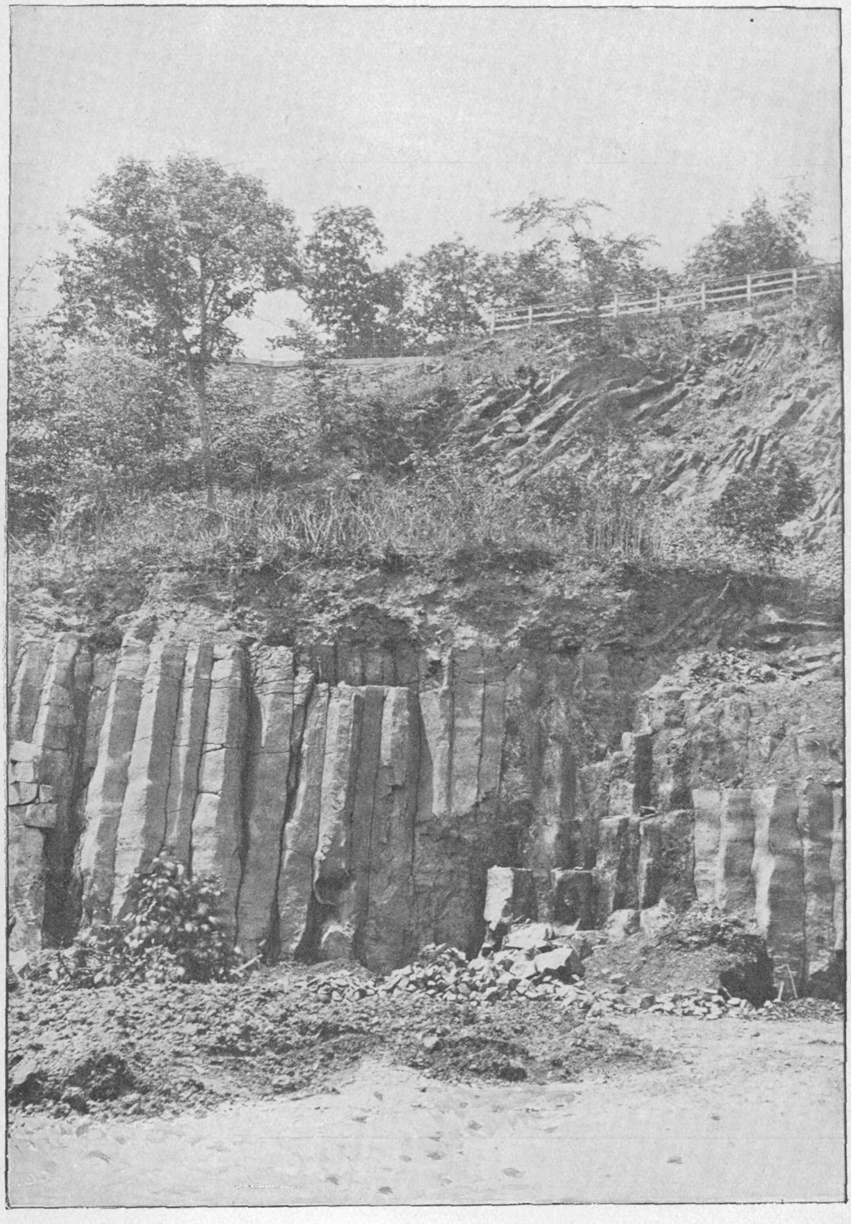
FIG. 2.—Smeeth separating apparatus.

All of these separate parts have ground fittings, so as to be water-tight. To make a separation, place the tube *b* in *a*, as in the figure, but with the stoppers *c* and *d* removed. Fill the tube *b* about three-quarters full of the heavy solution; add the rock powder, then the stopper *c*, and after the tube has been shaken so as to thoroughly wet the powder allow it to stand for separation. The particles heavier than the liquid will sink to the bottom and those lighter will rise to the surface. On account of adhesion among the particles some of the heavier ones will be lifted to the top, while lighter ones will be pulled down to the bottom. These may be liberated by stirring both portions at the same time with a small glass rod inserted from above. By repeating the stirring several times it is possible to secure a complete separation.

It will be readily seen that by inserting the stopper *d* the tube *b*, with its contents of heavy liquid and light material floating on top, may be removed and the heavy material washed out of *a* for study.

The tube *b* may be again inserted in *a* and the stoppers removed, allowing the heavy liquid to fill the standard of *a*. Distilled water may be added to the liquid to lower its specific gravity, so that the next heavier particles will sink and separate as before. Thus by successive additions of small quantities of water a powdered rock composed of many minerals differing in specific gravity may be separated into its constituents.

In making mineral separations it is especially desirable to discover



COLUMNAR JOINTING, WATCHUNG MOUNTAIN, ORANGE, NEW JERSEY.

as closely as possible the specific gravity of the mineral separated, and this may be accomplished approximately by determining the specific gravity of the solution at the time of separation. There are several ways of doing this: (1) By means of indicators of known specific gravity; (2) by using the Westphal balance; or (3) by using Solomon's apparatus for determining the specific gravity of liquids. Only the first two of these need be noticed more fully here.

With a series of indicators, the specific gravity of which has been accurately determined, the specific gravity of the liquid may be found by placing the indicators in the liquid. These indicators may be suitable fragments of minerals, or other specially prepared material. Those heavier than the liquid will sink; the others will rise; if one has the same specific gravity as the liquid it will remain suspended and thus indicate the specific gravity of the liquid. If several such indicators are placed in the tube with the powder to be separated, the specific gravity of the material may be approximately determined by comparison at the time of separation.

A simple but efficient series of indicators has been devised in the petrographic laboratory of Harvard University, under the direction of Prof. J. E. Wolff. To prepare them, seal up by melting at one end a number of short lengths of small glass tubes; put in each a certain amount of mercury or lead, so that they will form a regular series increasing in weight from the lightest to the heaviest; seal up the other end of each, leaving a short piece of platinum wire projecting to form a loop or hook by which the indicator can easily be removed from the heavy liquid. It is best to make a large number of these at once, and then by successive dilutions of the heavy solution to determine the specific gravity of the series by using the Westphal balance. Thus solutions are obtained in which the minerals remain exactly suspended, and by measuring with the balance the specific gravity of the solution, that of the minerals is determined.

The Westphal balance, made by G. Westphal, of Cella, province of Hanover, Germany, is illustrated in fig. 3. It consists of a base with an upright hollow cylinder *a*, in which slides the rod *b*, controlled by the screw *c*. On *b* is supported the frame *d*, which at *e* forms the fulcrum of the beam *f*. The base may be leveled by the screw *g*, and when *a* is vertical and the two points at *h* are together the beam *f* is horizontal. From the hook *k* hangs the sinker *l*. The liquid whose specific gravity is to be determined is put in a glass vessel *m*, and the specific gravity is weighed directly by a decimal series of weights and riders hung at *k* or upon the dividing beam *f* between *e* and *k*. The specific gravity indicated by the riders in the figure, that at *k* having the value 2, is 2.915.

As the particles of different minerals in the same rock vary greatly in size, structure, and hardness, it is not to be expected that all of them will be present in the powder prepared for separation in the same proportion as in the original rock. In fact, some of them may disappear entirely in the dust while the powder is preparing for separation. Upon examination of the powder it is generally found also that many of the grains, instead of being homogeneous, are composed of more than one mineral. Furthermore, different minerals may have the same specific gravity. For these reasons it is not possible by using heavy liquids to make accurate mineral analyses of rocks, but only a rough approximation of their mineral composition can be attained. This method, however, affords a most convenient means of obtaining separately considerable quantities of particular rock-forming minerals for study.

Thin laminated minerals may be separated from others by allowing the rock powder to glide gently over paper, or to fall upon the moistened sides of a glass funnel. On account of their shape they sink slowly in water, and may be separated to some extent by vigorously stirring the powder in water and, after allowing it to stand a few moments, decanting quickly.

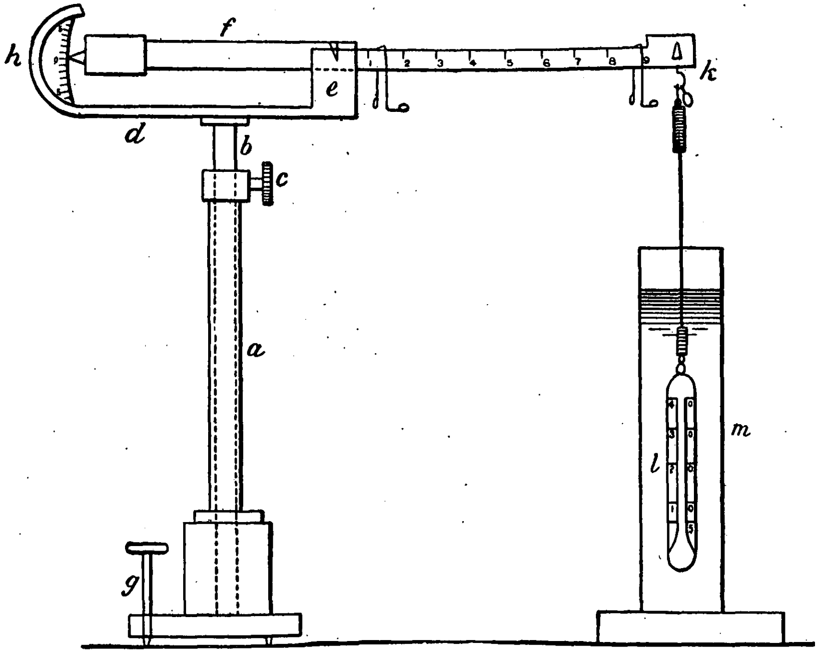
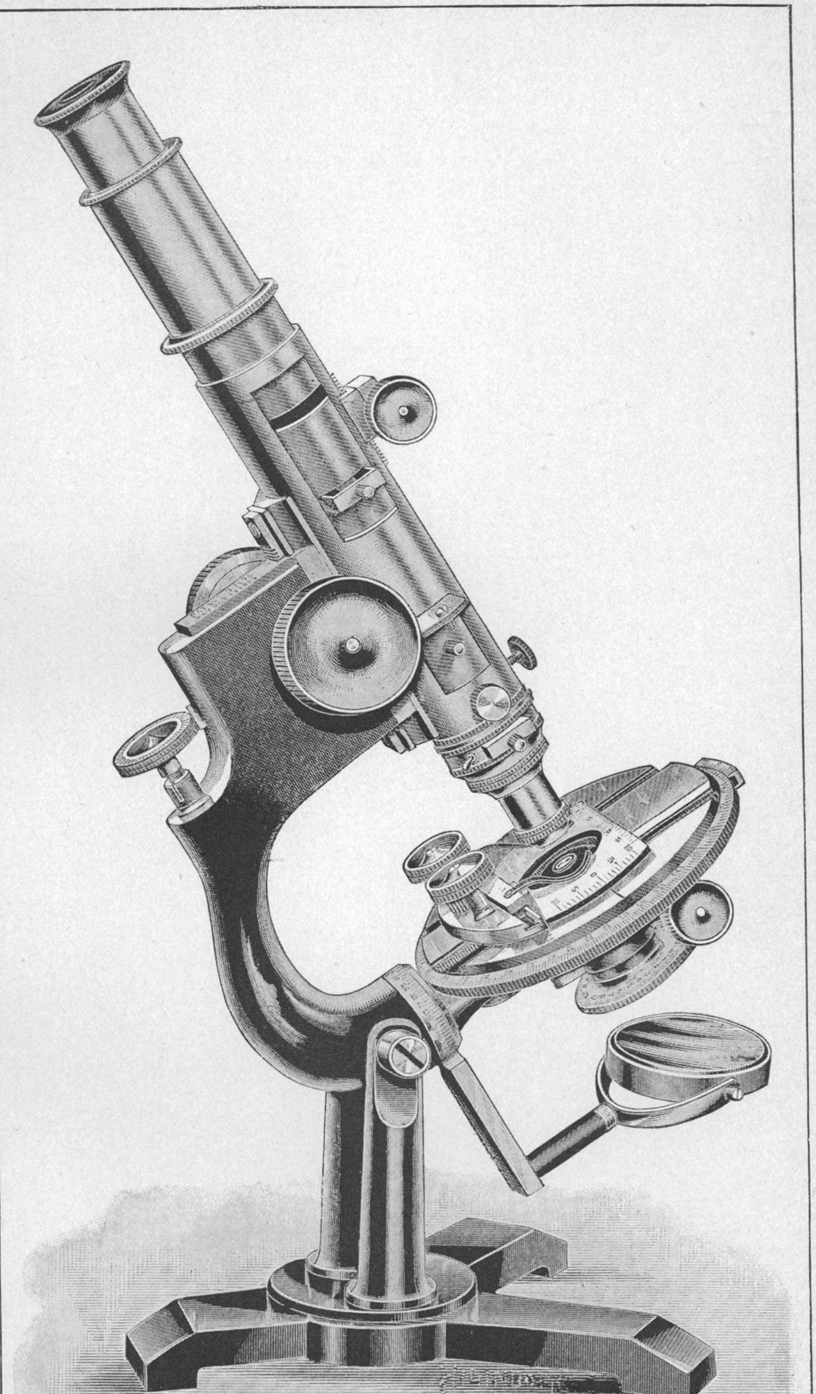


FIG. 3.—Westphal balance.

ELECTRO-MAGNETIC METHOD.

Magnetite may readily be removed from rock powder prepared as already indicated, by passing an ordinary magnet closely over the powder spread out upon paper. With a much stronger magnet—an electro-magnet—a number of other minerals, such as amphibole, pyroxene, olivine, epidote, garnet, etc., having considerable iron in their



PETROGRAPHIC MICROSCOPE.

composition, may be lifted from the paper and thus separated from feldspar, quartz, and other nonmagnetic minerals. By varying the magnetic moment of the instrument the iron-bearing minerals may be more or less completely separated from one another.

MICROSCOPIC METHOD.

As minerals differ among themselves in the forms of their crystals, so also they differ in their effect on light which passes through them. The optical properties of minerals are directly dependent on crystallographic relations, and afford especially valuable data for their determination in rocks.

Petrographic microscopes are arranged with reference to studying rocks by transmitted ordinary and polarized light so that the optical properties of their component minerals may be discovered.

In the accompanying cut (Pl. V) is shown such a microscope,[1] a description of which is here given.

The screw supporting the arm between the pillars allows the instrument to be inclined at any angle. The main tube is provided with a cloth lining, into which the drawtube carrying the ocular is fitted. There is a coarse adjustment by rack and pinion, and a fine adjustment by a micrometer screw. The mirror is both flat and concave and the mirror-bar is adjustable.

Coming now to the peculiarly petrographical features, we have the lower nicol-prism, or polarizer, inclosed in a cylindrical metal box, both ends of which are protected by glass. This box is capable of a complete revolution, and is provided with a graduated silvered circle and index. It is held by a cylindrical frame, in which it may be raised or depressed at will by a rack-and-pinion movement. This frame is attached to the under side of the stage by a swinging arm, so that the whole polarizing apparatus may be thrown to one side if desired. A strong compound lens may be screwed upon the upper end of the polarizer whenever strong illumination or converged polarized light is needed.

The circular stage (9.5 cm. in diameter) is provided with a beveled silvered edge, graduated to degrees. Upon this is mounted, for smooth and concentric revolution, the admirable mechanical stage known in the manufacturers' catalogue as No. 1052. This carries an index for reading the graduated circle, and is also provided with silvered graduations for its two rectangular movements, whereby any point within a section can be readily located. The upper sliding bar, which carries the object, has been shortened, so as to be flush with the revolving stage only when pushed to its extreme limit on either side. With this, square or short rectangular glasses must be used for mounting, which will avoid any interference with the revolution of the stage.

Into the nose piece, just above the objective, is an opening, intended to receive the four following accessories, each mounted in a separate brass frame: (1) A Bertrand lens for magnifying the interference figures; (2) a quarter undulation mica plate; (3) a quartz wedge; (4) a Klein quartz plate or a gypsum plate, with red of the first order.

The centering of the various objectives is secured by two screws, having motions at right angles to each other.

The upper nicol-prism, or analyzer, is inserted in the tube, in order to avoid the diminishing of the size of the field, which is unavoidable when the prism is placed over the ocular as a cap. To accomplish this, and at the same time to keep the

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[1] Manufactured by the Bausch & Lomb Optical Company, Rochester, New York.

tube dust-tight, the nicol is inclosed in one side of a double-chambered box. The other side is left vacant, and the box may be slid to and fro as ordinary or polarized light is desired. A metal sheath protects this box from above.[1]

For the microscopic study of rocks the material is best prepared in the form of thin sections.

Preparation of thin sections.—For the preparation of thin sections of rock, a thin but strong chip about as large as a 25-cent piece is selected. The chip is held in the hand and ground smooth on one side. The grinding may be done on a fine sandstone, emery stone, whetstone, or iron plate on which emery, first coarse (No. 70) and finally fine (flour), is used to make the surface perfectly smooth. It is much more convenient, however, and less laborious to grind on a revolving iron plate mounted on the top of a vertical axis to which power is applied by the foot or from some other source.

After making a smooth plane surface as large as the chip will permit, cement it with Canada balsam to a piece of heavy glass about 1 inch square in the following manner. Place the square glasses and ground chips on a small, gently heated brass table. When the chips are thoroughly dry, place on the glasses some balsam, hardened by evaporating part of the turpentine, and press the flat side of the chips on the glasses, so as to remove all bubbles of air. When cooled, the chips should adhere firmly to the glass.

A cement which is preferred by some to Canada balsam is obtained by slowly melting together a mixture of 16 parts by weight of viscous Canada balsam and 50 parts of shellac and keeping them heated for some time. The mass, as it completely cools, may be drawn out in strings and rolled between the hands into convenient rods about 1 cm. thick and 20 to 30 cm. long.

Holding the chip by means of the thick glass, after mounting as above described, grind down its other side carefully until the rock shows signs of breaking away. The glass should be thick, so as not to bend, and should be pressed evenly, so that the section may be ground uniformly throughout. Finer emery (No. 120) should be used toward the last, on a perfectly flat iron plate, and for the final grinding the finest washed emery (No. FFFF), on a smooth glass plate, until the section is completely transparent.

The extra balsam around the section should be removed with a warm knife blade and the section thoroughly cleaned by washing it first in alcohol with a soft camel's hair brush, and finally with clean water. It is then put, section upward, in a shallow bath of turpentine for some hours, until the balsam is dissolved and the thin section completely loosened from the thick glass. After removal from the bath it is carefully washed again, to prepare it for transfer to a thinner glass. The thoroughly cleaned object-glass on which the section is to be finally

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[1] Copied from a paper on a new petrographic microscope of American manufacture, by the late Prof. G. H. Williams: Am. Jour. Sci., Feb., 1888, 3d series. vol. XXXV, pp. 114-117.

mounted is placed on a small table as before, and a drop of balsam is placed on it from the bottle (fig. 4) by pressing the rubber bulb. The sections are then carefully transferred by sliding them with mounted needles from the thick glass to the drop of balsam. The balsam, heated by a lamp beneath the table, becomes more liquid, and the section is manipulated by the mounted needles until all parts of it above and below are covered with balsam and all bubbles are removed. Bubbles are easily removed by pricking them with a heated needle. When the balsam has been evaporated sufficiently, a bit of it removed by a mounting needle will not adhere to the thumb-nail if applied while yet fluent. It must be heated gently and not too long, else it will become too brittle. The thin cover glasses, having been thoroughly cleaned with alcohol and water, are then put on the section and pressed down gently, so as to squeeze out the superfluous balsam, which, after cooling, is removed and the cover section cleaned as before.

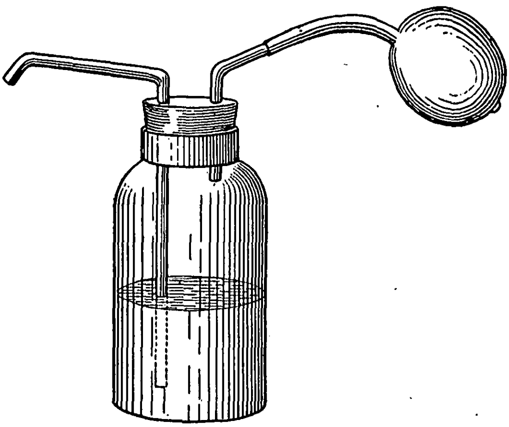

FIG. 4.—Balsam bottle.

Oriented and other sections are often desired of rocks which may not be chipped. In such cases, to obtain a slice for grinding, it is necessary to have a rock saw. An apparatus combining both saw and grinding disk with motive power was devised by the late Prof. George H. Williams. It contains a storage battery and an electric motor, a grinding disk, an emery wheel, and a diamond saw.[1] Diamond saws may be made by taking a flat circular sheet-tin (tinned iron) disk 6 or 8 inches in diameter and placing it in a vise between flat wooden disks, allowing the tin to project one-fourth of an inch all around. Place a knife-edge across that of the tin disk at an angle of about 15 to 20 degrees and strike it a blow, so as to cut a nick an eighth of an inch deep into the edge of the disk. Repeat this operation until the entire periphery of the tin disk has been notched or nicked, the nicks to be about one-tenth of an inch apart, cut in directions which may vary in different quadrants of the disk. While nicks in the same quadrant of the disk's edge should be parallel, those of adjacent quadrants should be nearly perpendicular to each other. Mix diamond dust or bort with a little oil to make it adhere, and fill the nicks, using a small pointed stick. Lay the edge of the tin disk on a flat iron and hammer gently on the sides along the edge, so as to

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[1] For a complete description of this machine by Professor Williams, see Am. Jour. Sci., February, 1893, 3d series, Vol. XLV, p. 102.

close the nicks and hold the diamond dust. If the dust is deeply buried in the nick the saw will not cut at first.

A very serviceable saw may be made of annealed iron wire, as illustrated in fig. 5. *c* is an endless wire (gauge 16) running over two pulleys, *a* and *b*, 18 inches in diameter. To the lower pulley, *b*, the power is applied by a shaft. These pulleys at work should make about 250 revolutions a minute. The upper one is pulled up on a sliding frame by the weight and cord *g*, to keep the wire stretched. The ends of the wire must be carefully soldered together and filed smooth. Water should be dropped by the tube *i* where the specimen to be cut is pressed against the wire, which may be supplied with emery by the fingers of the operator. The wire may be used as a scroll saw and a slice may be thus cut out of the middle of the specimen. This saw has been successfully used in the petrographic laboratory of the United States Geological Survey for the last seven years.

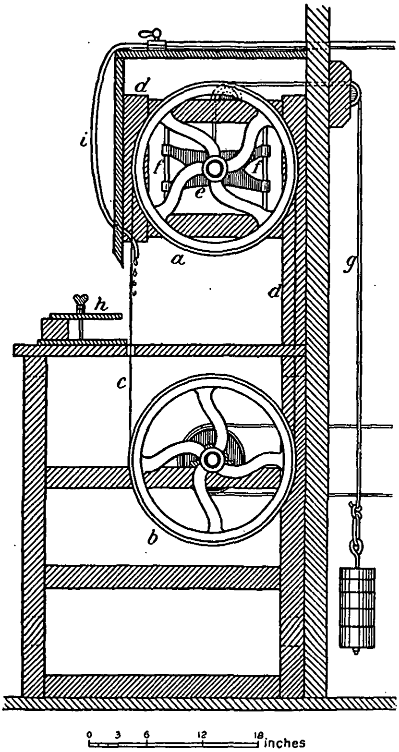

FIG. 5.—Wire saw, United States Geological Survey. *a*, *b*, pulleys with V groove; *c*, endless iron wire; *d*, frame; *e*, guide; *f*, bolts, three-fourths inch; *g*, tension; *h*, clamp; *i*, water tube.

In the same laboratory the grinding apparatus represented in fig. 6 has been found equally successful. The cast-iron frame *a* carries the steel spindle *b*, to which is screwed on top the cast-iron plate *c*, 12½ inches in diameter. The plate revolves when at work about 1,200 times a minute, in a box, *d d*, and is underlain by a block of same size, *e*, to prevent emery from getting to the spindle. Separate plates may be kept for coarse and fine grinding, and a buff wheel may be fitted to the same spindle for polishing. For grinding and polishing large specimens for exhibition a larger plate may be used.

Soft, porous material may be hardened by heating it in Canada balsam, and when cooled a section may be made as already indicated.

Rock powder may in many cases be most conveniently studied by mounting it between a glass slide and cover in a drop of water. To study the internal structure and optical properties, one must avoid the total reflection from the surface of the particles, and it is better to mount the powder, which should be of nearly uniform size, in a substance whose index of refraction is nearly the same as that of the powdered mineral. For this purpose glycerin ($n = 1.46$), Canada balsam ($n = 1.54$), and a concentrated solution of iodide of potassium and mercury ($n = 1.73$) have been used, but for preservation Canada balsam is preferred. To secure a uniform distribution of the powder in the balsam, put a thin film of solid balsam on the central portion of the slide and spread the powder properly on it, then upon heating it slightly the powder will adhere. It can then be covered with balsam dissolved in ether or chloroform and furnished with a glass cover.

Three of the methods of physical analysis by means of which rocks may be separated more or less completely into their mineral components have been given in the preceding pages. In applying the first and second of these methods, the observer discovers some of the important properties of the minerals by which they are distinguished from one another, but their final determination generally depends largely upon the microscopic and optical study of the separate grains.

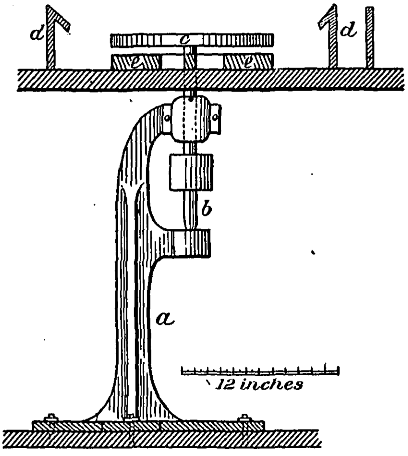

FIG. 6.—Grinding apparatus, United States Geological Survey.

The third method, the microscopic method of rock analysis, is by far the most comprehensive, and affords the most valuable means of discovering not only the mineral composition but also the structure of rocks, and throws much light upon their genesis and history. To apply it successfully it is necessary to know something of minerals, especially of their optical properties. In the succeeding chapter are given brief descriptions of the minerals which play a part, more or less important, in any of the rocks of the series. Only brief mention is made of their optical properties.

Full and systematic accounts of rock-making minerals may be found in the works of Dana,[1] Rosenbusch,[2] Zirkel,[3] and Fouqué and Michel Lévy.[4]

For the convenience of English and American students an excellent translation of Rosenbusch has been made by Prof. J. P. Iddings.[5]

THE PRINCIPAL ROCK-MAKING MINERALS.

Although there are over 800 species of minerals, there are only about 100 which enter, to any considerable extent, into the composition of

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[1] System of Mineralogy of J. D. Dana, 6th ed., by Edward S. Dana; New York, 1892.

[2] Mikroskopische Physiographie der Mineralien und Gesteine, von H. Rosenbusch; Band I: Die petrographisch wichtigen Mineralien; 1892.

[3] Lehrbuch der Petrographie, von Dr. Ferdinand Zirkel; Vol. I; Leipzig, 1893.

[4] Minéralogie micrographique, Roches éruptives françaises, par Fouqué et A. Michel Lévy; 1879.

[5] Microscopical Physiography of the Rock-making Minerals; An Aid in the Study of Rocks, by H. Rosenbusch; translated and abridged for Use in Schools and Colleges by Joseph P. Iddings; Third Edition, 1893.

rocks, and scarcely a score of them are of prime importance as rock constituents. Rock-making minerals have been variously classified according to their conditions and the part they play in the constitution and history of rocks.

Those minerals whose presence is necessarily implied in the definition of the rock are *essential* minerals, while the others present are *nonessential* or *accessory*. This is well illustrated by granite, of which the essential minerals are quartz, orthoclase, and a ferromagnesian silicate. They are always present, otherwise the rock would not be granite. Apatite, magnetite, titanite, and a number of other minerals are accessory in granite, because they may be present or absent without affecting the kind of rock.

Minerals present in the rock at the time of its origin are *original* or *primary* minerals. The others now present are *secondary* minerals, in that they originated in the rock after it was formed. Secondary minerals may originate within a rock either from the alteration of primary minerals or from the accession of new material from without. Orthoclase, which is an original constituent of granite, is frequently altered to muscovite, quartz, and kaolin, all of which, when so derived, are secondary minerals. A granite may contain at the same time not only the essential and original quartz and muscovite, but also some secondary quartz and muscovite which have resulted from the alteration of the feldspar.

The mineral matter of rocks is in one of two conditions, either *amorphous* or *crystalline*. The amorphous condition arises in the solidification of matter from a molten or gelatinous state under such circumstances as prevent its crystallization. In this way glasses and opals are produced.

The degree of crystallization in solidification from a molten condition depends chiefly on the rate of cooling. If very sudden, practically all the material becomes glass, but in other cases, where the cooling is slower, some of the matter crystallizes, and the amount that becomes glass grows less and less as the rate of cooling decreases. It follows that, if allowed to cool slowly enough, all the mineral matter will crystallize and the rock will become holocrystalline. While many lavas, like pumice (59), obsidian (60), and perlite (61), are glassy, and others, like nevadite (64) and dolerite (105), are holocrystalline, a large number of volcanic rocks, like many basalts, andesites, and rhyolites, contain more or less glassy material. The chemical composition of the glassy material found in rocks varies greatly, not only in its original constitution, but in proportion to the degree of crystallization in the solidification of the lava. Under the microscope between crossed nicols glass is seen to be isotropic and generally to contain minute but more or less distinct crystals.

Opal is hydrated silica; composition, SiO_2+aq. Like glass, it is wholly isotropic, unless affected by internal strains which give it anomalous double refraction. Hardness, 5.5 to 6; specific gravity, 2.2; infusible, and so distinguishable from glass, which is fusible. It forms irregular patches, strings, and veins, as well as pseudomorphs after various minerals, in altered acid eruptive rocks. Its most important occurrence is in siliceous sinter deposited by many hot springs and geysers (23), and in silicified wood (37).

In the following list are given the minerals commonly found in rocks, but it must not be supposed that all are equally important and abundant. The most important mineral of unaltered sedimentary rocks of mechanical origin is quartz, on account of its ability to withstand attrition, as well as its resistance to solvents, both chemical and organic. Calcite and dolomite, although of no importance among sedimentary rocks of mechanical origin, are of greater importance than quartz in the unaltered sedimentary rocks of chemical and organic origin. Among the igneous and metamorphic rocks, quartz, the feldspars, nephelite, leucite, the amphiboles, the micas, the pyroxenes, and olivine are the most important rock-making minerals, and are generally regarded as of prime significance in their classification. Magnetite, zircon, and titanite are of somewhat less importance, while the scapolites, garnet, tourmaline, topaz, epidote, andalusite, cyanite, sillimanite, staurolite, chlorite, talc, and serpentine are of nearly equal importance.

MINERALS ILLUSTRATED BY THIS SERIES OF ROCK SPECIMENS.

The minerals of the succeeding list are arranged according to their systems of crystallization, which bring together generally those having similar optical and other properties.

Isometric system.

Pyrite.
Magnetite.
Chromite.
Spinel.
Fluorite.
Garnet.
Leucite.
Sodalite.
Haüynite.
Noselite.
Analcite.
Perofskite.

Tetragonal system.

Rutile.
Zircon.

Hexagonal system.

Graphite.
Pyrrhotite.
Hematite.
Ilmenite-leucoxene.
Quartz.
Tridymite.
Calcite.
Dolomite.
Apatite.
Nephelite.
Cancrinite.
Tourmaline.

Orthorhombic system.

Marcasite.
Andalusite and Chiastolite.
Topaz.
Staurolite.
Pyroxenes (orthorhombic).
Olivine.
Fayalite.
Zoisite.
Phrenite.
Talc.

Monoclinic system.

Gypsum.
Pyroxenes (monoclinic).
Amphiboles.
Micas.
Chlorite.
Epidote.
Allanite.
Titanite.
Zeolites.
Feldspars (monoclinic).

Triclinic system.

Feldspars (triclinic).
Microcline.
Plagioclase.

Homogeneous aggregates.

Serpentine.
Kaolin.
Glauconite.
Limonite.

MINERALS OF THE ISOMETRIC SYSTEM.

Pyrite.—Disulphide of iron. Composition, FeS_2. Isometric. When well crystallized, usually appears in the form of cubes or pentagonal dodecahedrons. Fine-granular, sometimes radially fibrous, forming nodules. Brittle; hardness, 6 to 6.5.[1] Specific gravity, 4.8 to 5.2. Luster, metallic; color, pale brass-yellow. Streak, grayish black. Opaque. Before the blowpipe on charcoal or in a closed tube gives off sulphurous odors and becomes magnetic. Often occurs as crystals and grains, rarely in large masses. In many rocks, both sedimentary and igneous, but is always an accessory constituent. It is readily distinguished by its color, hardness, and chemical reaction. It occurs as small grains, generally microscopic, in minette (91), camptonite (92), diorite (93), garnetiferous gabbro (109), and hornblende-schist (131). Marcasite (page 37) is essentially like pyrite in all respects excepting crystallization and its easier alterability. Instead of being isometric, it is orthorhombic.

Magnetite.—Magnetic oxide of iron. Composition, Fe_3O_4. Isometric, octahedrons common, dodecahedrons less common, and generally occurs in irregular grains. When massive, often granular. Hardness, 5.5 to 6.5. Specific gravity, 4.9 to 5.2. Color, iron black. Streak, black. Opaque. Strongly magnetic. Magnetite occurs occasionally in large deposits, and is mined as a valuable ore of iron. It is one of the most widely distributed accessory constituents of igneous and metamorphic rocks, in which it occurs as microscopic crystals and grains. Being strongly magnetic it is readily recognized. It forms the whole of specimen 146, but in most of the other metamorphic and igneous rocks it can not be seen without the aid of the microscope unless the rock is powdered and brought under the influence of a magnet, when the little

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[1] The scale of hardness by Mohs and that of fusibility by Von Kobell, used in these descriptions, are as follows:

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

Fusibility.—1. Stibnite: fusible in the flame of a candle in large fragments; 2. Natrolite: fusible in the flame of a candle in small fragments; 3. Almandite garnet: infusible in the flame of a candle, but easily fusible before a blowpipe, even in somewhat large pieces; 4. Green actinolite: fusible before the blowpipe in rather fine splinters; 5. Orthoclase: fusible before the blowpipe in finer splinters; 6. Bronzite: before the blowpipe becomes rounded only on the finest points and thinnest edges.

grains of magnetite will leap forth. Grains of magnetite resemble chromite and ilmenite, but may be distinguished from them by the strong magnetism and the lack of definite blowpipe reaction showing the presence of chromium or titanium.

Chromite.—Isometric, generally in regular octahedrons. Composition, $FeCr_2O_4$. Color, black, but in thin sections by transmitted light, brown. Hardness, 5.5. Specific gravity, 4.3 to 4.5. It commonly occurs in serpentine and olivine and is closely related to picotite, from which it differs chiefly in the amount of chromium it contains. It occurs in the olivine of saxonite (114) and in serpentine (145).

Spinels.—The spinels are aluminous minerals whose crystals are regular octahedrons. The common varieties are given in the table:

The common varieties of spinel.

	Formula.	Color.	Specific gravity.	H.
Spinel	$MgAl_2O_4$	Red	3.5–4.1	8
Pleonaste	$(MgFe)(AlFe)_2O_4$	Dark green	3.6	8
Hercynite	$FeAl_2O_4$	Dark green	3.9	7.5–8
Picotite	$(FeMg)O(AlCr)_2O_4$	Yellowish brown	4.0	8

The first two occur most commonly in gneiss, while the last, occurring in eruptive rocks, is generally enveloped by olivine. All the spinels are accessory minerals, usually small, but unchangeable, for they remain perfectly fresh in rocks whose other minerals are decomposed. Although the spinels occur in many of the rocks of the collection, they are most common in the olivine of the basalts and peridotites, but are visible only in thin sections with the aid of the microscrope. Picotite occurs in the olivine of quartz-basalt (101) and olivine nodules (104), and pleonaste has been observed in cortlandite (113).

Fluorite.—Calcium fluoride. Composition, CaF_2. Isometric crystals, usually cubical. Hardness, 4. Specific gravity, 3.1 to 3.25. Luster, vitreous. Color, various, usually bright, making pretty cabinet specimens. Occurs generally in veins, and rarely in small particles as an accessory constituent of rocks, as in the biotite-granite (67) of Platte Canyon, Colorado.

Garnets.—Silicates of aluminum, iron, manganese, chromium, calcium, and magnesium. The principal varieties are given in the table:

The principal varieties of garnet.

	Formula.	Color.	Specific gravity.
Grossularite	$Ca_3Al_2Si_3O_{12}$	Pale green or yellow	3.4–3.75
Almandite	$Fe_3Al_2Si_3O_{12}$	Red	3.5–4.3
Melanite	$Ca_3Fe_2Si_3O_{12}$	Black	3.6–4.3
Common garnet	Isomorphous mixture of three above	Reddish brown, yellowish red.	....
Spessartite	$Mn_3Al_2Si_3O_{12}$	Red or yellow	3.7–4.3
Pyrope	$Mg_3Al_2Si_3O_{12}$	Blood-red	3.7–3.8

Isometric crystals, usually rhombic dodecahedrons. Hardness, 6.5 to 7.5. Luster, vitreous-resinous. Transparent. Sometimes massive, forming garnet rock. As an accessory constituent it occurs usually in crystals in altered rocks, both eruptive and sedimentary. In the collection, crystals of common garnet appear in garnetiferous gabbro (109), mica-schist (130), and garnetiferous hornblende-schist (141). Pyrope appears in kimberlite (112).

Leucite.—Silicate of aluminum and potassium. Composition, $KAlSi_2O_6$. Probably isometric, with the characteristic roundish crystals icositetrahedral, generally in grains, rarely massive, granular. Hardness, 5.5 to 6. Specific gravity, 2.4 to 2.5. Luster, vitreous. Color, white or gray. Translucent to opaque. Infusible, but decomposed without gelatinization by hydrochloric acid. Resembles analcite, but distinguished by infusibility and greater hardness.

In thin sections under the microscope leucite is polyhedral or round. Small crystals are practically isotropic, but larger ones show complicated twinning lamellæ between crossed nicols, and frequently contain numerous inclusions arranged in zones. Leucite is known only in igneous rocks, chiefly in volcanics. It occurs in orendite (72), where, although abundant, it can be seen only in the thin section with the microscope.

Sodalite.—Chlorosilicate of aluminum and sodium. Composition, $Na_4Al_3ClSi_3O_{12}$. Isometric. Crystals dodecahedral or octahedral. Hardness, 5.5 to 6. Specific gravity, 2.1 to 2.3. Luster, vitreous. Color, blue, greenish, or gray. Easily and completely soluble in hydrochloric acid. On standing, gelatinous silica separates out, and when the solution is evaporated crystals of common salt appear. Heated in a closed tube, blue varieties become white. Before the blowpipe, at 3.5 they fuse, with intumescence, to a colorless glass.

Under the microscope, cross sections of its crystals are quadratic or hexagonal, and appear isotropic, with a low index of refraction. Sodalite occurs chiefly in granular-crystalline igneous rocks of the nephelite-leucite series. It occurs in some parts of pulaskite (74), and also in the nephelite-syenite (77) of Litchfield, Maine, where its small blue grains may be seen occasionally in a hand specimen.

Haüynite and noselite.—Sulphureto-silicate of aluminum, sodium, calcium. Composition, an isomorphous mixture of $Na_5Al_3(SO_4)Si_3O_{12}$ and $Na_3CaAl_3(SO_4)Si_3O_{12}$. The members rich in sodium are called *noselite*, while those rich in calcium are called *haüynite*. Isometric crystals as in sodalite. Hardness, 5.5 to 6. Specific gravity, 2.3 to 2.5. Color, blue, gray, red, or various. Heated in a closed tube, unlike sodalite it retains its color, but before the blowpipe at 4.5 it fuses to a white glass.

Both haüynite and noselite gelatinize easily in hydrochloric acid, and on evaporation abundant needles of gypsum are found in the case of haüynite, but few or none in the case of noselite. Noselite in some rocks has a characteristic dark border. Haüynite and noselite are frequently full of inclusions. Haüynite occurs in the theralite (75) of Gordons Butte, Montana.

Analcite.—Hydrous silicate of aluminum and sodium. Composition, $NaAlSi_2O_6H_2O$. It is one of the zeolites, and, although sometimes a primary constituent, in this series of rocks it is always a secondary mineral, frequently resulting from the alteration of nephelite or leucite. It resembles leucite, and may be distinguished by fusing at 2.5 and gelatinizing in hydrochloric acid. It occurs in the groundmass of porphyritic theralite (76), and possibly also in camptonite (92).

Perofskite.—Calcium titanate. Composition, $CaTiO_3$. Isometric. Crystals generally very small octahedrons or rounded grains. Hardness, 5.5. Specific gravity, 4.1 to 4.4. Luster, metallic. Grayish yellow or brown. Has high index of refraction and anomalous double refraction. It frequently occurs in melilite, nephelite, and leucite rocks, and also in some peridotites. It occurs abundantly in kimberlite (112), but can be seen only with the aid of a microscope.

MINERALS OF THE TETRAGONAL SYSTEM.

Rutile.—Titanic oxide. Composition, TiO_2. Tetragonal crystals, generally prismatic but sometimes in grains, and also extremely minute microscopic crystals in certain schists and slates. Hardness, 6 to 6.5. Specific gravity, 4.19 to 4.25. Luster, metallic, adamantine. Color, yellow, brownish, or red. High index of refraction. Not affected by acids. It is often an original accessory mineral, but in other cases it appears to be secondary from titanite or ilmenite. Rutile is common in gneisses, mica-schist, and rocks rich in hornblende and augite. The hairlike crystals often seen in quartz are supposed to be rutile. It occurs in the quartzite of Eureka, Nevada (118), the phyllite of Ladiesburg, Maryland (126), and the schistose biotite-gneiss of Manhattan Island (132).

Zircon.—Silicate of zirconium. Composition, $ZrSiO_4$. Tetragonal. Crystals usually small, square prisms, ending in pyramids. Hardness, 7.5. Specific gravity, 4.05 to 4.75. Colorless to yellow, pink, violet, or brownish. Luster, adamantine, translucent. Double refraction strong, with high index of refraction. Infusible, not affected by acids excepting by concentrated sulphuric acid when the mineral is in powdered form.

Zircon is one of the most widely distributed original accessory minerals in many igneous rocks as well as metamorphosed sediments. Like spinel, it does not decompose readily, but remains unaltered in the residual material of the crystalline rocks in which it was contained. It may sometimes be obtained by washing such material. It is contained in hornblende-biotite-granite (68), nephelite-syenite (77), schistose biotite-gneiss (132), and many other specimens of this series.

MINERALS OF THE HEXAGONAL SYSTEM.

Graphite.—Nearly pure carbon. Hexagonal crystals, flat six-sided tables, and foliated grains. Hardness, 1 to 2. Specific gravity, 2.09 to 2.23. Luster, metallic. Color, iron-black. Opaque. Thin lamellæ, flexible, but not elastic. Feel, greasy. Infusible and not affected by acids. It is widely disseminated as a pigment in the older metamorphic rocks and occasionally occurs in beds. It occurs in metamorphic conglomerate (128?).

Pyrrhotite.—Sulphide of iron, often containing nickel. Composition, chiefly Fe_7S_8 to $Fe_{11}S_{12}$. Irregular opaque grains of a bronze-yellow to copper-red color and metallic luster. Magnetic, and thus readily distinguished from pyrite. Occurs in cortlandite (113), but is usually microscopic; occasionally it may be seen among the scales of talc in steatite (142).

Hematite.—Ferric oxide. Composition, Fe_2O_3. Hexagonal. Crystals usually thin hexagonal plates. In transmitted light, blood-red. Luster of crystals splendent, hence called specular iron. Sometimes irregular scales. Hardness, 5.5 to 6.5. Specific gravity, 4.5 to 5.3. Color, iron-black to red. Streak, red. Usually opaque, but when thin enough to be transparent is blood-red in transmitted light. Is infusible, but becomes magnetic when heated.

Micaceous hematite and red hematite of themselves form rock masses, often of large size, occurring in beds among the metamorphic rocks, chiefly Archean. Specular iron is widely distributed as an accessory constituent of acid eruptive rocks. It is one of the first minerals to crystallize, and in the form of minute red scales is usually included by the minerals of later crystallization. Occurs forming almost the whole of specimen 121, and also in 52 and 120, as well as in many others.

Ilmenite.—Mainly ferrous titanate, but variable in composition. Formula commonly $FeTiO_3$. Hexagonal. Crystals rhombohedral, but generally in irregular grains. Hardness, 5 to 6. Specific gravity, 4.5 to 5.2. Color, black and opaque. Luster, submetallic. Streak, nearly black. Not magnetic, or feebly magnetic; less so than magnetite. It frequently alters to a white or yellowish-brown, strongly refracting substance, called leucoxene, which, although it contains titanium, is of variable chemical composition. Ilmenite is a widely distributed ingredient of eruptive rocks, especially diorite, diabase, gabbro, and peridotite, and is found less frequently in metamorphic sedimentary rocks. It occurs in kimberlite (112). Leucoxene occurs in aporhyolite (136) and in the residual sand of diabase (148).

Quartz.—Pure or nearly pure silica. Composition, SiO_2. Hexagonal. Six-sided prisms terminated by six-sided pyramids. In eruptive rocks the prismatic faces are very short or altogether absent, so that the faces of the two terminal pyramids come together, forming bi-pyramidal crystals. Hardness, 7. Specific gravity, 2.6. Generally colorless in rocks, but sometimes smoky or bluish.

Under the microscope it is clear and transparent. It is uniaxially positive, and these features usually distinguish it from other minerals with which it is associated. It often contains numerous extremely minute cavities filled with water or liquid carbon dioxide in which there is a bubble in continuous rapid motion.

Quartz is one of the most important and widely distributed of all rock-forming minerals, in both altered and unaltered sedimentary and igneous rocks. It is an essential constituent of granite, quartz-diorite, rhyolite, and dacite, as well as of quartzite, many gneisses, schists, and sandstones.

Rock-making quartz occurs in three phases: granitic phase, porphyritic phase, and clastic phase.

Granitic quartz is such as occurs in granite. It is the youngest original constituent of the rock, and fills the irregular spaces left between the other minerals. Its form is therefore determined by its surroundings—that is, it is *allotriomorphic*. It is usually filled with fluid inclusions. The quartz in gneiss, mica-schist, and other similar crystalline rocks is irregular, granular, and closely related to granitic quartz. It forms veins and sometimes contains gold. In California the auriferous gravels are derived from rocks containing such veins. Granitic quartz is well illustrated by that in the granites (66 to 69); and that in many of the gneisses (132 and 137), schists (119, 129 to 131), and veins (25) is closely related to it. Jaspilite (120) is composed largely of quartz of this character.

Porphyritic quartz usually has well-developed crystal form—that is, it is *idiomorphic*. Fluid inclusions are common, but not so abundant as in granitic quartz, and, furthermore, porphyritic quartz often contains glass inclusions. In many cases crystals of porphyritic quartz have been corroded by the magma in which they originated and reduced to round grains; that is, they have become *anhedral* (90) or are completely destroyed. Porphyritic quartz is illustrated by nevadite (64) and dacite-porphyry (90). It belongs wholly to igneous rocks.

Clastic quartz is such as is found in sandstones and conglomerates of sedimentary origin. It is illustrated in specimens 3 to 5, 10, 12 to 19. Some of the quartz found in rocks is occasionally in the form of chalcedony, which is optically negative and usually fibrous. Of such material agates are composed. Silica in the amorphous state usually contains water and is called opal.

Tridymite.—Pure silica. Composition, SiO_2, like quartz. Hexagonal crystals, usually minute, thin tabular forms. Imbricated, like tiles on a roof. Within rocks tridymite is always of microscopic dimensions. It is found chiefly, almost exclusively, in acid volcanic rocks. It occurs in lithoidite (62) and aporhyolite (136).

Calcite.—Calcium carbonate. Composition, $CaCO_3$. Hexagonal. Crystals rhombohedral, but massive in limestone. Hardness, 2.5 to 3.5. Specific gravity, 2.5 to 2.7. Rhombohedral cleavage perfect, so that it may generally be split with ease into rhombohedrons. Sometimes colorless and transparent (Iceland spar) and used to illustrate double refraction. By placing it on a dot on white paper two dots appear. Often yellowish gray or white. Infusible, but glows and becomes lime. Effervesces readily in cold hydrochloric acid. When powdered, will effervesce in strong vinegar.

Calcite is one of the most important and widely distributed of minerals in rocks. It forms essentially the whole of many limestones (28 to 31, 39, 40, 42, etc.), is the cementing material in calcareous fragmental rocks (12), and is generally abundant in the altered basic eruptives.

Under the microscope it is usually clear and may be distinguished by its cleavage—two sets of lines crossing at an acute angle—and its peculiar pinkish-yellow gray, often irridescent, colors between crossed nicols.

Dolomite.—Carbonate of calcium and magnesium. Composition, $(CaMg)CO_3$, in which varying amounts of magnesia may be replaced by iron or manganese. Hexagonal. Crystals, cleavage, color, and optical and other properties very like those of calcite, but it may usually be distinguished from the latter by means of the characteristic that, unless powdered, it does not effervesce readily in acetic or cold dilute hydrochloric acid. Hardness, 3.5 to 4. Specific gravity, 2.8 to 2.9.

Dolomite, like calcite, is widely distributed, often in crystals whose cross sections under the microscope appear triangular, six-sided, or rhombic. It is an essential constituent of limestone and massive dolomites. Much of the limestone in the United States is dolomite. It occurs in specimens 116 and 117 of the collection, also as a secondary product in the kimberlite (112) of Kentucky.

Apatite.—Calcium phosphate + calcium chloride or fluoride. Composition, $3(Ca_3P_2O_8)+Ca(ClFl)_2$. Hexagonal, crystals generally microscopic, six-sided prisms. Granular in crystalline schists. Hardness, 5. Specific gravity, 3.16 to 3.22. Usually colorless or whitish under the microscope. Rather high index of refraction, so as to appear to stand up in surrounding minerals of later crystallization by which it is included. Soluble in nitric acid without gelatinization, and the solution gives, with ammonium molybdate, a yellow precipitate. Moistened with sulphuric acid and heated, it colors the flame pale bluish green. This distinguishes it from nephelite, with which it is often associated. Widely distributed as an original accessory constituent of granular igneous rocks; common, but less abundant, in basic lavas. Reddish-brown grains of apatite may be seen in the magnetite (146) from Port Henry, New York. It is a microscopic constituent of granite (68), pulaskite (74), nephelite-syenite (78), dacite-porphyry (90), and many other rocks of this series.

Nephelite.—Silicate of potassium, sodium, and aluminum. Composition probably $NaAlSiO_4$, in which one-fourth of the Na is generally replaced by K. Hexagonal. Crystals six-sided prisms, or massive. Hardness, 5.5 to 6. Specific gravity, 2.6. Colorless. Luster vitreous in crystals, but greasy when massive. Fuses at 3.5 into colorless glass. Gelatinizes in acid. The glassy colorless variety in younger volcanic rocks is *nephelite;* the massive form, usually with greasy luster and often colored, in intrusive rocks is sometimes called *eleolite.* They are identical in chemical composition. Nephelite readily alters to zeolites. They are essential constituents of a whole series of extrusive and intrusive igneous rocks. Nephelite occurs in phonolite (73), pulaskite (74), theralite (75 and 76), and, in the phase commonly called eleolite, in nephelite-syenite (77 and 78).

Cancrinite.—Silicate and carbonate of aluminum, sodium, and hydrogen. Composition, $Na_4HAl_3(CO_3)Si_3O_{12}$. Hexagonal. Crystals columnar and massive. Hardness, 5 to 6. Specific gravity, 2.42 to 2.5. Colorless and transparent when fresh, but frequently yellow and of other colors. Fuses easily, effervesces in hydrochloric acid, and when heated gelatinizes. Like nephelite, cancrinite alters to zeolites, and as yet has been found only in nephelite-syenite. It occurs in that of Litchfield, Maine (77), usually as conspicuous yellowish grains.

Tourmaline.—Silicate and borate of aluminum, magnesium, and iron; of complicated composition. Hexagonal. Crystals usually three-sided. Hardness, 7 to 7.5. Specific gravity, 2.94 to 3.24. Color, usually black; luster, vitreous. Readily distinguished under the microscope by its strong absorption when the longer axis of the section is perpendicular to the short diagonal of the polarizer. Tourmaline occurs in granitic igneous rocks, especially near the borders of regions of contact metamorphism and in fissure veins. It occurs commonly also in the members of the crystalline schists; for example, mica-schist (130) and quartz-schist (119). It occurs also in phyllite (126) and other altered rocks.

MINERALS OF THE ORTHORHOMBIC SYSTEM.

Marcasite.—Iron disulphide. Composition, FeS_2. Orthorhombic. Before the blowpipe, on charcoal or in a closed tube, gives off sulphurous fumes and becomes magnetic. Color, pale bronze-yellow. Like pyrite in all essential respects, excepting form of crystallization, by which means alone are the two distinguishable. Marcasite alters much more easily than pyrite. Marcasite is illustrated by specimen 35. The general form of its crystals is suggested by the points projecting from the surface of the nodule. Both pyrite and marcasite readily change to limonite. In specimen 35 the marcasite is almost wholly changed to limonite.

Andalusite and chiastolite.—Aluminum silicate. Composition, Al_2SiO_5. Orthorhombic. Crystals generally in square thick-set prisms, rarely in rounded grains. Hardness, 7 to 7.5. Specific gravity, 3.1 to 3.2. Color, various, often reddish brown or dark; under the microscope usually colorless or reddish; when colored, is pleochroic. Transparent.

replaced Cleavage quite perfect, parallel to prismatic faces. Infusible. Saturated with cobalt solution after ignition and then again ignited, becomes blue. Occurs in argillaceous rocks affected by contact metamorphism, less commonly in mica-schists and gneisses of the Archean, and rarely in granites.

Chiastolite is andalusite containing carbonaceous matter so arranged as to form light and dark squares or a cross on a cross section of a crystal. It is especially abundant in some zones of contact metamorphism, and is well illustrated by the chiastolite-schist (135) near Mariposa, California.

Topaz.—A fluosilicate of aluminum. Composition, $Al_2SiO_4F_2$. Orthorhombic. Crystals usually short, flattish prisms, rarely in grains. Hardness, 8. Specific gravity, 3.52 to 3.56. Color, light yellow, blue, or colorless. Transparent, infusible, and only partially attacked by sulphuric acid. Often contains inclusions of hematite and ilmenite and minute cavities filled with water or carbonic acid in a liquid state.

Crystals of topaz occasionally occur in cavities of the rhyolite (nevadite, 64) of Chalk Mountain, Colorado.

Staurolite.—Silicate of iron and aluminum. Composition, $HAl_5FeSi_2O_{13}$. Orthorhombic. Generally crystallized in short prisms, often twinned, forming a cross. Hardness, 7 to 7.5. Specific gravity, 3.3 to 3.8. Color, usually brownish; under the microscope pleochroic. High index of refraction, and yields brilliant colors between crossed nicols.

Staurolite does not occur in igneous rocks, but appears in crystalline rocks, especially of the Archean, in gneiss, mica-schist, and others poor in amphibole. It is found also in rocks highly altered by contact metamorphism, and is well illustrated by prominent crystals in the staurolite-mica-schist (133) of Charlestown, New Hampshire.

Pyroxenes.—The pyroxenes are silicates chiefly of iron, magnesium, and calcium, and form a series with considerable range of chemical composition. With the amphiboles, micas, and olivine they are the most important rock-forming ferromagnesian silicates in igneous masses. Pyroxenes may be divided according to their crystallization into three groups—rhombic, monoclinic, and triclinic. At this place only the rhombic pyroxenes, *enstatite*, *bronzite*, and *hypersthene*, will be considered. Their crystals are prismatic. Cleavage parallel to the pinacoidal planes is sometimes better developed than that of the prismatic planes. Enstatite contains less than 5 per cent of iron, bronzite from 5 to 14 per cent, and hypersthene over 14 per cent. While enstatite in thin sections is colorless and not pleochroic, hypersthene is usually greenish, light red, or brownish, and strongly pleochroic. The most important distinguishing feature under the microscope is the parallel extinction in prismatic sections and distinct rectangular cleavage in cross sections, which are usually octagonal, with four of the sides larger than the others.

The orthorhombic pyroxenes, especially hypersthene, are important rock-forming minerals, occurring in many andesites and basalts, as well as gabbros and peridotites, but are of little consequence in rocks of sedimentary origin, either unaltered or metamorphic.

Enstatite ($MgSiO_3$) occurs as an essential constituent in saxonite (114), also in some of the olivine nodules (104), and occasionally in basalt. It occurs also in the pyroxenite (110) from near Baltimore. Bronzite occurs in the feldspathic peridotite (111) of the same region. Hypersthene occurs in hypersthene-andesites (86 and 87), and forms an important part of the gabbro (108) of Mount Hope.

A fibrous substance having the composition of serpentine, but usually forming pseudomorphs, resulting from the alteration of orthorhombic pyroxene, is *bastite*. It occurs in peridotite from near Baltimore (111).

Olivine.—Silicate of magnesium and iron. Composition, $(MgFe)_2SiO_4$. Orthorhombic. Crystals short, prismatic. Sections usually four, six, or eight sided. Often granular. Hardness, 6.5 to 7. Specific gravity, 3.3 to 3.45. Colorless or yellowish. Decomposed, with separation of gelatinous silica, by heated hydrochloric acid. Under the microscope, in thin section, olivine is seen to be without distinct cleavage and to have a high index of refraction. Its rough surface apparently rises above the adjacent minerals, and becomes brilliantly colored between crossed nicols.

Three phases of olivine have been distinguished: (1) That of granular igneous rocks, such as olivine-gabbros and peridotites, where it is granular; (2) that of porphyritic igneous rocks, where it forms prominent crystals, as in many basalts; (3) that of crystalline schists, where it occurs as an accessory constituent. In the first two cases it is one of the minerals which crystallize early in the solidifying molten matter, and includes only such minerals as magnetite, ilmenite, picotite, etc., of earlier crystallization. In igneous rocks it is always an original, and generally an essential, constituent.

Olivine alters to calcium carbonate, iron oxide, silica, and serpentine, and a large proportion of the masses of serpentine exposed among the metamorphic rocks have resulted from the alteration of rocks rich in olivine. The process will be described under rocks of the peridotite series (110 to 114) and serpentine (145). Specimens 104 and 114 illustrate granular olivine. The porphyritic form may be seen in porphyritic theralite (76); also in kimberlite, as illustrated in Pl. XXXIX.

Fayalite.—Silicate of iron. Composition, Fe_2SiO_4. Orthorhombic, usually in minute tabular crystals. Hardness, 6.5. Specific gravity, about 4. Color, light yellow, but upon exposure generally becomes opaque, dark brown, or black. Fuses readily to magnetic globule and gelatinizes in acids. The minute nonmagnetic crystals in the lithophysæ of specimen (62) are fayalite.

Zoisite.—Silicate of calcium and aluminum. Composition, $HCa_2Al_3Si_3O_{13}$. Orthorhombic. Usually in columnar aggregates. Hardness, 6.

Specific gravity, 3.25 to 3.36. Has two cleavages, at right angles to each other, one perfect and the other imperfect. Usually colorless or gray. Index of refraction high, but double refraction low, and between crossed nicols its color is a feeble blue. Epidote, which it resembles, gives brilliant colors between crossed nicols.

It occurs in some altered gabbros (143), and more commonly in hornblende-schists (131?), but is much less common than epidote.

Prehnite.—A silicate of lime and aluminum. Composition, $H_2Ca_2Al_2Si_3O_{12}$. Orthorhombic, but usually in irregular plates. Hardness, 6 to 6.5. Specific gravity, 2.8 to 2.95. Colorless or greenish. Fuses at 2 with intumescence, and then readily gelatinizes in acid. Occurs only as a secondary mineral in basic eruptive rocks (102), but occasionally may be an original constituent of calcareous rocks and crystalline schists.

Talc.—Hydrous silicate of magnesium. Composition, $Mg_3H_2Si_4O_{12}$. Orthorhombic. Usually occurs in plates or rods. Basal cleavage perfect, giving it a foliation like mica, but soft (hardness, 1), and not elastic. Specific gravity, 2.8. Colorless in thin scales, but in larger bodies usually greenish or gray, with pearly luster and greasy feel. Like muscovite, gives brilliant colors between crossed nicols, but may be distinguished by the fact that after ignition, if it is moistened with a solution of nitrate of cobalt and heated again, it becomes when cooled pale red.

Talc is an essential constituent of talc-schist and steatite (142), and is not uncommon among metamorphic rocks. In basic eruptive rocks it sometimes appears as a secondary mineral, resulting from the alteration of hornblende.

MINERALS OF THE MONOCLINIC SYSTEM.

Gypsum.—Hydrous calcium sulphate. Composition, $CaSO_4+2aq$. Monoclinic, crystals tabular, but in rocks generally irregular, granular, lamellar, or fibrous aggregates. Hardness, 2. Specific gravity, 2.2 to 2.4. Colorless to gray and yellowish. Yields water in a closed tube, is slowly soluble in hydrochloric acid without gelatinization or effervescence, and fuses rather easily. Occurs in beds as gypsum rock. It is of chemical origin and is interstratified with other sedimentary rocks.

Pyroxenes (monoclinic).—The pyroxenes are silicates, chiefly of iron, magnesium, and calcium, with sufficient variation in chemical composition and physical properties to give rise to a number of species. The orthorhombic pyroxenes are treated on page 38. The only monoclinic forms which appear in this series of rocks are *augite, diallage, diopside,* and *ægirite.* Crystals, short prismatic. Also in irregular grains. Hardness, 5 to 6. Specific gravity, 3.23 to 3.5. Color, grayish white, ranging through green and black. By transmitted light it is usually greenish, yellowish, or pale brownish. Sections parallel to the prism show one cleavage, and between crossed nicols the extinction angle may be as large as 45°. Corresponding sections of orthorhombic pyroxenes have parallel extinction, and those of amphibole only a small extinction angle. Cross sections are often nearly square, with slightly truncated corners, or octagonal, with sides of nearly equal length. They show two directions of cleavage nearly at right angles. Diallage differs from augite in having, besides prismatic cleavage, a distinct parting, parallel to the orthopinacoid, giving diallage a more or less lamellar structure. Like bronzite, diallage often contains minute inclusions which give it a metallic sheen.

Augite is one of the most common essential primary minerals in igneous rocks. The phenocrysts of dolerite (105) and theralite (76) are augite. In granular form augite constitutes a large part of diabase (106), basalt (95 to 102), and quartz-norite-gneiss (140). It occurs as an accessory constituent in many eruptive rocks. Among metamorphic rocks it is not common, for in the process of dynamo-metamorphism augite is usually changed to hornblende.

Diallage has rather limited distribution, occurring with olivine forming nodules in basalt (104), in olivine-diabase (107), and as an essential constituent in gabbros (108 and 109). Diopside (malacolite) is a monoclinic pyroxene, poor in alumina and without lamination parallel to the orthopinacoid. It occurs in pulaskite (74), basalts (102), and pyroxenite (110), as well as in some olivine nodules (104) and some of the Archean granites and limestones. Acmite and ægirite are forms rich in sodium and iron. Ægirite occurs in the theralite (75 and 76) of Crazy Mountains, Montana.

Amphibole.—The amphiboles are silicates, mainly of magnesium and calcium, in which the former predominates over the latter. The orthorhombic forms do not occur in any of the rocks of this series. Only the monoclinic forms will be considered. Crystals prismatic, with cleavage angle 120°, well marked and characteristic. Hardness, 5 to 6. Specific gravity, 2.9 to 3.55. Not affected by acids. Color, various. The colorless or white variety is *tremolite*. The green is *actinolite*, *arfvedsonite*, or *uralite*. The black and brown are *hornblende* or *grünerite*, and the blue is generally *glaucophane*.

Cross sections of amphibole prisms are four or six sided, with prominent cleavage lines parallel to the principal sides and crossing each other at an angle of 124°. In prismatic sections the extinction angle is small, which distinguishes it from augite. Pleochroism usually strong in green, brown, and blue amphiboles. The cleavage, angle of extinction, and pleochroism distinguish the amphiboles from the pyroxenes, which they so closely resemble chemically.

Tremolite ($CaMg_3Si_4O_{12}$) occurs as lamellar masses or crystals in Archean limestones, silicate hornfels, and some serpentines. Actinolite occurs in many green schists of the Archean. It occurs also as tufts of radiating needles in the cortlandite (113) of Stony Point, New York. Common black hornblende is an essential constituent of hornblende-granite (69), many dacites (81 and 82), hornblende-andesites (83 to 85), camptonite (92), and cortlandite (113) among igneous rocks. In hornblende-schist (131) and garnetiferous hornblende-schist (141) the hornblende is green. Arfvedsonite occurs in leucite and nephelite rocks (pulaskite 74), grünerite in rocks rich in iron (hematite 121), and glaucophane in glaucophane-schists, not represented in this series. Uralite and fibrous green hornblende occur in metamorphic rocks, and are usually paramorphic after pyroxene. As such, uralite occurs in hornblende-gabbro-gneiss (143 and 144).

The micas.—The micas are silicates, chiefly of aluminum, magnesium, iron, and the alkaline metals. In composition and other properties there is considerable variation, and the group is divided into a number of species. The most common, for the sake of brevity, may be included under the names of *biotite* and *muscovite.* The former, containing considerable iron, is dark colored, strongly pleochroic, and approximately uniaxial, while the latter, rich in potassium, is colorless or gray and biaxial. The micas are all characterized by crystallizing in thin hexagonal plates with eminent basal cleavage, producing foliated structure and easily affording very thin elastic laminæ which show a black cross or bisectrix apparently at right angles to the cleavage surface. They are generally regarded as belonging to the monoclinic system, although their habit is hexagonal.

In porphyritic igneous rocks the mica is often in well-developed hexagonal plates, but in granitic rocks and schists it is in irregular scales. Under the microscope sections parallel to the cleavage are frequently isotropic, yield an optic-axial figure, and show no cleavage lines, but sections perpendicular to the cleavage show conspicuous cleavage lines, brilliant polarization colors, and parallel extinction.

The colorless transparent micas, included for petrographic convenience under muscovite, are *lepidolite, zinnwaldite, sericite, damourite, paragonite*, and *margarite.* The micas generally black by reflected light but by transmitted light colorless, deep brown, yellowish, reddish, or green, with strong pleochroism, included under biotite, are *anomite, rubellan*, and *phlogopite.*

Muscovite ($KH_2Al_3Si_3O_{12}$) is not a volcanic mineral. As an original constituent in igneous rocks it is limited to the granitic series (66), but is a widely distributed and common constituent of metamorphic sedimentary rocks, gneisses, and schists (119, 129, and 130). In the form of sericite it is often an early product of metamorphism in phyllite (126), staurolite-mica-schist (133), and aporhyolite (136).

Biotite has a wide distribution in igneous rocks. In hornblende-mica-andesite (83), dacite (81 and 82), and dacite-porphyry (90) it occurs in regular crystals among phenocrysts. It is an essential constituent also of biotite-granite (67), minette (91), and cortlandite (113), and an accessory constituent in many others. It is widely distributed as an essential constituent of many gneisses and schists, especially in specimens 66, 129, 130, and 132. *Lepidomelane* occurs in nephelite-syenite (77).

Chlorites.—The chlorites are hydrated silicates of magnesium, iron, and aluminum. On account of differences in chemical composition and also to a limited extent in physical properties, the chlorite group has been divided into a number of species, but for ordinary petrographic purposes these need not be distinguished. Monoclinic. Crystals often hexagonal, but occurring generally, like mica, in flat or bent plates of irregular outline. Hardness, 1 to 3. Specific gravity, 2.6 to 2.96. Color, green. Basal cleavage perfect, producing foliated structure. Laminæ flexible. Basal sections show a distinct black cross or bisectrix. Sections perpendicular to the cleavage are lath-shaped. Pleochroic, yielding greenish or bluish to yellowish or red colors. Interference colors between crossed nicols much lower than those of mica.

Chlorites are widely distributed among igneous and metamorphic rocks, but are always secondary, resulting from the alteration of silicates rich in magnesium and iron, such as mica, pyroxene, and amphibole. They occur in hornblende-pyroxene-andesite (85) and many other igneous rocks, but can be seen only in the thin section under the microscope. They occur also in chlorite-phyllite (127), which is composed chiefly of chlorites, and in steatite (142), of which chlorite sometimes forms a considerable portion, although steatite is usually talc.

Epidote.—A hydrous silicate of aluminum, iron, and calcium. Composition, $H(CaFe)_2(AlFe)_3Si_3O_{13}$. Monoclinic. Crystals prismatic and, in rocks, generally granular. Hardness, 6.5. Specific gravity, 3.3 to 3.5. Basal cleavage perfect. Color, generally yellowish green, sometimes brownish. Under the microscope, in thin sections, usually colorless, but yields between crossed nicols especially brilliant colors, which distinguish it from zoisite.

Epidote is never a primary or essential constituent of igneous rocks. It frequently occurs as a secondary mineral resulting from the alteration of igneous and sedimentary rocks. It occurs in some gneisses (138), schists, and phyllites (127), and in aporhyolite (136), and is one of the commonest of all silicates resulting from weathering.

Allanite.—Silicate of aluminum, iron, cerium, and other rare elements. Occurs in crystals and irregular grains, like epidote. Hardness, 5.5 to 6. Specific gravity, 3 to 4.2. Color, generally pitch black, brown, or gray; in thin sections reddish brown or greenish, usually with strong pleochroism. Cleavage indistinct or absent. Optical properties vary; many allanites are isotropic, others highly double-refracting.

Allanite occurs in gneisses (138) as well as in diorite (93), diorite-porphyry (89), and other igneous rocks.

Titanite.—Silico-titanate of calcium. Composition, $CaSiTio_5$. Monoclinic. Crystals frequently double-wedge shaped. Occurs also in irregular grains. Hardness, 5 to 5.5. Specific gravity, 3.3 to 3.7. Color, brown to black and reddish yellow. Feebly transparent. Index of refraction very high and surface appears rough, but double-refraction low, giving between crossed nicols a brownish-gray color. Not affected by acids. Light-yellow titanite usually in wedge-shaped crystals is commonly called *sphene*. It is one of the primary accessory minerals in many granites, syenites, diorites, and other igneous rocks. Granular titanite is of secondary origin, frequently resulting from the alteration of titaniferous magnetite, ilmenite, or rutile in igneous and metamorphic rocks. Titanite occurs in pulaskite (74), diorite (93), and in the form of sphene in minette (91), and in many other igneous and metamorphic rocks, but rarely in particles sufficiently large to be seen without the aid of a lens.

Zeolites (*monoclinic*).—Zeolites are hydrous silicates of aluminum, calcium, potassium, and sodium, with other bases, and, excepting rare cases of analcite, all are secondary minerals. They have low index of refraction and low double refraction. They are transparent, usually colorless or white, readily attacked by hydrochloric acid, and easily fusible. The most common forms besides analcite, already mentioned (page 33), are *heulandite*, *stilbite*, *scolecite*, *epistilbite*, and *laumontite*, which may be distinguished chiefly on optical grounds. Laumontite is well illustrated in the amygdules of the diabase amygdaloid (139); scolecite, in the feldspathic peridotite (111) near Baltimore.

Feldspars (*monoclinic*).—The feldspars are silicates, chiefly of aluminum, with more or less potassium, sodium, or calcium. According to crystallization they may be divided into two groups, monoclinic and triclinic, but all are very closely related in chemical and physical properties.

Their principal common feature is the possession of two cleavages, one parallel to the base, perfect, and the other parallel to a lateral pinacoid, less perfect and variable. The angle between the two cleavage planes in monoclinic feldspar is 90 degrees, and the basal cleavage shows no twinning striæ. In the triclinic feldspars, however, the two cleavage planes are slightly inclined to each other, and the basal plane is striated. These striæ are well illustrated by the large feldspar crystals in specimen 90. The striation is due to oft-repeated lamellar twinning, which under the microscope and between crossed nicols produces numerous distinct parallel alternating color bands, and affords an easy means of distinguishing the triclinic from the monoclinic feldspars.

Monoclinic feldspar, usually called orthoclase or potash feldspar, is a silicate of alumina and potash. Composition, $KAlSi_3O_8$. Crystals short tables and square prisms, but in rocks it usually occurs in irregular grains. Crystals may be simple, but are often twinned parallel to the orthopinacoid (Carlsbad twins). Color generally white or gray, but often reddish. Frequently more or less turbid and semitransparent. Not acted on by ordinary acids, and before the blowpipe fuses at 5.

Sections of simple crystals of orthoclase between crossed nicols are seen to be optically the same throughout, but Carlsbad twins show two bands of interference colors, less bright than those of quartz.

Orthoclase is an essential constituent of granites (66–69), syenite (71), metarhyolite (quartz-porphyry, 65), phonolite (73), and pulaskite (74), and traces of it have been found in dolerite (105).

In the recent acid volcanic rocks orthoclase is clear and glassy, and has been designated *sanidine*. This form of orthoclase is an essential constituent of nevadite (64) and trachyte (70). It occurs also in the cavities of lithoidite (62).

MINERALS OF THE TRICLINIC SYSTEM.

Feldspars (*triclinic*).—As already stated, feldspars are silicates, chiefly of aluminum, with more or less potash, soda, or lime. There are three essentially distinct chemical compounds which exist as separate varieties of feldspar, often designated, respectively, potassium feldspar (*orthoclase*), sodium feldspar (*albite*), and calcium feldspar (*anorthite*). The second of these compounds combines in definite proportions with the first and third, forming the intermediate members of several series of feldspars, designated, respectively, the potash-soda series (*anorthoclase*) and the soda-lime series (*plagioclase*). Orthoclase is monoclinic, but anorthoclase and plagioclase are triclinic. Although the cleavage angle of plagioclase is clearly oblique (86° to 87°), that of anorthoclase varies scarcely any from a right angle.

The characteristic feature of triclinic feldspar is the lamellar or polysynthetic twinning, producing striations on the basal cleavage plane. The twinning parallel to the brachypinacoid (least perfect cleavage plane) is the albite type, while that at right angles to it is the pericline type. The fine parallel banding such twinning produces is evident under the microscope between crossed nicols, and is highly characteristic of the triclinic feldspars.

The potassium-feldspar compound crystallizes in the monoclinic system as orthoclase, and in the triclinic system it is called *microcline*. It occurs in irregular grains, and in the thin section under the microscope between crossed nicols may be readily distinguished by its colored rectangular grating, produced by the two sets of fine parallel lamellar twins, crossing each other at right angles. Basal cleavage plates between crossed nicols extinguish at an angle of 15° 30′ to the line of the pinacoidal cleavage, and a pinacoidal cleavage plate extinguishes at an angle of 5° to the line of basal cleavage. Reddish microcline is abundant in the biotite-granite of Platte Canyon, Colorado (67). It is present also in the granite of Fox Island, Maine (68), granitoid gneiss (137), and epidote-mica-gneiss (138). Microcline often contains parallel intergrowths of orthoclase and albite.

Plagioclase feldspars are those of the lime-soda series, including albite and anorthite and their isomorphic mixtures, oligoclase, andesine, labradorite, and bytownite. The composition of albite is $NaAlSi_3O_8$; of anorthite, $CaAl_2Si_2O_8$. The average intermediate mixtures are:

Intermediate mixtures of albite and anorthite.

Albite	Ab
Oligoclase	Ab_8An_2
Andesine	Ab_7An_5
Labradorite	Ab_2An_3
Bytownite	Ab_4An_7
Anorthite	An

These feldspars are much alike, and are most readily distinguished by their specific gravity and extinction angles, which are given in the following table and in the diagram prepared by Michel Lévy:[1]

Extinction angles and specific gravities of plagioclase feldspars.

	Extinction angle on base, OP.	Extinction angle on pinacoids, iĭ.	Specific gravity.
	° °	° °	
Albite	+ 4 to + 3	+19 to +13	2.62
Oligoclase	+ 3 to + 1	+13 to − 2	2.64
Andesine	− 2 to − 3	− 2 to −10	2.65
Labradorite	− 5 to −12	−16 to −26	2.69
Bytownite	−17 to −27	−29 to −33	2.71
Anorthite	−28 to −39	−35 to −36	2.75

Plagioclase is an important and essential constituent of diorite (93 and 94), basalt (100 to 102), dolerite (105), diabase (106 and 107), and gabbro (108 and 109). It occurs as an accessory mineral in many metamorphic rocks; for example, gneiss (132) and schists (129 and 131). It is especially prominent, showing fine striations, in specimen 90.

Albite occurs in albite-schist (129), oligoclase in trachyte (70), andesine in dacite (81 and 82) and hornblende-mica-andesite (83), labradorite in most of the andesites (83 and 88), basalt (102), and diabase (106 and 107); bytownite in gabbro (108), peridotite (111), and gneiss (144); and anorthite in the hornblende-gabbro-gneiss near Baltimore (143).

Anorthoclase, as far as is yet definitely known, is very rare in rocks as compared with orthoclase and plagioclase. It often shows intersecting systems of extremely fine, twinning lamellæ, which pass into areas free from them without there being any visible boundary between. Like orthoclase, it occurs in the acid series (granitic and syenitic) of rocks. It possibly occurs in theralite (76).

HOMOGENEOUS AGGREGATES.

Serpentine.—Serpentine is a hydrous silicate of magnesium. Chemical composition, $H_4Mg_3Si_2O_9$. Serpentine is always a secondary mineral, and when in the form of crystals is generally pseudomorphous. It is usually massive and sometimes fibrous (chrysotile). Hardness, 2.5 to

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[1] Étude sur la détermination des feldspaths, 1894, p. 32. See, also, Becker's Pl. XI in Eighteenth Ann. Rept., Part III, 1898, p. 36.

4. Specific gravity, 2.5 to 2.6. Color, generally green, sometimes red or mottled. Feel, often greasy. Structure, splintery. Chrysotile, a silky, fibrous form of serpentine, belongs to the orthorhombic system and has parallel extinction. Massive serpentine has low double refraction with aggregate polarization, as if composed of minute scales, fibers, or grains.

Serpentine results chiefly from the alteration of olivine. The change begins along the cracks in the olivine, and often gives rise to a peculiar reticulated structure, in which the net is serpentine. If the alteration is not complete, remnants of olivine occur in the meshes.

Serpentine results also from the alteration of augite and hornblende, and in the latter case it is generally characterized by a grating structure with rhombic interspaces, due to the arrangement of the fibers normal to the cleavage of the hornblende. In that derived from augite the meshes are rectangular.

Serpentine has a wide distribution among metamorphic rocks, and has been derived from intrusive rocks rich in olivine, such as peridotite; also sometimes from gabbro-diabase and pyroxenite.

Specimen 145 illustrates serpentine derived from the alteration of pyroxenite.

Kaolin.—Kaolin forms earthy aggregates which under the microscope are seen to be composed of minute scales resembling muscovite, but they have a weak double refraction. It is usually white and results from the alteration of feldspar, nephelite, scapolite, and similar minerals in the process of weathering. It occurs in specimen 149, also in the white portions of 147 and 148.

Glauconite.—Glauconite is essentially a hydrous silicate of potassium and iron, and is amorphous. It occurs in small grains, which are generally spherical, but also elliptical or irregular. Hardness, 2. Specific gravity, 2.2 to 2.4. Refraction and double refraction weak. It constitutes the essential part of greensand (5).

Limonite.—Limonite is a hydrous ferric oxide having the following composition: $2Fe_2O_33H_2O$. It is not crystallized, but often fibrous, stalactitic, botryoidal, concretionary, or earthy. Its color is various shades of yellow or brown, whence its other name, *brown hematite.* When heated before a blowpipe it becomes magnetic, and in a closed tube yields water. Its streak is yellowish brown and differs from the cherry-red streak of red hematite. Hardness, 5 to 5.5. Specific gravity, 3.6 to 4. Iron rust and most of the yellowish-brown stains resulting from the alteration of iron-bearing minerals are limonite. It accompanies siderite in specimen 32, and results from the alteration of marcasite in specimen 35. The yellow tint of phyllite (126) is due to the presence of limonite.

CLASSIFICATION OF ROCKS.

Rocks may be classified according to any of their many features, but the most fundamental one upon which the primary divisions are based is genesis. From this point of view rocks are of two great groups, *igneous* and *sedimentary*. Igneous rocks are those which, like basalt and granite, have solidified from a molten state. The material of which they are formed, like that erupted from volcanoes, has come up from the interior of the earth in a highly heated igneous condition. Sedimentary rocks, on the other hand, are formed by the accumulation of sediments brought together by some transporting agent, generally water, and are well illustrated by sandstones, conglomerates, shales, and limestones. The material of which they are made up is derived from the degradation of the land of the earth's surface. Sedimentary rocks are sometimes called *aqueous*, *fragmental*, or *stratified*, and igneous rocks are correspondingly designated *eruptive*, *massive*, or *unstratified*, but the various terms in the two series are not strictly synonymous.

Before proceeding further with the classification, attention should be given to the various stages through which a rock may pass in the cycle of its existence.

Under the influence of the weather, rocks exposed upon the earth's surface gradually decompose and disintegrate, and the loose material thus formed is carried away by the rills, brooks, and rivers as sediment to the sea, where it is deposited to form new rocks. By the long-continued accumulation of sediments and outpouring of igneous material, sedimentary and igneous rocks once upon the surface may become deeply buried and affected by the internal heat of the earth. Furthermore, many of them become involved in mountain-building processes and subjected to such high degrees of heat and pressure that the material of which they are composed is rearranged more or less completely, in accordance with crystallographic and other forces. By this process, which is largely dynamic, the unaltered sedimentary and igneous rocks become altered or metamorphosed into slates, schists, gneisses, and other forms of metamorphic rocks. In specimen 128, metamorphic conglomerate, the original fragmental structure may yet be seen. In Hoosac Mountain this conglomerate passes into gneiss, in which the original structure has entirely disappeared. It should be borne in mind that this change, called *metamorphism*, does not produce new rocks; it simply modifies old ones.

The earth movements by which rocks are metamorphosed may raise them in mountain masses above the sea. After erosion has removed the surface material the once deeply buried metamorphic rocks become exposed, weathering takes hold of them, and they disintegrate, forming residual sands and clays, which are ultimately washed away and deposited in the sea. Old rocks are thus destroyed in providing material for new rocks. The history of a rock embraces three stages: (1) the stage of its origin, including the time it remained unaltered; (2) the stage of its alteration; and (3) the stage of its disintegration, which is usually very local and brief.

In accordance with these stages rocks may be arranged under three heads: (1) unaltered rocks; (2) altered or metamorphic rocks; (3) residual rocks.

It is evident that the classification of rocks should refer primarily to those which are unaltered. Metamorphic rocks should, as far as possible, be traced back to their original condition, and be arranged accordingly. As already indicated, the two fundamental groups of unaltered rocks, based on origin, are sedimentary and igneous, and to the subdivision of these two great groups attention will now be given, beginning with the sedimentary.

Sandstone (13), vein quartz (25), and diatom earth (51) are all sedimentary rocks, and being composed chiefly of silica have essentially the same chemical composition. In each case water was the agent which bore the material to the point of accumulation, but the modes of deposition were unlike. To make the sandstone, the sediment was precipitated from mechanical suspension in the water, while for both vein quartz and diatom earth the material was precipitated from solution, the former by a chemical agent and the latter by an organism. On account of these differences sedimentary rock may be divided into *mechanical*, *chemical*, and *organic*, as indicated in the table, page 53.

The ultimate classification of igneous rocks is a matter concerning which there is much difference of opinion. The chief divisions are often based in large measure upon mode of geologic occurrence and chemical composition, for these two factors are the principal ones in a determination of the structural and mineralogic features of igneous rocks.

Igneous material ("magma") rising from the earth's interior may break entirely through the overlying rocks and reach the surface, where, exposed to the atmosphere, it cools rapidly; or it may stop beneath the surface on the way up and cool slowly to solidification under circumstances very unlike those which obtain upon the surface. Igneous rocks have thus been divided by some geologists into two groups, *volcanic* and *plutonic*, sometimes called *extrusive* and *intrusive* rocks. Although the igneous rocks of this collection are not divided into these two groups, some of the structural features of these, as usually given, will now be considered, for convenience in other subdivisions.

Volcanic or extrusive rocks are delivered upon or near the surface by volcanic action and spread out in streams or layers, either as continuous flows or as accumulated fragments of lava. On account of their sudden cooling many volcanic rocks are either wholly glassy or only partially crystalline. Others are holocrystalline, but the mineral particles forming the principal mass in such cases are usually, but not always, very minute.

Plutonic rocks, on the other hand, cooling at some distance beneath the surface, solidify more slowly than volcanic rocks and attain a rather coarsely crystalline granular structure, excepting along their borders, where they come in contact with cooler rocks. They occur in masses of various shapes and sizes, ranging from dikes to bosses and irregular batholiths miles in extent.

Rising through stratified rocks, the molten material often spreads out between the strata, forming low dome-shaped masses (laccoliths) or sheets of nearly uniform thickness. Intrusive sheets lying conformably between strata resemble contemporaneous surface flows which were buried in the sediments as they were deposited. Generally the two cases may be easily distinguished by studying the contact. Intrusive rocks highly heat the rocks with which they come in contact, and frequently metamorphose them, and are themselves finer grained near the contact, owing to the cooling influence of neighboring masses.

Although plutonic rocks generally do not extend to the surface, it is evident that volcanic rocks always connect, at the orifice from which they issue, with plutonic masses extending into the earth. Plutonic and volcanic rocks grade into each other, forming more or less continuous series. All these, coming from essentially the same magma, may be regarded as belonging to the same series.

As to chemical composition, igneous rocks have a wide range. For example, their content of silica may range from 30 per cent to 80 per cent, and on this basis alone igneous rocks may be conveniently spoken of as *acid*, that is, containing over 65 per cent of silica; *intermediate*, 55 per cent to 65 per cent; and *basic*, below 55 per cent.

The chemical nature of the magma determines almost wholly the mineral composition of the resulting igneous rocks. For this reason the classification of igneous rocks on a chemical basis, which is really fundamental, may be expressed in large measure also in terms of mineral association, and its application may be thus rendered much more convenient.

On a chemical-mineralogic basis igneous rocks may be divided into a number of families, each embracing all rocks, both volcanic and plutonic, which have essentially the same composition, and each series ranging in structure from the glassy and porphyritic forms of lava to the coarsely crystalline, even-granular forms, like granite and gabbro.

Silica is one of the most abundant and widely distributed components of rocks. For this reason the principal rock-forming silicates become the most important basis of classification, especially the silicates of the alkalies—feldspar, nephelite, and leucite—and the ferromagnesian silicates—amphibole, mica, pyroxene, and olivine. Only those families that are represented by specimens in the collection will be here considered, and some of these families are not limited as they might be if the collection were larger and of greater variety. The following classification corresponds closely to that reported May 27, 1897, by a committee consisting of C. R. Van Hise, W. H. Weed, H. W. Turner, Whitman Cross, and J. S. Diller, appointed by the Director of the United States Geological Survey to consider the nomenclature of the igneous rocks and to adopt a system for use in the geologic folios published by the Survey.

Granite-rhyolite family.—Granite among plutonic rocks and rhyolite among volcanic rocks are the types of this family. They are rich in silica, usually containing about 70 per cent (65 to 80), with approximately 8 per cent of the alkalies, K_2O generally but not always being a little in excess of the Na_2O. When holocrystalline, their essential minerals are quartz and alkali feldspars. Oligoclase is present, sometimes in considerable but subordinate quantities; also one or more of the ferromagnesian silicates hornblende, mica, or augite, with smaller amounts of accessory minerals.

Syenite-trachyte family.—Syenite among plutonic rocks and trachyte among volcanic rocks are the types of this family. They are not so rich in silica as the members of the granite-rhyolite family, usually averaging about 59 per cent (55 to 68), with approximately 9 per cent of the alkalies, K_2O being in general slightly in excess of Na_2O. Mineralogically they are characterized by the general absence of quartz and the predominance of alkali feldspars. As in the granite-rhyolite family, there is often a large but always subordinate amount of oligoclase present. Hornblende, mica, or augite may be rather abundant, but the whole amount of the ferromagnesian silicates present is less than that of the feldspar. The rocks of this series are rare.

Nephelite-leucite rocks.—Nephelite-syenite and phonolite are respectively the abyssal and surface igneous rocks of this family. They contain so low a percentage of silica (about 54 per cent) and so high a percentage of the alkalies (about 14 per cent) that nephelite and leucite are formed and, although generally associated with feldspar, are considered the characterizing minerals. In the phonolite and nephelite-syenites the associated feldspar is largely orthoclase, but in the theralites it is chiefly plagioclase, and on account of such differences the nephelite-leucite rocks, although rare, may be divided into several families. The hornblende and augite which these rocks contain are usually rich in alkalies.

Diorite-andesite family.—Diorite and andesite are the plutonic and volcanic type rocks of this family. They average about 60 per cent (48 to 70) of silica and 7 per cent of the alkalies, Na_2O being in excess, with about 6 per cent of the alkaline earths, of which the greater part is generally lime. Consequently the characterizing minerals are soda-lime feldspars. Quartz is often present, and also hornblende or mica, but not in predominating quantities. Augite is common in andesites, but less so in diorites, where its relative abundance indicates a degree of approach to the gabbros.

Gabbro-basalt family.—Gabbro and basalt are respectively the plutonic and volcanic types of this family. They average about 50 per cent of silica, 9 per cent of iron oxides, 9 per cent of CaO, 6 per cent of MgO, and 4 per cent of the alkalies. Feldspar is usually less abundant in this family than in the preceding ones, and on account of increase in the CaO and decrease in the alkalies, it is prevailingly of the lime-soda variety, as distinguished from the soda-lime variety which prevails in the diorite family, although in some cases the alkali feldspars become important. As the CaO and MgO increase, pyroxene becomes more abundant, so that the holocrystalline members of this family in general are essentially labradorite-pyroxene rocks. The members of this family and of the diorite-andesite family are the most abundant of igneous rocks.

Peridotite family.—Pyroxenite and peridotite are the plutonic types of this family and are composed, essentially, the first of pyroxene and the last of olivine, by which they are characterized. In chemical composition they are especially rich in MgO, containing an average of about 29 per cent, with rather low silica (about 44 per cent) and a very small percentage of the alkalies and alumina, so that they are essentially feldspar-free rocks. Volcanic rocks of this series are rare, and as yet, perhaps, wholly unknown in the United States.

TABULAR VIEW AND CLASSIFICATION OF THE ROCKS OF THIS SERIES.

STAGES OF A ROCK CYCLE.

Origination.	Alteration.	Disintegration.
	CLASSIFICATION OF ROCKS.	
Unaltered.	*Metamorphic.*[1]	*Residual.*
Sedimentary:		
Mechanical.	Mica-schist.	
Chemical.		
Organic.	Crystalline limestone.	Clay of limestone.
Igneous:		
Granite-rhyolite family.	Granite-gneiss.	Sand of granite.
Syenite-trachyte family.		
Nepheline-leucite rocks.		
Diorite-andesite family.		
Gabbro-basalt family.	Gabbro-gneiss.	Sand of diabase.
Peridotite family.	Serpentine.	

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[1] Only a few examples of *metamorphic* and *residual* rocks are given, for the purpose of showing their relations to the unaltered forms.

Unaltered sedimentary rocks.

	Number of specimen in the series.
Mechanical:	
Gravel	1, 2.
Sand	3, 4, 5, 6.
Loess	7.
Clay	8, 9.
Conglomerate	10.
Breccia	11.
Sandstone	12, 13, 14, 15, 16, 17, 18, 19.
Graywacke	20.
Shale	21, 22.
Chemical:	
Siliceous sinter	23.
Vein—vein quartz	24, 25.
Siliceous oolite	26.
Gypsum	27.
Limestone—	
Stalactite	28.
Travertine	29.
Oolitic sand	30.
Oolite	31.
Limonite	32.
Concretions—	
Claystone	33.
Containing fern	34.
Marcasite	35.
Geode	36.
Silicified wood	37.
Silicified shell	38.
Organic:	
Limestone	39, 40, (41), 42, 43, 44, (45), 46, 47, 48, 49, 50.
Diatom earth	51.
Fossiliferous iron ore	52.
Peat	53.
Coals	54, 55, 56.

Unaltered igneous rocks.

[Dike, 57.]

Granite-rhyolite family.		Syenite-trachyte family.		Nephelite-leucite rocks.		Diorite-andesite family.		Gabbro-basalt family.		Peridotite family.	
								Volcanic sand	95		
Volcanic dust (rhyolitic?)	58					Andesitic tuff	79	Lapilli	96		
Rhyolitic pumice	59							Scoria	97		
Rhyolitic obsidian	60							Volcanic bomb	98		
Rhyolitic perlite	61							Basalt-tuff	99		
				Orendite	72						
						Dacite	80 81 82				
Lithoidite	62	Trachyte	70	Phonolite	73			Cellular basalt	100		
						Hornblende-mica-andesite	83	Quartz-basalt	101		
Liparite	63							Basalt	102		
Nevadite	64					Hornblende-andesite	84	Columnar jointing	103		
						Hornblende-pyroxene-andesite.	85	Olivine nodule	104		
a Metarhyolite (quartz-porphyry).	65					Hypersthene-andesite	86, 87	Dolerite	105		
						Olivine-bearing pyroxene-andesite.	88				
						Hornblende-diorite-porphyry.	89				
						Dacite-porphyry	90				
				Pulaskite	74						
Granite	66	Syenite	71	Theralite	75	Minette	91	Diabase	106	Pyroxenite	110
Biotite-granite	67			Porphyritic theralite	76	Camptonite	92	Olivine-diabase	107	Peridotite	111
Hornblende bearing biotite-granite.	68			Nephelite-syenite	77, 78	Diorite	93, 94	Gabbro	108	Kimberlite	112
Biotite-bearing hornblende-granite.	69							Garnetiferous gabbro	109	Cortlandite	113
										Saxonite	114

a This rock would have been included among the altered igneous rocks, but was obtained to replace another after the other specimens of the series were all numbered, and circumstances permitted no change.

Metamorphic sedimentary rocks.

	No. of specimen.
Crystalline limestone	115
Marble	116
Marble (dolomite)	117
Quartzite	118
Quartz-schist	119
Jaspilite	120
Magnetic specular hematite	121
Slate (clay slate, roofing slate)	122
Indurated jointed shale	123
Crumpled shale	124
Faulted pebble	125
Phyllite (sericite-schist)	126
Phyllite (chlorite-phyllite)	127
Metamorphic conglomerate (conglomerate gneiss)	128
Albite-schist	129
Mica-schist	130
Hornblende-schist	131
Schistose biotite-gneiss	132
Staurolite-mica-schist	133
Hornfels	134
Chiastolite-schist	135

Metamorphic igneous rocks.

	No. of specimen.
Aporhyolite	136
Granitoid gneiss	137
Epidote-mica-gneiss	138
Diabase-amygdaloid	139
Quartz-norite-gneiss	140
Garnetiferous hornblende-schist	141
Steatite	142
Hornblendic gabbro-gneiss (gabbro-diorite)	143
Do	144
Serpentine	145
Magnetite	146

Residual rocks.

	No. of specimen.
Residual sand of gneiss	147
Residual sand of diabase	148
Residual clay of feldspathic rock (kaolin)	149
Residual clay of limestone	150

Illustrations of surface modifications.

	No. of specimen.
Spheroidal weathering in igneous rocks	151
Spheroidal weathering in shale	152
Differential weathering on impure limestone	153
Differential weathering, fluted limestone	154
Glaciated rock	155
Desert varnish	156

DESCRIPTIONS OF SPECIMENS.

UNALTERED SEDIMENTARY ROCKS OF MECHANICAL ORIGIN.

No. 1. Beach Gravel.

(From Nahant, Massachusetts. Described by J. S. Diller.)

Specimen No. 1 consists of smooth pebbles of various sizes. These illustrate the character of the pebbles accumulated to form the *beach gravel* of Nahant. They range in size from that of a pea to that of an egg. When the fragments are as large as a man's head, the accumulation of pebbles and cobblestones is called *shingle.* The round form and smooth surface of the pebbles in specimen No. 1 show that they have been subject to much attrition on the beach. The breaking waves (breakers) are continually dashing against the shore, often with great violence, knocking the pebbles together, breaking off their corners, and grinding all the material within their grip to finer gravel, sand, and clay. The water of the broken wave returning to the sea flows down the beach, carrying with it some of the gravel, sand, and clay. As the water at the surface of the ocean is carried landward by the wind waves,[1] that on the beach flows seaward as an undercurrent (undertow) and distributes the fragmental material, according to size, over the bottom. This process is illustrated in the accompanying fig. 7.

The beach is composed largely of pebbles, with some sand. The undertow is generally not strong enough to carry pebbles far from shore, but off shallow and stormy coasts sand may be carried to a considerable distance (nearly 100 miles off the Atlantic coast), and the silt and clay will be deposited still farther beyond, where the undertow meets the deeper water. In this manner the waste of the coast land is spread over the bottom of the sea to form new rocks. As the transporting power of the undertow varies with the force of the waves in changing tide and winds, so its deposits will vary and become arranged in layers—i. e., stratified.

The cliff cut by the sea in forming the beach is a *sea cliff.* It is the source of the beach gravel. Pebbles may already exist in the loose

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[1] G. K. Gilbert, Lake Bonneville: Mon. U. S. Geol. Survey, Vol. I, 1890, pp. 29 and 30.

material of the cliff, as along the New England coast at many points, but this is not generally the case. The gravel of the beach is usually made from the solid rocks which form the cliff. The force of the waves is so great on stormy coasts that fragments, small and large, sometimes weighing tons, are broken off from the fissured cliff and tumbled about by the dashing waves, pounding one another until ground to small pebbles and clay. The rocks of the sea cliff are weakened for the attack of the waves by weathering, but a large part of the destructive effect of the waves is due to the fact that they are armed with fragments of rock, which are hurled with great force against the cliff, as in a bombardment. The noise of such rock-pounding by the waves on a stormy coast may sometimes be heard a number of miles.

Pebbles of soft material are readily ground to pieces and disappear. It is only those, like specimen No. 1, of hard, relatively tough, homogeneous material that stand the continuous battering and become well rounded. Of all minerals, quartz is the most common one which is both physically and chemically hard and can well resist the wear of wave action. For this reason many of the beach pebbles are composed largely of quartz. When the waves are not normal to the beach the pebbles are thrown up the beach in the direction of the moving wave and made to travel along the beach. Such pebbles are well rounded, and their size is usually, but not always, proportional to the distance they have traveled. The original shape and structure of the fragments are the chief factors in determining the ultimate form of the pebbles subject to the attrition brought about by the waves on a beach. If the original fragments are flattish, and especially if their material splits readily in one direction, the pebbles will be flat with rounded edges, but if of nearly cubical blocks of practically homogeneous material, such as granite, syenite, and many other igneous rocks, they will be spheroidal, as specimen No. 1.

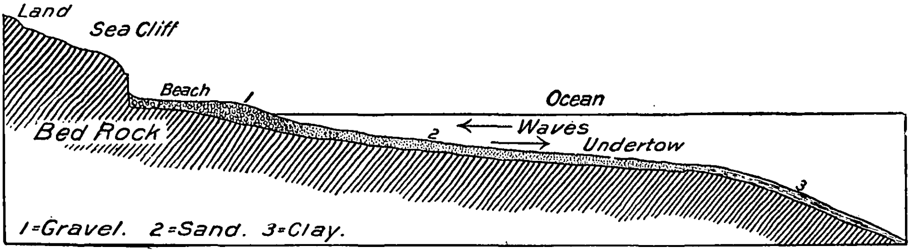


FIG. 7.—Section of coast, showing beach and sediments.

There is another natural process of gravel formation which is of much importance and should be mentioned in this place, although not represented by specimens. Streams of water flowing over the surface of the land carry with them rock fragments which have been detached in various ways, rolling them along the bottom of the channel and sometimes picking them up and dropping them again. The stones thus carried give and receive many blows, not only striking the bed rock of the channel, but striking one another, and by these blows they are rounded, just as are the stones rolled upon the beach. The resulting forms are the same, and if a typical sample of stream gravel were added to this collection it would merely duplicate the sample of beach gravel.

No. 2. GLACIAL GRAVEL (STRIATED PEBBLES).

(FROM ELKHORN, WALWORTH COUNTY, WISCONSIN. DESCRIBED BY G. K. GILBERT.)

A glacier is a large mass of ice moving slowly under the influence of gravity. Glaciers on mountain slopes descend valleys and have the form of broad, deep rivers. They are fed at the upper end by annual accumulations of snow, and waste away by melting at the lower end. Glaciers on plains are called ice sheets. They are built up by accumulations of snow until their own weight forces them to spread outward, and they waste away by melting at their margins. A mountain glacier carries a load of rock. Some stones fall upon its back and are borne along without modification; others are picked up from beneath and embedded in the ice. As one part of the ice moves faster than another, the embedded pebbles are rubbed against one another and are thereby scratched. Some of them are also rubbed against the rocky bed over which the glacier moves and are still more vigorously abraded. Often they are rubbed until quite flat on one side, the flat surface being polished and marked by parallel scratches. Sometimes after such flattening they are turned and similarly rubbed upon another side, and in this way a large number of facets may be ground upon the same pebble. Ice sheets, similarly, have stones embedded in their lower portions, but usually carry none upon their backs. The parts of glaciers and ice sheets which waste by melting are traversed by streams, which may flow across the upper surface, beneath the under surface, or in tunnels midway. These streams wash along the pebbles that come in their way, rolling them as they go and giving them all the ordinary characters of stream gravel or beach gravel (see specimen No. 1). The stones carried by glaciers are thus of three types: (1) The unmodified material of the back load, which usually consists of fragments fallen from cliffs and is angular; (2) the pebbles and bowlders embedded in the ice, which are usually subangular in general form, and are characterized by scratches, or by scratches and ground facets; (3) the pebbles finally acted upon by glacial streams, which are well rounded and have smooth surfaces. Those of the first type resemble the stones of talus slopes; those of the third are not distinguishable from other stream-worn pebbles, nor from beach-worn pebbles (specimen No. 1); those of the second type are peculiar to glaciers and are distinctively said to be *glaciated*. They are illustrated by the specimen No. 2.

The corners of glaciated pebbles are usually rounded, so that there are no sharp angles, but the rounding does not approach in perfection that illustrated by stream pebbles and beach pebbles. On each flat facet the striæ are parallel, but the direction is often different on contiguous facets. Usually the facets show also irregular scratches, and such scratches, with little parallelism, characterize the unfaceted portions of the surface.

A glacier moves continuously, but slowly, from the region of accumulating snow to the region of ablation or melting, so that the stones it receives are all carried in the same direction, and where the ice stream ends by melting, the stones stop and are accumulated. Where pebbles are deposited without other material they constitute glacial gravel, but more frequently the glaciated pebbles are deposited in association with clay and sand, constituting a material called *bowlder clay* or *till*. (See specimen No. 9.)

In the Pleistocene period there were many glaciers in the high mountains of Colorado, Utah, Nevada, California, and the area lying north of these States, and there were ice sheets in the northern part of the continent. One of the ice sheets, having its center of accumulation in Canada, spread over New England, covered most of the area bordering the Great Lakes, and occupied the northern part of the Great Plains. During its existence it moved an immense quantity of clay, sand, and stones southward, producing a deposit which in many districts deeply buries the bed rock. The pebbles constituting specimen No. 2 are from a deposit at Elkhorn, Walworth County, Wisconsin, where they were embedded in clay.

The reader will find further information in the descriptions of specimens Nos. 9 and 155. He is also referred to the second chapter of The Great Ice Age, by James Geikie; to The Drift: Its Characteristics and Relationships, by R. D. Salisbury, in Vol. II of the Journal of Geology, and to The Rock Scorings of the Great Ice Invasion, by T. C. Chamberlin, in the Seventh Annual Report of the United States Geological Survey.

NO. 3. BEACH SAND.

(FROM SULLIVANS ISLAND, NEAR CHARLESTON, SOUTH CAROLINA. DESCRIBED BY J. S. DILLER.)

The mineral fragments next smaller than pebbles are grains, and an accumulation of them is *sand*. Fragmental material grades in size from gravel through sandy gravel and pebbly sand to pure sand. Sand is variously designated, according to its mode of occurrence and origin, as well as with reference to its color, shape, and mineralogic composition. Beach sand, river sand, residual sand, black sand, sharp sand, quartz sand, etc., are among the names thus given it.

Specimen No. 3, from the ocean beach on Sullivans Island, at the entrance of Charleston Harbor, is a uniformly fine-grained sand, composed chiefly of angular grains of colorless transparent quartz. Some of the grains of quartz are rounded and a few are stained yellowish by oxide of iron. If the sand is stirred with a small horseshoe magnet, only a few small grains of magnetite may be found adhering to the poles. Some of the black grains are relatively earthy material, such as results from the decomposition of ferromagnesian silicates like augite. Other black grains are yellowish green by transmitted light, and slightly pleochroic, with a large cleavage angle, but a small angle of extinction, and are believed to be hornblende. There are a few thin, light-gray, pearly scales of a cloudy, transparent, biaxial mineral like somewhat-altered muscovite. Clear, angular, glassy grains of microcline and plagioclase were seen, without traces of kaolinization. Numerous small white fragments of molluscan shells are present.

The sand is so largely composed of quartz that it affords a good example of *quartz sand.* Many of the grains are sharp-angular, showing shallow-curved pittings, resulting from conchoidal fracture. A larger proportion of the grains show more or less rounded corners with dull surfaces like ground glass, due to the attrition of the grains among themselves when moved. Grains of sand are so light in water that the feeble knocks they give one another when hustled about by the waves and currents make little impression as compared with that made and received by pebbles. For this reason grains of beach sand will remain angular where pebbles become well rounded. Sand of well-rounded grains worn only by water indicates long-continued exposure to the action of the waves. Waves and currents inclined to the coast cause the sand to travel along the coast. The farther the sand travels the larger the proportion of its rounded grains.

The character of the sand in specimen No. 3 is such as to indicate that it is derived from two sources: (1) From the decomposed and disintegrated crystalline rocks, like gneiss and granite, rich in quartz; and (2) from the breaking up of quartz-feldspar rocks without decomposition. The iron-stained grains of quartz and the complete absence of decomposed feldspar indicate that it was derived from residual materials; the feldspar, having completely decomposed, forming kaolin and muscovite, was entirely separated from the quartz by the sorting action of the waves. The glassy quartz with conchoidal-fracture surfaces and the clear fresh feldspar indicate rock breaking, for such unaltered material could not be of residual origin. The feldspar would show clouding, due to alteration.

The beach sand of the Atlantic coast is part of the formation now developing in that region from the waste of the land. Other minerals besides feldspar are reduced to finer particles by decomposition, and removed in the process of sorting, thus concentrating the quartz to form sand. The bulk of nearly all sand is quartz, a condition which naturally results from the chemical and physical durability of that mineral. A considerable portion of it has been derived from the erosion of the Cretaceous, Tertiary, and Pleistocene sandstones of the Coastal

Plain. Thus it happens that the same grain of sand in the course of its history may have belonged successively to a series of different sandstones, and be much older than the formation in which it occurs.

Closely related to beach sand is *river sand*, which is deposited along the courses of streams through the land. The grains of river sand are usually less rounded than those of beach sand. When composed wholly of angular grains, it is often called *sharp sand* by builders, who use it in making mortar. Varieties of both river and beach sand are sometimes based on mineralogic composition. *Magnetic sand* or *iron sand* is rich in magnetite or other ore of iron. *Micaceous sand* contains much mica. *Feldspathic sand* is rich in feldspar. *Gold sand* or *auriferous sand* contains particles of gold, and at some places along the coast of Oregon and elsewhere has been washed for gold. Auriferous sand is usually black and is sometimes called *black sand*, because of the magnetite and other heavy black minerals it contains.

NO. 4. DUNE SAND (EOLIAN SAND).

(FROM SAN FRANCISCO, CALIFORNIA. DESCRIBED BY J. S. DILLER.)

This sand was collected from the dunes near Golden Gate Park, between San Francisco and the Cliff House. Pl. XI illustrates a portion of the wind-rippled surface of one of these dunes. The twigs in the foreground show the direction of the prevailing wind from the coast. The sand from the adjacent seabeach, like that on many other coasts, is blown inland by the storms from the sea to form the knolls and ridges of the dunes. They are well developed occasionally in arid regions, and also along the shores of lakes; for example, Lake Michigan (see Pl. VI), where the evidence of strong winds is seen in the inclination of the trees.

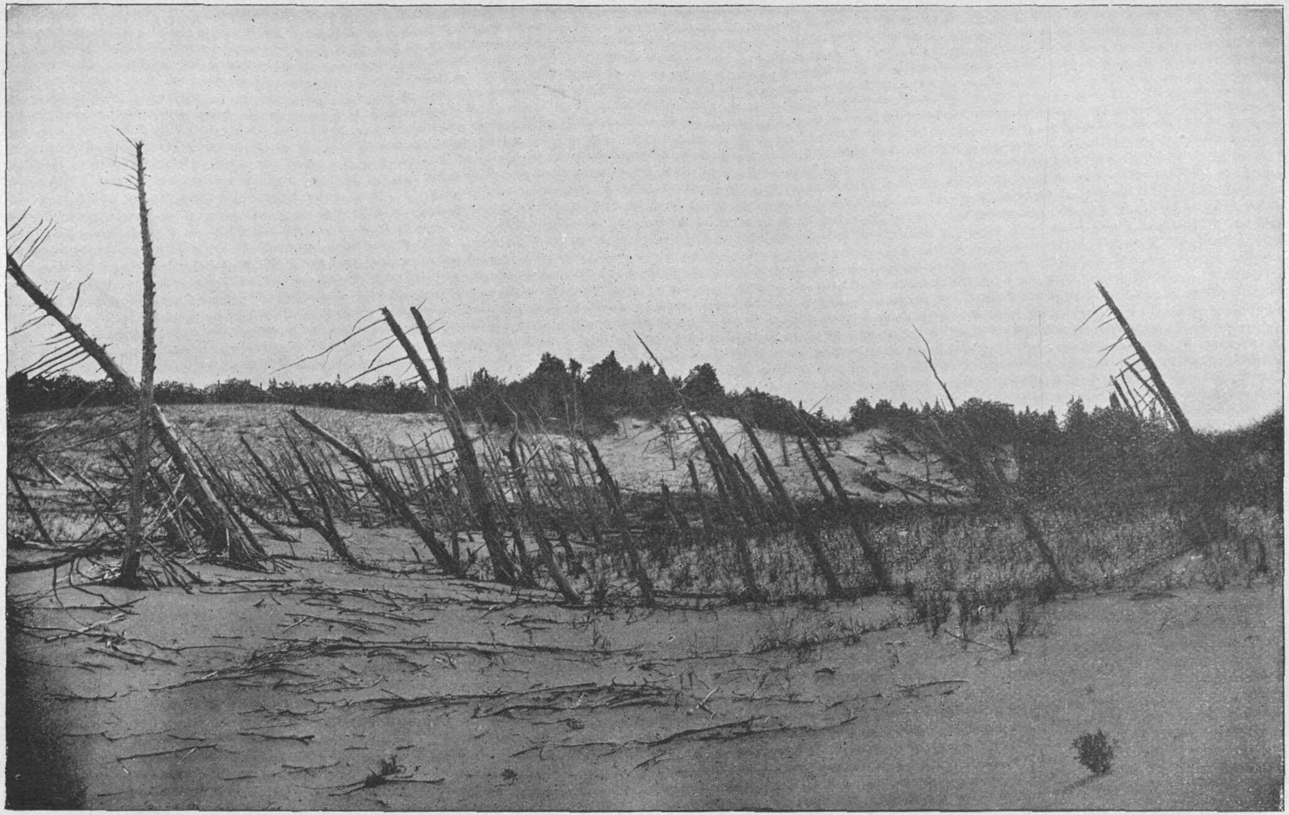
A glance at specimen No. 3 with a lens discloses the fact that the grains are all well rounded. In this respect *dune sand* differs from ordinary beach and river sand, but the difference is only one of gradation. Sand is relatively much heavier in air than in water, so that when hurled by wind the grains strike much harder blows than when borne by water, and this fact fully accounts for the greater roundness of dune sand.

In mineralogic composition dune sand is generally as variable as river and beach sand. Specimen No. 4 is composed chiefly of quartz, although the proportion of quartz is not so large as in specimen No. 3. In No. 4 there are so many grains of hornblende and other black minerals as to give the sand a decidedly dark color. Most of the coarse grains are clear and colorless or have a slight rusty tinge due to oxide of iron. Considerable sand was examined, but no feldspar was found in it. The magnet picks up numerous small black grains of magnetite and grains of other colors inclosing small particles of magnetite. Most of the larger black grains in the sand, when crushed, are found to be a transparent, pleochroic, greenish-yellow mineral with the extinction and cleavage angle of hornblende. Other clear-green vitreous grains without pleochroism and with a large angle of extinction are probably pyroxene. The grains with a dull or waxy luster, ranging in color between red, light yellow, gray, green, and brown, when crushed and exposed under a lens appear to be fine, powdery, siliceous material like that obtained by crushing small pieces of variously colored siliceous slates and jasper, such as are abundant in the Coast Range. Sand dunes border nearly all lacustral and marine coasts that are not rocky, and are usually in the form of irregular rounded ridges or mounds parallel to the beach and with the steeper slope to the landward. They occur not only along the coasts, where the sand is derived from the beaches, but also in arid regions of the interior. They are abundant in the great desert region of North Africa and Arabia, as well as at a number of points in the western part of our own country. They sometimes cover many square miles, and the accumulated sand may be hundreds of feet in thickness. San Francisco is largely built on sand dunes, which cover most of the northern end of the peninsula. The prevailing winds from the southwest blow the sand inland in a rhythmical way and beautifully ripple-mark the surface of the dunes. Owing to the local eddies and frequent shifting of the winds, the structure of the dunes is very irregular. It may be compared with the cross bedding occasionally seen in water deposits. (See Pl. I.)

With variation in the direction and force of the winds and in the supply of sand, the dunes change their form and sometimes travel slowly inland. On the western border of Europe, where blowing sand occupies nearly half the coast from the Pyrenees to the Baltic, their advance varies from place to place, and ranges between 3 and 24 feet per annum. Fertile fields and houses of once populous districts have been buried by advancing dunes. Streams have been turned from their courses, and the whole region has been converted into sand wastes. Such devastation can be averted to a great extent by planting grass to hold the sand, and trees to break the wind. In Gascony, on the southwest coast of France, where dunes are very large, extending along the sea for 150 miles, with a breadth of belt at times as much as 6 miles, and rising frequently to the height of 300 feet, the devastation by the advancing dunes was checked and averted to a considerable extent by planting and growing pines.

Sands shifted by the winds are not confined to the seacoast, but occur on the borders of many lakes, as well as in the arid regions of the interior. They may be seen on the western shore of Lake Michigan (see Pl. VI), where the dunes reach a height of 100 to 200 feet. Forests once entombed beneath them are being again exposed by eolian erosion.

In desert regions the absence of vegetation exposes the rocks directly to the weather, and the dryness is especially favorable to transportation of sand by the winds, which are often vigorous. The blown sand in



HIGH PART OF SOUTH MANITOU ISLAND, LAKE MICHIGAN, SHOWING FOREST FORMERLY BURIED BENEATH DRIFTING SAND AND NOW EXPOSED BY EOLIAN EROSION.

such regions carves the exposed stones and ledges in a peculiar manner. The discovery of this geologic phenomenon led to the invention of the sand blast, which is now a mechanical process of considerable importance in the arts.

The eolian sands of the arid regions of North America have been described by Prof. I. C. Russell: Geological Magazine, July 1889, p. 289. Like those of the coast, the dunes of the interior regions are composed chiefly of quartz, but exceptions to this rule occur occasionally. Professor Russell reports small dunes in Carson Desert composed of casts of small crustaceans (*Cypris*), and others near Fillmore, Utah, composed of crystals of gypsum. On parts of the coast of Cornwall, England, the dune sand consists mostly of fragments of land and sea shells. The material has been used as a fertilizer. In places it is so firmly lithified by calcareous cement that the rock can be used for building. References to the most important papers on dune sand are given by Geikie in his Text-Book of Geology, third edition, pp. 335, 336.

No. 5. GREENSAND.

(FROM FARMINGDALE, MONMOUTH COUNTY, NEW JERSEY. DESCRIBED BY J. S. DILLER.)

Greensand is a sand characterized by the presence of the greenish mineral glauconite, which is essentially a hydrous silicate of aluminum, iron, and potash. It is abundant in the Cretaceous formation along the Atlantic coast, especially in New Jersey, where the series which it characterizes has a thickness of nearly 550 feet. The greensand series is well stratified, and contains in places an abundance of marine fossils.

Typical greensand, of which specimen No. 5 is an example, is composed, besides the glauconite, of some clay, and generally also some calcareous matter, with minerals like those derived from the disintegration of crystalline rocks in the waste of the land. Quartz is most abundant, but feldspar, hornblende, magnetite, augite, zircon, epidote, tourmaline, garnet, and other minerals are present in small amounts. It contains also a few small fragments of gneiss and other rocks.

The principal component, glauconite, is usually in more or less rounded, sometimes mammillated grains about 1^{mm} in diameter. By means of a phosphatic cement the smaller grains are occasionally bound together, forming nodules. The color of the glauconite grains is black or dark green when fresh, and brownish when altered. The mineral is soft and easily crushed, yielding in thin section light-green colors by transmitted light and fine aggregate polarization between crossed nicols. Fine punctures may occasionally be seen upon the surface of the grains; at other times they are smooth and shining; but generally they are dull and the surface is rather irregular. Some of the grains are distinct internal casts of foraminiferal calcareous shells, but generally the form of the shell chambers is not sharply preserved. Dr. C. E. Lord, who examined in the laboratory the upper marl of Farmingdale, reports that, besides containing glauconite, the marl is characterized mineralogically by the presence of microcline, biotite, and muscovite, a great scarcity of chlorite and amphibole, and an increase in the size of the quartz grains, which are round and often attain 3^{mm} in diameter, although generally in the greensands the average diameter is about 1^{mm}. Gypsum and phosphorite are present. These minerals are rarely separated, and occur in large quantities in the argillaceous gray marl near Farmingdale. The phosphorite occurs in the form of an earthy, amorphous, colorless substance, frequently inclosing grains of glauconite or fragments of other minerals, and occasionally the spines and teeth of fishes. It is easily separated and subjected to qualitative analysis to prove that it is phosphate of lime.

Much light has been thrown upon the formation of greensand by the work of the *Challenger* expedition. Approximately 1,000,000 square miles of the sea floor is now covered by glauconitic deposits, and they are limited in their development to certain areas adjacent to the land where Foraminifera are present and the amount of sediment is small. The depth generally is between 100 and 200 fathoms, although glauconite is sometimes found at much greater depths.

In the glauconitic material dredged up from the present sea floor by the *Challenger* and other expeditions, the grains of glauconite are commonly found in the cavities of Foraminifera and other organisms, and in many other cases the grains show clearly the interior casts of such shells, the shells having disappeared. This association is so general that all the probabilities appear to favor the opinion that the glauconite was formed originally in the cavities of organisms. Greensand has been found in greater or less amounts in nearly every geologic horizon from the Cambrian down to the present time, but is especially abundant, as already indicated, in portions of the Cretaceous. Greensand is extensively used in New Jersey as a fertilizer.

The student will find much additional information concerning the formation of the glauconitic deposits of the present oceans in the Challenger Report of Deep Sea Deposits, especially on pp. 378 to 391. Concerning the greensands of the Atlantic coast, reference may be made to A Preliminary Report on the Cretaceous and Tertiary formations of New Jersey, by W. B. Clark, in the Annual Report of the State Geologist of New Jersey for 1892, pp. 169 to 245; also to the Journal of Geology (February and March, 1894), Vol. II, p. 161.

No. 6. FOSSILS FROM MARINE SAND.

(FROM GROVE WHARF, JAMES CITY COUNTY, VIRGINIA. DESCRIBED BY J. S. DILLER.)

In the beach sand of specimen No. 3 there are fragments of shells broken up by the waves. At many places along the coast the shells are buried in the sand before they are broken. This takes place especially beneath the water a little offshore, or in a bay, where the force of the waves is not so violent as on an exposed beach and animal life is abundant to supply the shells. When buried so as to become a part of the earth, and thus to form a record of the kind of animals that lived while the sand was being deposited, the shells are *fossils*. The two shells of specimen No. 6 are fossils whose specific names are *Venus mercenaria* and *Pecten jeffersonius*. They were found buried in the sand as illustrated in fig. 8. The clams and scollops which bore these shells lived and died in the sea during the geologic epoch known as the Miocene. The bodies disappeared, but the shells remained unaltered, buried in the sand, to tell of the life of that ancient time.

The presence of the shells in the bluffs on the land far from the sea shows that during the Miocene epoch the ocean covered much of what is now dry land, and that since then the sea bottom at that particular place, and in fact all along the Atlantic coast of the United States from Massachusetts to Florida, has been raised and the coast line moved farther eastward to its present position.

Specimen No. 6 furnishes an example of the simplest type of fossilization. The organism is buried and a large part of it, the shell, remains unaltered. Specimen No. 38 illustrates a type of fossilization in which the shell is completely changed, and only the outer form is preserved, while in specimen No. 37, which is a third type, although the organic matter is completely replaced, the outer form and delicate internal structure of the wood are completely preserved.

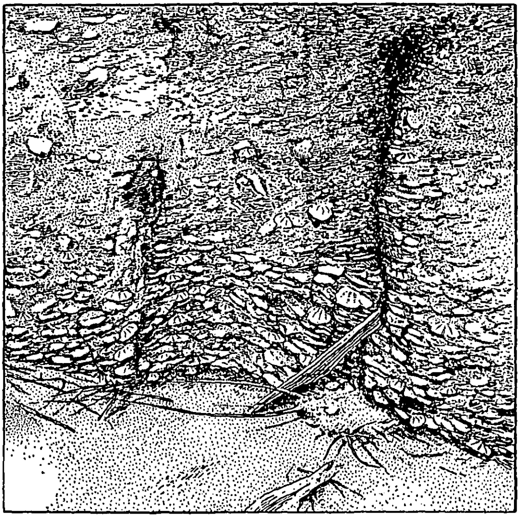


FIG. 8.—Shells in marine sand at Carters Grove, on James River, Virginia.

No. 7. LOESS.

(FROM MUSCATINE, IOWA. DESCRIBED BY J. S. DILLER.)

The pale-yellowish, homogeneous, fine-granular, somewhat calcareous earthy material forming the bluffs at Muscatine, Iowa, and elsewhere along the Mississippi is called *loess*. The name was first given to material of the same sort occupying the valley of the Rhine.

The loess of Muscatine is intermediate in fineness of grain between sand and clay, and, although it appears remarkably uniform, there is considerable range in the size of the particles—from about 1 mm. to

0.0001 mm. in diameter—the finer material forming by far the greater portion of the mass.[1] Under the microscope it is seen that most of the grains are angular or subangular, but many are distinctly rounded, showing that at some stage of its existence they have been subjected to considerable attrition. Quartz is the most abundant mineral in both rounded and angular grains. Clear, colorless grains of orthoclase and plagioclase feldspar and green pleochroic fragments of hornblende are common but not abundant. Yellowish, strongly pleochroic, foliated scales of biotite occur occasionally, and rarely fragments of a pale-reddish, strongly absorbing mineral, supposed to be tourmaline. There are a small number of black, opaque grains, some of which are probably ores of iron, although none were found to be magnetic, even after heating. The flocculent yellowish or rusty-gray particles are clay, colored chiefly by oxide of iron. They become decidedly reddish by ignition, just as in the manufacture of red bricks the yellowish hydrous oxide of iron (limonite), by heating and driving off the water, is changed to red hematite.

In dilute hydrochloric acid the loess effervesces vigorously, but only for a few moments, showing the presence of small amounts of carbonate of lime. It generally occurs in the form of small nodules or tubes, and by studying the loess in the field it has been found that the minute tubes represent the rootlets of vegetation penetrating from the surface. They ramify the deposit, but as their general direction is vertical they give to the loess a vertical structure, which tends to make it form cliffs where sufficiently thick and properly exposed. This feature can be seen in Pl. VII, which shows a typical exposure of the loess at Muscatine. At this exposure the loess appears to be massive, i.e., without evident stratification. Such is the general character of the loess, but at other exposures in the same region there are distinct traces of stratification due to aqueous deposition.

Besides the mineral constituents already noted, the loess from Muscatine contains a few minute coiled shells of land snails. According to W J McGee,[2] the loess of the southern part of the State contains also the fragments of other land animals, a few water snails, and still fewer mussels, the latter of subarctic and arctic facies. The land animals are most closely related to arctic and subarctic forms, indicating that the loess originated during a cold epoch.

The distribution of the loess in the Mississippi Valley, as recently pointed out by Chamberlin, may be summed up in two great features: It is distributed (1) along the leading valleys, and (2) along the border of the former ice sheet at the stage now known as the Iowan. The loess occurs principally in the valleys of the Missouri, Mississippi, Illinois, and Wabash rivers. Along the Missouri River it is found from southern Dakota to its mouth, and along the Mississippi River

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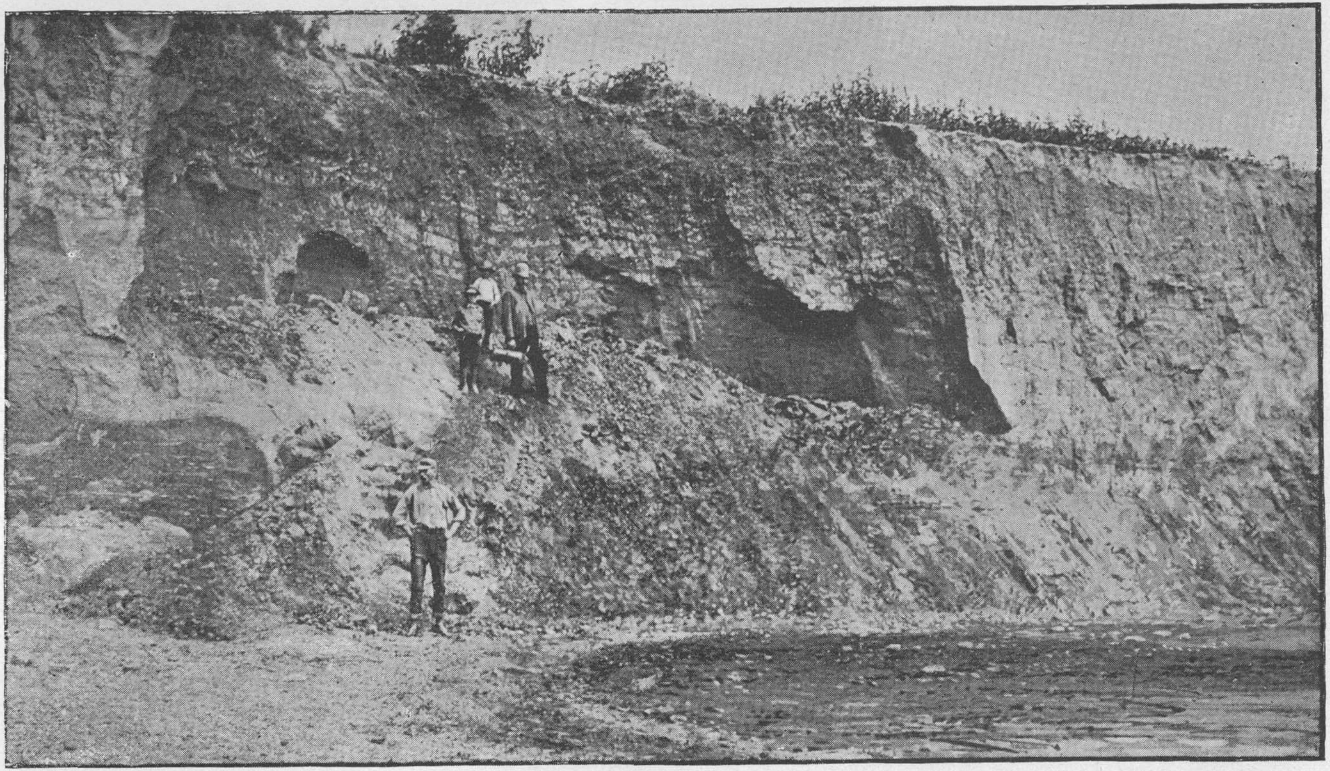
[1] Report of the Illinois World's Fair Commission, by Milton Whitney, pp. 93-114.

[2] Eleventh Ann. Rept. U. S. Geol. Survey, Part I, 1891, pp. 300 and 471.



A TYPICAL EXPOSURE OF SOUTHERN LOESS, MUSCATINE, IOWA.

from Minnesota to southern Mississippi. Along the Illinois and the Wabash it occurs from the points of their emergence from the territory of the later glacial sheet to their mouths. In all these valleys the loess is thickest, coarsest, and most typical in the bluffs bordering the rivers, and becomes finer, thinner, and nontypical as the distance from the rivers increases.

The distribution of the loess along the front of the ice sheet in glacial times was elaborately worked out for Iowa by Mr. McGee, who showed that the loess material was the fine stuff ground up by the glacier which, during the loess epoch, terminated in that region. Many others have so greatly extended the evidence of this relation that it is now generally accepted as one of prime importance in considering the origin of the loess. While it appears to be clear that the material of the loess in the Mississippi Valley was furnished by the ice sheet, and that in some way it was distributed chiefly by water, there are many puzzling features of its distribution that are not easily accounted for; as, for example, the wide range in altitude of the loess deposits. The extent of the vertical range, as pointed out by Chamberlin, is about 1,000 feet, and frequently the range within a score of miles is from 500 to 700 feet. The fluctuating floods of the loess epoch must have exposed portions of the loess-covered flats to the action of the winds, and the fact that evidences of wind action in the original deposition of the loess have been observed has led Chamberlin to suggest that eolian as well as aqueous agencies may have played an important part in the deposition of the loess of the Mississippi Valley.

Loess similar to that of the Mississippi Valley has been recognized in many parts of the earth, especially in the valley of the Rhine, along the Danube, and in various portions of southeastern Asia. Notwithstanding the similarity of its general features in many regions, its origin may be very diverse. In China, for example, its large masses are supposed by Richthofen to be chiefly wind-blown material derived from the disintegration of the rocks in the adjacent hills. Prof. I. C. Russell[1] has shown that the "adobe" in the arid regions of the West is practically identical with the loess of China, and that its subaerial accumulation is to be mainly ascribed to the action of ephemeral streams. Wherever it occurs the loess or adobe is a fertile soil and, excepting in arid regions, sustains a large agricultural population.

The student will find further information on this subject in the following papers: The Driftless Area of the Upper Mississippi Valley, by T. C. Chamberlin and R. D. Salisbury, Sixth Annual Report of the United States Geological Survey (1884-'85), pp. 278-307; The Pleistocene History of Northeastern Iowa, by W J McGee, Eleventh Annual Report of the United States Geological Survey (1889-'90), Part I, pp. 291-303; Supplementary Hypothesis Respecting the Origin of the Loess of the Mississippi Valley, by T. C. Chamberlin, Journal of Geology, Vol. V (November-December, 1897), pp. 795-802.

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[1] Geological Magazine, 1889, p. 349.

No. 8. BRICK CLAY.

(FROM BRICK HAVEN, ALEXANDRIA COUNTY, VIRGINIA. DESCRIBED BY J. S. DILLER.)

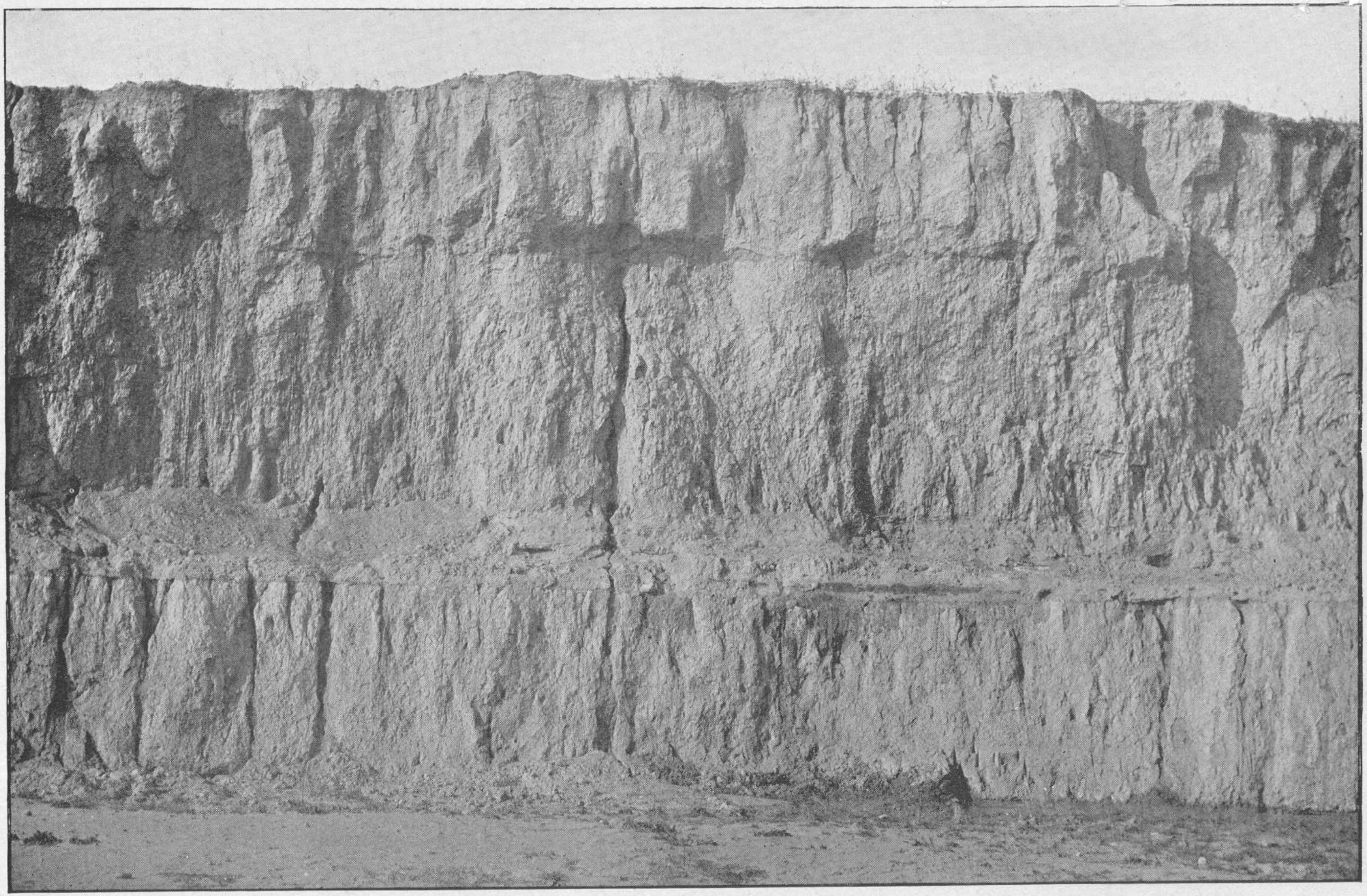
Fine earthy material like specimen No. 8, which is somewhat firm and brittle when dry, but plastic and tenacious when wet, is *clay*. When pure, it is composed essentially of silicate of aluminum. Generally, however, it is impure from the presence of fine grains of quartz and oxide of iron, as well as other minerals.

Specimen No. 8 is clay from a bank, represented in Pl. VIII, on the Virginia side of the Potomac, nearly opposite Washington. Its pale-yellowish color is due to the presence of hydrous oxide of iron (limonite), which when the brick is burned loses water and becomes hematite, coloring the brick red.

When stirred in water the clay readily goes to pieces; the coarse particles subside rapidly, the finer ones slowly. By decanting, the material can be separated into portions differing in size of the particles. Under the microscope the coarser portion is seen to contain numerous grains of quartz, with a few of clear banded feldspar. There are occasional minute round nodules of limonite; and nearly all the grains of sand, as well as of clay, are stained yellowish by oxide of iron. The coarser portion is made up chiefly of quartz grains and oxide of iron, and many of the grains of quartz are well rounded. In the finer portion clay particles are more abundant, but they are much smaller than the quartz and other mineral fragments. The clay is in very fine scales and is stained reddish yellow by oxide of iron. The scales look like minute flakes of mica, but may be distinguished by their very weak double refraction. The basis of clay is silicate of aluminum, and when pure in minute scales it is colorless. The aggregation of such scales looks white, like snow, on account of its porous structure.

Clay is the insoluble residue left from the decomposition and disintegration of aluminous silicates, especially feldspar, but it is derived also from nephelite, scapolite, and other minerals containing much silica and alumina. The white clay (kaolin) derived from feldspar is illustrated in specimens Nos. 147, 148, and 149, which are the residual material of feldspathic rocks. Specimen No. 150 is clay derived from the decomposition of an argillaceous limestone. The clay was originally deposited with the carbonate of lime in the limestone as it formed. Later, when the limestone was raised above the sea and exposed to the weather, the rain dissolved the soluble carbonate of lime and left the insoluble residual clay.

The clay represented by specimen No. 8 forms a deposit of considerable extent along the Potomac near Washington, and differs from the clays mentioned above in that it has been transported by water from the place where it originated to its present position. The deposit rises less than 150 feet above the river. It is extensively used in the manufacture



CLAY BANK AT BRICK HAVEN, VIRGINIA, OPPOSITE WASHINGTON, DISTRICT OF COLUMBIA.

of brick, and a view in one of the clay pits is given in Pl. VIII. According to W J McGee,[1] the clay belongs to the Columbia formation, and was deposited in an estuary on the borders of a river delta of the ancient Potomac. At the time this clay was deposited (i. e., during the later Columbia epoch) the Atlantic slope in the vicinity of Washington stood about 150 feet below its present level. The Potomac entered the estuary at Washington and dropped its load of sediment, of which the clays were the finer portion. They were derived, at least in large part, from the loose mantle of residual material resulting from the decomposition and disintegration of the rocks in the Potomac basin.

From a study of the relation of the Columbia formation to bowlder-bearing strata and to the great terminal moraine which stretches across the country from Cape Cod in Massachusetts to Dakota, Mr. McGee concludes that the clays of the Potomac river near Washington were deposited during the first and second glacial periods, in the early part of the Pleistocene.

No. 9. BOWLDER CLAY.

(FROM ROCHESTER, NEW YORK. DESCRIBED BY G. K. GILBERT.)

Certain clays produced by glaciers contain pebbles and bowlders, and are therefore called *bowlder clays*. In the description of specimen No. 2 some account is given of glaciers and ice sheets, and mention is made of the ice sheet which in Pleistocene time covered a large portion of northeastern North America. As the stones held in an ice sheet rub one on another and are gradually reduced in size, the particles ground off remain embedded in the ice. Where the stones rub against the bed rock, not only are they ground away, but the bed rock itself is worn, and the product of all this abrasion is received by the ice and carried forward. Where the ice melts, its load comes to rest, forming a deposit, and in this deposit the coarser and finer fragments may be indiscriminately mixed. Such a mixed deposit is called *till*. Sometimes its finer part is sand, but usually there is enough clay to make it coherent, and the name bowlder-clay is then commonly used. Bowlder-clays are heterogeneous not only in mechanical structure but in composition. The ice in its journey abrades many rocks, and the particles ground from all these are mingled together in the resulting till. The ratio in which the different rocks traversed are represented in the till depends partly on the extent of their outcrops and partly on the readiness with which they are ground away; and it is also found that the nearest rocks are relatively better represented than the more remote. In the northern States the motion of the ice sheet was southward, and the till at each locality is largely composed of pebbles and rock flour from the formation lying immediately north of it. Specimen No. 9 is

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[1] Proc. Am. Assoc. Adv. Sci., Vol. XXXVI, p 221. Also Am. Jour. Sci., 3d series, Vol. XXXV, p. 331.

from a till deposit underlain by the Niagara limestone, but a short distance to the north begins a broad outcrop of Medina shale, and this formation furnished the chief material of the clay, giving its reddish color.

The specimen appears, on first examination, to contain a few fine pebbles and very little sand; but when the coarser portion is separated from the finer by successive washings, sand is found to form a considerable proportion of the whole mass. The sand is chiefly quartz, with a small amount of feldspar and green hornblende and much oxide of iron. Some of the larger grains are angular, but the smaller ones are often rounded. The very fine material is not a normal clay, such as results from the decomposition of aluminous silicates, but is a rock flour, due to the trituration of a variety of materials, including various unaltered as well as decomposed silicates and the carbonates of lime and magnesia. The sand grains were probably derived chiefly from the sandstone of the Medina formation, and had been rounded before they were received by the ice.

Further information will be found in the descriptions of specimens Nos. 2 and 155. The reader is also referred to The Terminal Moraine of the Second Glacial Epoch, by T. C. Chamberlin, in the Third Annual Report of the United States Geological Survey; and to The Surface Geology of New Jersey, by R. D. Salisbury, in the Annual Report of the State Geologist of New Jersey for 1891.

No. 10. CONGLOMERATE.

(FROM UTICA, ONEIDA COUNTY, NEW YORK. DESCRIBED BY J. S. DILLER.)

When gravel is cemented so that the pebbles and sand of which it is composed are bound together, the rock formed is *conglomerate.* It differs from gravel only in containing a cementing substance which converts the loose material into a solid mass.

In specimen No. 10 the pebbles are quartz. They are small and generally well rounded. Some, indeed, are subangular, but most of them have the corners completely reduced. The sand, and also the cement which holds the fragments together, are chiefly quartz. Although there are a few brass-yellowish grains of pyrite, and some black ones of other minerals, almost the whole mass of the rock is silica. It is a deposit in which quartz is so abundant as to indicate that at the time the conglomerate was formed the conditions were especially favorable for the accumulation of quartz.

The bed of conglomerate from which specimen No. 10 was taken is well exposed in Oneida County, New York, and on this account is called Oneida conglomerate. It is associated with a thick sandstone—the Medina—which varies in color from red to white, and which may be traced almost continuously from western New York eastward to near the Hudson, where its upturned edge swings to the southwest, stretching away through New Jersey, Pennsylvania, Maryland, Virginia, and Tennessee into Alabama. From this long line the outcrops of the Medina sandstone and conglomerate extend westward to the Mississippi Valley, but in that direction the material gradually becomes finer.

The shells found in the sandstone, as illustrated in specimen No. 19, show that it was deposited in the ocean. The reduction in the size of the particles of the sediment toward the Mississippi Valley, in accordance with the general relations of littoral deposits illustrated in fig. 7 (p. 57), indicates that the shore of the ocean lay to the eastward, in the Appalachian region, and that at that time the sea occupied the Mississippi Valley.

Most conglomerates contain a considerable proportion of quartz pebbles, or pebbles of siliceous rock, but besides these they usually contain pebbles of many other kinds. The most abundant pebbles are those of the most durable rocks, such as vein quartz, quartzite, graywacke, granite, and various kinds of volcanic and plutonic rocks, especially those which contain a high percentage of silica. When pebbles of any one kind predominate, special names, such as *quartz conglomerate*, *limestone conglomerate*, and *volcanic conglomerate*, may be given to the rock, according to the prevailing constituent.

Conglomerates may be coarse or fine, according to the size of the pebbles of which they are composed. Fragments larger than pebbles are often called *bowlders*, and conglomerates containing them have been designated *bowlder conglomerates*. The size of the fragments and their surface features are indexes to the character and strength of the transporting power by which they were deposited.

As indicated in the descriptions of specimens Nos. 1 and 2, gravel originates wholly in the process of erosion, either by glaciers or streams of water on the land, or by waves of the sea beating on the coast. On stormy coasts, where much gravel is produced and the undertow is strong enough to carry it seaward, it is spread over the bottom near shore to form a bed of conglomerate, as illustrated in fig. 7. Being beneath the sea, the deposit is below the level of erosion and is preserved so long as it remains in that position. On the land, however, the conditions are different. The gravel deposits of glaciers and water-courses are ever exposed to erosion. By shifting floods they are gradually washed down to lower levels toward the sea, and finally the material is carried into the sea, where it finds a resting place. For this reason gravel deposits of the land are ephemeral. In the process of erosion they are carried into the sea, where, like those formed by the waves, they are added to the more permanent deposits which contribute to the upbuilding of new formations. The coarsest material is deposited nearest shore and marks approximately the direction of the shore line, so that by tracing out the coarse conglomerate among the ancient sedimentary rocks we can to a considerable extent make out the geography of the land and sea. The distribution of the sandstone and conglomerate of which specimen No. 10 is a sample shows clearly that the shore line of the Medina epoch was in the Appalachian region and that the land furnishing the sediment lay to the eastward.

The cement which binds the loose material together and converts gravel into conglomerate varies from place to place, and sometimes holds a more or less definite relation to the composition of the rock. In conglomerates where the sand and pebbles are chiefly quartz the cement is often siliceous; in those containing fragments rich in iron it is generally ferruginous. Silica and oxide of iron are the most common cementing substances, but carbonate of lime also occurs in some regions. These three cements are illustrated in sandstones by specimens Nos. 12, 14, and 15. In some cases there is no visible cement, the pebbles and matrix being so closely pressed together that they adhere.

NO. 11. BRECCIA.

(FROM VIRGINIA, OPPOSITE POINT OF ROCKS, MARYLAND. DESCRIBED BY J. S. DILLER.)

Breccia differs from conglomerate in the shape of the fragments of which it is composed. In conglomerate most of the pebbles are rounded, but in breccia the fragments are angular. Intermediate stages between the two rocks have been called brecciated conglomerate.

Breccias are much less common than conglomerates, and are produced in various ways. Those of sedimentary origin are of little importance and grade into conglomerate. Specimen No. 11 is of this type. It was selected on account of its distinctly fragmental structure, its availability, and its architectural application. Although many of the fragments are angular, others are well rounded; in fact, at most places where this rock crops out the round pebbles predominate, so that generally the rock is a conglomerate. The fragments are nearly all limestone, and at the time the breccia originated the fragments were transported only a short distance from their source. This fact is readily determined by studying the rock in the field, where it occurs near the limestone from which the fragments were derived.

The color of the limestone fragments in specimen No. 11 varies according to that of the parent rock, but the interstitial material of sand, carbonate of lime, and oxide of iron in which the pebbles are embedded is uniformly red, like much of the Triassic sandstone belonging to the same formation.

As in conglomerate, there are three substances which act as cement in the breccia—carbonate of lime, oxide of iron, and silica—and all are of nearly equal importance. If a piece of the red material between the pebbles is placed in hot hydrochloric acid until the carbonate of lime and oxide of iron are dissolved away, the fragment usually retains its form, owing to the siliceous cement present.

The rock of which specimen No. 11 is a sample has been used for ornamental building purposes. A series of large columns of this material adorn the old Hall of Representatives, now called Statuary Hall, in the Capitol at Washington. But it is so difficult to dress and polish evenly that it is not extensively used for such purposes.

For further information concerning this rock, reference should be made to a paper by Arthur Keith on The Geology of the Catoctin Belt, in the Fourteenth Annual Report of the United States Geological Survey, Part II, page 346, and to Stones for Building and Decoration, by G. P. Merrill, page 93.

FIG. 9.—Brecciated Devonian limestone, Fayette, Iowa.

Besides the breccias of sedimentary origin, illustrated by specimen No 11, there are *talus breccias*, *fault* or *friction breccias*, and *volcanic* or *eruptive breccias*. Under the influence of the weather, on steep slopes rocks break up into angular fragments, and beneath cliffs such fragments generally accumulate and form a talus, which in some places becomes cemented so as to form talus breccia. In breccias of this sort none of the fragments are rounded. They occur perhaps most frequently in regions of extensive limestones, especially such as are cavernous, limestones furnishing both the fragments and the cement.

Along lines of fracture, where rocks have been faulted and crushed, the angular fragments thus formed may be cemented by substances held in solution by water circulating in the fissures, and thus form breccia. Such breccia is called fault breccia or friction breccia. Breccias of a smilar sort, whose origin is in some cases at least not yet clearly understood, are illustrated by fig. 9, which represents a limestone breccia described by W J McGee in the Eleventh Annual Report of the United States Geological Survey, Part I, pages 319–321.

Fragments ejected from volcanoes are often angular, and a consolidated accumulation of them forms volcanic breccia. Acid lavas are usually viscous, and during their eruption are sometimes so crushed and broken as to become a mass of angular fragments. When cemented together by material of the same kind as the fragments, as is often the case, such lavas are breccias, and to distinguish them from others are called *lava breccias* or *brecciated lavas.* Lava flowing over angular fragments on the surface may pick them up, and the mass may thus become brecciated.

In the various kinds of breccias there may be a wide range not only in the size of the fragments but also in their chemical composition. Usually, however, there is less variety in composition than among the pebbles of a conglomerate, but a greater range in size.

NO. 12. PEBBLY SANDSTONE.

(FROM BARRON, NEAR ASHLAND, JACKSON COUNTY, OREGON. DESCRIBED BY J. S. DILLER.)

Conglomerates are composed of pebbles, and sandstones are composed of sand. They are often found intermingled as alternating layers of the same mass and pass into each other gradually or abruptly, recording the gradual or sudden change in the currents by which the material was deposited. Between conglomerates and sandstone there are many intermediate grades. These may be represented by specimen No. 12.

Pebbly sandstone is composed chiefly of sand, but contains so large a proportion of conspicuous pebbles that these deserve mention in the name. This specimen was collected from a pebbly bed in a mass of Cretaceous sandstone resting unconformably on the older rocks of the Klamath Mountains, from which the material to make the sandstone was derived. The dark-colored pebbles are chiefly slates, while the lighter-colored ones are from masses of serpentine and other eruptive rocks. The fragments are all metamorphic rocks, and some are full of small veins.

Gray sand, which constitutes the greater portion of the rock, is composed chiefly of quartz and feldspar, with some mica and other minerals derived from the diorities, granites, and similar eruptive rocks, as well as from the slates with which they are associated in the Klamath

Mountains. Some of the small, dark grains of sand are, like the pebbles, intersected by microscopic veins. Although the pebbles are well rounded, the grains of quartz and feldspar are angular. This feature is well illustrated in Pl. IX, *A*. Some of the grains are of plagioclase feldspar, but their banding can not be seen in ordinary light. The other grains are of quartz, with sharp, angular outlines, strongly contrasting with the rounded forms of the pebbles with which they are associated. This association shows clearly that the pebbles are rounded more easily than the grains of sand, and the reason for this is to be found in the fact that the grains of sand, being so light in the buoyant water, strike such tiny blows when they collide with one another during transportation that but little effect is produced. On the other hand, the pebbles, on account of their greater weight, strike much more effective blows and soon get their corners knocked off.

A drop of acid on specimen No. 12 causes brisk effervescence, showing the presence of carbonate of lime as a cementing substance between the grains of sand and pebbles.

At the time the pebbly sandstone was formed the Klamath Mountains were an island in the Cretaceous seas and received the beat of the waves, which, to a large extent at least, produced the fragments and deposited them to make the pebbly sandstone. Although all the fragments in the pebbly sandstone are of metamorphic rocks, the pebbly sandstone itself is entirely unaltered. So it is evident that the rocks of the Klamath Mountains were metamorphosed before the Cretaceous sandstone was deposited.

NO. 13. GRAY SANDSTONE.

(FROM BEREA, CUYAHOGA COUNTY, OHIO. DESCRIBED BY J. S. DILLER.)

Sandstone is consolidated sand. As long as the material is loose and incoherent it is sand, but whenever by any process the particles are made to cohere so as to form a solid rock, they become sandstone. All sandstones were originally sand and show similar variations in composition and texture. The range of variation, however, is greater than in sands, on account of the differences in the composition, color, and other properties of the cement.

The grains of some porous sandstones are angular and so loosely cemented that when broken the surface of the rock is rough and gritty to the feel. Such sandstones are commonly called *grits*, and of these specimen No. 13 is a good example. It is well exposed at Berea, Ohio, where it is extensively quarried for building stones and for grindstones and is generally known as the Berea grit.

The Berea grit is a fine-grained, homogeneous sandstone, composed almost wholly of quartz and orthoclase feldspar. The latter is greatly altered and in most cases completely changed to kaolin, which is readily distinguished by its whiteness. With the gray quartz, it gives color to the rock. Some grains of kaolin contain fresh cores of feldspar, and a few comparatively fresh grains of microcline and plagioclase may be seen.

Muscovite and pyrite are rather rare. The cementing substance is argillaceous and is impregnated by oxide of iron, but there is not a sufficient quantity present to modify the color of the rock. The cement is weak and does not fill all the interstices between the grains of sand. On this account the rock is soft and porous, so that it can be easily carved and readily absorbs a large amount of water.

Kaolin occurs in distinct grains of essentially the same shape as the quartz, although somewhat more rounded. These grains, as well as the thick coating of soft kaolin which envelops some of the rounded grains of feldspar, had not yet been formed at the time the sandstone was deposited, else it would have been removed by the attrition the grains have experienced during their transportation.

The original freshness of the material and the presence of such a considerable portion of feldspar suggest that the surface of the land at the time the sandstone was formed must have been one of considerable relief. It is only when streams have considerable fall that the currents are swift and strong enough to carry grains of sand and pebbles. In a rapid stream pebbles and bowlders are rolled along on its bed. They frequently knock together, break to pieces, and by long-continued attrition are reduced to sand and finer sediment, but the sand formed in such cases is composed of fresh minerals. The feldspar, at least when the sand originates, is chiefly unaltered, but on subsequent exposure to weathering it may readily become changed to kaolin, as in the Berea grit. Had the land been one of gentle relief, worn down to almost a plain (peneplain), the streams would have been sluggish and able to remove only the material resulting from the decomposition and disintegration of the rocks. The fine particles of kaolin derived from the alteration of the feldspar are readily separated from the quartz during transportation, leaving the sand composed almost exclusively of quartz. Thus it appears that the original presence of a considerable proportion of unaltered feldspar indicates that the land from which it was derived at the time the Berea grit was formed was one of considerable relief. Chemical analysis of the rock, according to Mr. G. P. Merrill,[1] shows that the rock contains about 95 per cent of silica, with a small amount of lime, magnesia, oxide of iron, alumina, and alkalies. When freshly quarried it contains from 5.83 to 7.75 per cent of water, but when dry only 3.39 to 4.28 per cent.

The Berea grit has a wide distribution in Ohio, having an extent of about 15,000 square miles above and below ground. This wide extent is remarkable considering its thickness, as it seldom reaches 50 feet. In the northern part of the State it is medium grained and contains some pebbles, but in the middle and southern portion of the State it is fine grained. Its surface is often ripple-marked, and worm burrows abound as on the sands of modern beaches, indicating that the Berea grit was formed along an ancient shore line.

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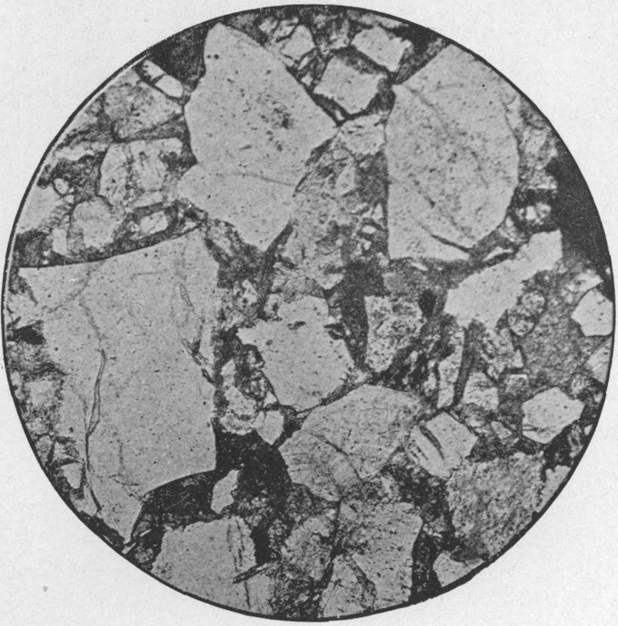
[1] Stones for Building and Decoration, p. 77.



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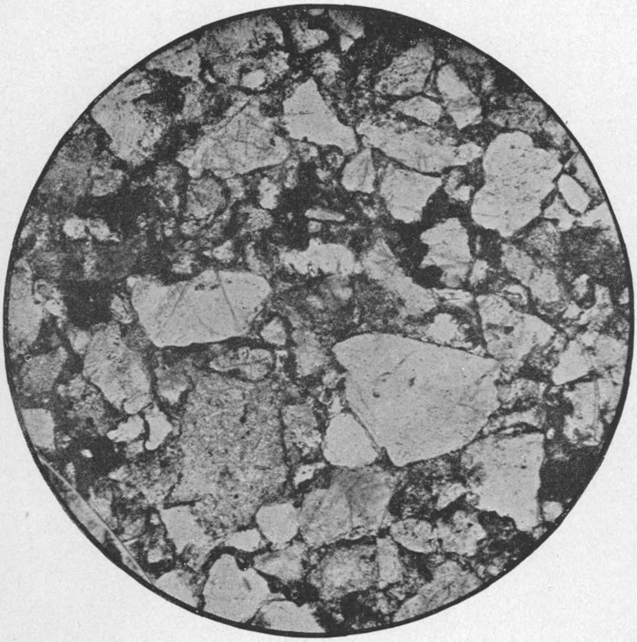

B

THIN SECTIONS OF SANDSTONE.

A. Pebbly sandstone from Barron, Oregon, as seen under a microscope in ordinary light, × 50.
B. Brown sandstone from Hummelstown. Pennsylvania, as seen under a microscope in ordinary light, × 50.

On account of its agreeable color, its durability, and the ease with which it is worked, it is a valuable building stone. Its grit makes it valuable for grindstones, and its porosity makes it a reservoir for petroleum and gas. According to Prof. Edward Orton,[1] it is "the most important single stratum in the entire geological column of Ohio. Its economic value above ground is great, but it is greater below. In its outcrops it is a source of the finest building stone and the best grindstone grit of the country, and when it dips beneath the surface it becomes the repository of valuable supplies of petroleum, gas, and salt water."

No. 14. Brown Sandstone.

(From Hummelstown, Dauphin County, Pennsylvania. Described by J. S. Diller.)

The sandstone of Hummelstown, Pennsylvania, is a typical sandstone with ferruginous cement. In color it is usually purplish brown with minute white specks. The uniformity in the size of its rather small grains gives the rock an even texture. Its feel is decidedly gritty, owing to the angular form of the grains. It is composed chiefly of angular grains of quartz with some clear, fresh microcline and plagioclase, showing distinct twinning. Occasionally fragments of a mineral with very strong absorption perpendicular to the prismatic axis, and parallel extinction like that of tourmaline, may be found. The kaolin present is sometimes in distinct grains of about the same size as those of quartz. It was deposited chiefly as finer silt between the grains of sand, and is much less abundant than the quartz. The largest grain shown in the lower left-hand quarter of Pl. IX, *B*, is kaolin. The others are nearly all quartz. The brownish cement which is the chief interstitial substance and coats many of the grains of quartz is ferric oxide. On account of its abundance it gives color to the whole mass. As its color varies through shades and tints of brown and red, so also the rock varies in color.

The following analysis, by E. A. Schneider, shows the chemical composition of the rock:

Analysis of brown sandstone from Hummelstown, Pennsylvania.

	Per cent.
SiO_2	88.13
Al_2O_3	5.81
Fe_2O_3	1.77
FeO	.31
CaO	.20
MgO	.53
K_2O	2.63
Na_2O	.06
H_2O (105°)	.23
H_2O (ignition)	.26
Total	99.93

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[1] Geological Survey of Ohio, Economic Geology, vol. 6, p. 28.

At the quarry from which specimen No. 14 was obtained the rock near the surface is reddish brown, and the greater body of the rock deeper in the earth is purplish brown. The bedded arrangement of the rock is a prominent feature of the quarries. The even layers are usually less than 10 feet in thickness and are cut by joints, which greatly facilitate quarrying.

The formation represented by the brownstone of Hummelstown, Pennsylvania, has a wide and irregular distribution along a belt stretching from New England to South Carolina. Throughout the whole belt, although it varies in texture considerably, ranging all the way from a coarse conglomerate and angular breccia to shale, it is everywhere deeply colored by oxide of iron and frequently associated with compact, dark, heavy, igneous rock, such as the basalt of Orange, New Jersey, illustrated by specimen No. 102. Specimen No. 11 is breccia from the border of the same formation near the Potomac.

Much has been written on this formation. Its bibliography is given by Prof. I. C. Russell,[1] who illustrates its distribution by maps and fully describes its character and the hypotheses concerning its history. He calls it the Newark system. Fossil plants and fishes, and also the footprints and bones of huge reptiles and batrachians, have been found at a number of places, and their evidence fixes the age of the Newark as Juratrias. Whether it was deposited in a series of local basins, corresponding to the present disconnected distribution of the rocks, or as a broad terrane in one irregular and continuous arm of the sea stretching from New England to South Carolina, is as yet a matter of discussion.

The uniformly red and brown color of the formation throughout its whole extent indicates uniform conditions over the whole area. As shown by Mr. Russell,[2] it suggests a mild, moist climate. Gneiss, schists, and similar rocks containing much pyroxene, hornblende, and mica or other ferromagnesian silicates are not usually red when undecomposed. Under the influence of the weather, however, these iron-bearing minerals may be altered and much ferric oxide developed, coating the grains of quartz and other unchanged minerals red or brown. If these products of subaerial decay are washed away and deposited to form sandstones and shales without wearing off the ferric oxide coating the grains, the new rock will be red or brown; and thus, it is thought, the red color of the Newark system may be explained.

The great length of the formation, taken in connection with its small breadth and great thickness, and its intimate association with basaltic igneous rocks having the same lineal arrangement and being, at least in part, of contemporaneous origin, are among its most important features. The rock is extensively used as a building stone in cities of the Atlantic States, and at several points coal beds of importance have been discovered.

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[1] Bull. U. S. Geol. Survey No. 85, 1892.

[2] Bull. U. S. Geol. Survey No. 52, 1889, p. 56.

No. 15. POTSDAM SANDSTONE.

(FROM ABLEMANS, SAUK COUNTY, WISCONSIN. DESCRIBED BY J. S. DILLER.)

The Potsdam sandstone is so named from its occurrence at Potsdam, in northern New York. It has been traced through a wide stretch of country southwest and west of New York; and at many points, as in Wisconsin, where it has been positively identified, the same name is applied.

It is a typical quartz sandstone in which the sand is largely siliceous. It is light, almost colorless, on account of the transparency of the quartz of which it is composed, although there is here and there a suggestion of pale rusty yellow, due to the trace of ferric oxide present in the cement.

Its structure is decidedly granular and somewhat porous. The interstices between the grains are in many cases not completely filled. The feel of specimen No. 15 is less gritty than that of specimen No. 14, and if the surfaces of the two specimens be examined with a lens it will be observed that when specimen No. 15 is fractured many of the grains break, but in specimen No. 14 the cement breaks and the grains pull apart, leaving the surface with more angular projections.

The grains are nearly all quartz, colorless and transparent, excepting the faint gray clouding due to the occasional presence of the large number of liquid inclusions. The dark material forming part of the cement between the grains in Fig. *A*, Pl. X, is ferric oxide. The outlines of the original well-rounded grains are generally indicated by a clouded border which marks off the siliceous cement between them. In Fig. *B*, Pl. X, it may be seen that the cement is sometimes oriented, so as to be optically continuous with the adjoining grain and extinguished at the same time. In the lower right-hand portion of Fig. *B*, Pl. X, is a banded grain of feldspar. At the upper left hand of the feldspar, as seen in Fig. *A*, Pl. X, is an elongated triangular grain of ferric oxide, and at its right a well-defined area of interstitial quartz which belongs to the adjoining grain. The fragment of quartz crystal represented by the grain grew by additions to the outside until the intervening space was completely occupied. In some places complete crystal faces have been developed. The growth of quartz grains and of other minerals in this manner, and the consequent induration of the rocks containing them, is a metamorphic process. It has been illustrated and discussed by a number of authors, especially by Irving and Van Hise.[1]

This rock is much used for building purposes, and on account of its siliceous cement is especially durable. In some localities, however, where the formation crops out, the cement is not siliceous, or the rock may contain small accumulations of clay. Both of these features, wherever they occur, lessen the value of the stone for building purposes.

The sand of which the Potsdam sandstone was formed is much more

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[1] Bull. U. S. Geol. Survey No. 8, and Am. Jour. Sci., Vol. XXX, p. 231, and Vol. XXXIII, p. 285.

distinctly rounded than most of the beach sand along the Atlantic coast from New England to Florida. It has been so much worn that the feldspar and other minerals softer than the quartz have been almost completely ground to silt and removed. It suggests, also, that the material from which the sand was derived may have been in a greatly decomposed and disintegrated condition, and the landscape one in which gentle slopes prevailed; for under such circumstances the altered minerals are unusually soft, so that they are easily ground fine during transportation, and separated from the quartz.

The following chemical analysis, by E. A. Schneider, shows the highly siliceous character of this sandstone:

Analysis of Potsdam sandstone from Ablemans, Wisconsin.

	Per cent.
SiO_2	99.42
Al_2O_3	.31
H_2O (ignition)	.18
Total	99.91

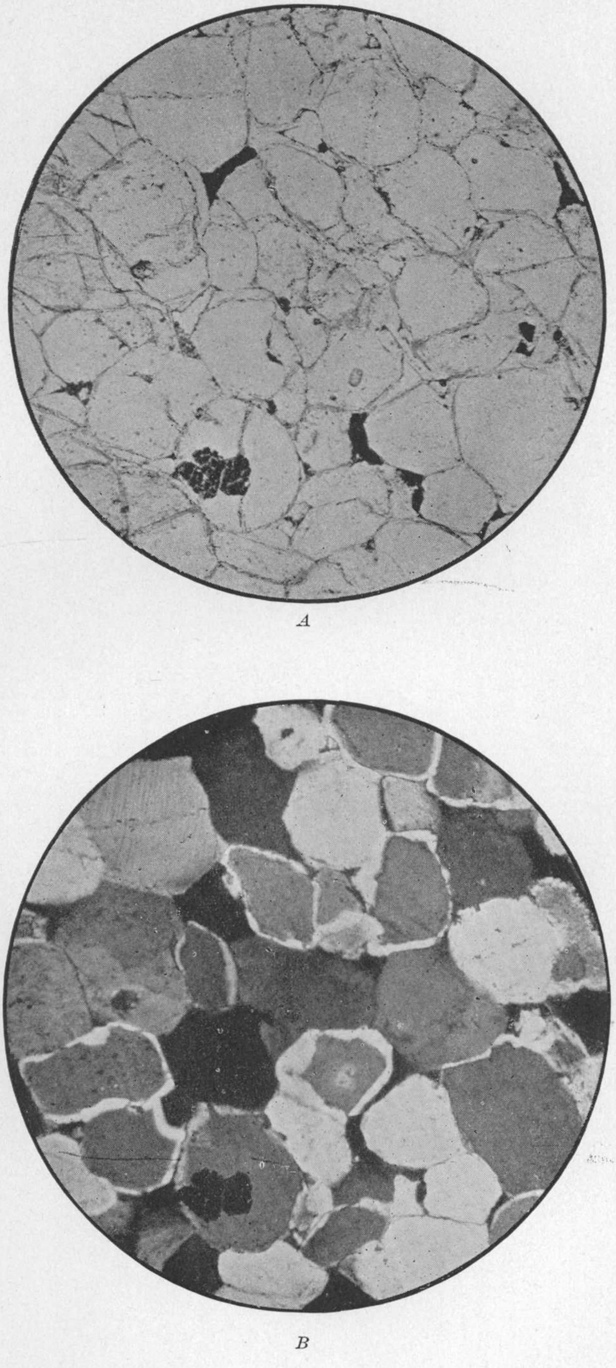
No. 16. BANDED SANDSTONE.

(FROM PEOA, SUMMIT COUNTY, UTAH. DESCRIBED BY J. S. DILLER.)

This sandstone is arranged in distinct layers, beds, or bands, which in the field, where large exposures may be seen, are clearly expressed, chiefly in differences of color. The banding may be seen in the hand specimen, but is not conspicuous. It is parellel to the stratification, and was determined when the material was deposited, although the peculiarities of color may not all have been developed at that time.

The sand of which this stone is composed is almost wholly quartz. Here and there are traces of unaltered feldspar. Grains of kaolin are more abundant than those of fresh feldspar, and they may in some cases be seen as minute white specks in the hand specimen.

Under the microscope the granular structure is much more distinct. The grains of quartz are well rounded. Both silica and ferric oxide appear in the cement. The former is perhaps the more abundant, and is in places optically continuous with the adjoining grain, showing that the crystallographic force in the grain controlled its deposition, and the matter was so arranged as to form a growth in the crystal like that in the Potsdam and many other sandstones. The ferric oxide is sufficiently abundant to give a decidedly reddish color to the rock, and its arrangement has given rise to the banding of the rock. Some bands contain much oxide of iron and others but little. The grains of sand in the various bands do not differ among themselves essentially in size or material. This is not generally the case in beds of stratified rocks, for in such rocks the sediments are ordinarily arranged according to the



THIN SECTIONS OF POTSDAM SANDSTONE, FROM ABLEMAN, WISCONSIN, AS SEEN UNDER A MICROSCOPE, × 50.

A. In ordinary light. *B*. Between crossed nicols.

size and weight of the fragments, thus producing stratification, as illustrated in the laminated sandstone, specimen No. 17.

Following is a chemical analysis of the sandstone, by E. A. Schneider, which shows the very siliceous character of the rock:

Analysis of banded sandstone from Peoa, Utah.

	Per cent.
SiO_2	96.60
Al_2O_3 } Fe_2O_3 }	2.02
FeO	....
CaO	.04
MgO	.08
K_2O	....
Na_2O	....
H_2O (105°)	.11
H_2O (ignition)	.29
Total	99.14

NO. 17. LAMINATED SANDSTONE.

(FROM HOLYOKE, HAMPDEN COUNTY, MASSACHUSETTS. DESCRIBED BY J. S. DILLER.)

The sand of which this stone is composed is very fine and is arranged in such thin sheets as to produce laminated structure. The material is much finer than that of other sandstones in the series, and approaches mud or clay in character. Upon the broad surfaces of the hand specimen may be seen many glistening scales of mica, which lie parallel to the stratification. On account of their extreme thinness the scales of mica readily float and are carried away to be deposited with finer sand and mud.

The composition varies greatly perpendicular to the stratification or lamination, but parallel to it within the same layer the composition is comparatively uniform. The lighter-colored layers are composed chiefly of quartz grains with mica, some grains of feldspar, tourmaline, and other minerals. The quartz is often well rounded and coated with oxide of iron. The darker-colored, red layers contain finer material and more angular particles. Mica, oxide of iron, and argillaceous material are much more abundant, and represent a quieter stage of the water than the coarser films. Systematic variation of these layers indicates a corresponding variation in the conditions of deposition. Where the coarser and thicker portions were laid down the water was more vigorously in motion than where the fine sediment was deposited. The coarser may represent times of heavy rains, melting snow, or flood-tide, and the finer, periods of low, quiet water, carrying a much smaller amount of sediment.

Specimen No. 17 illustrates the laminated sandstone of the Triassic rocks in the Connecticut Valley, and belongs to the same formation as the brownstone of Hummelstown, Pennsylvania, the distribution of which is indicated under specimen No. 14. Throughout this large area the conditions vary greatly, and while the laminated sandstone was forming in some places, coarser sandstone and conglomerate were forming in other places, so that the same stratum may show lateral transitions from the finer to the coarser sediments.

No. 18. RIPPLE-MARKED SANDSTONE.

(FROM HOLYOKE, HAMPDEN COUNTY, MASSACHUSETTS. DESCRIBED BY J. S. DILLER.)

The wavelike marks upon the upper surface of specimen No. 18 are ripple marks, and were produced by corresponding movements of the water at the time the sediments were deposited. In the water they are formed only where it is shallow, and they do not extend beyond the depths to which the water is agitated by the wind. At low water they are well exposed along the sandy shores of the ocean, but they generally attain their most regular development upon the land in regions of wind-blown sand.

Pl. XI illustrates the ripple-marked surface of one of the sand dunes near Golden Gate Park, San Francisco, California. The bent twigs in the foreground show the direction of the prevailing strong winds to be from the left; that is, from the ocean. The axes of the ripple marks are perpendicular to the course of the wind, and the slopes of the small ridges are not equal. Upon the windward side the slope is long and gentle; to the leeward it is short and steep. The sand blown by the wind moves up the long slope and falls over the shorter one, causing the ridge to move forward with the wind, but at a much slower rate. Under the influence of strong winds from the Pacific, the ripple marks illustrated in Pl. XI gradually advance from left to right. The whole surface is in motion and the dunes travel landward.

The development of ripple marks under water is not so simple a matter as their subaërial development, where they are due wholly to the influence of the wind. The ripple marks formed by water are rarely so regular as those illustrated in Pl. XI. In specimen No. 18 the upper surface is of finer material than that of which the ripple marks are chiefly composed, and in the deposition of this sediment the irregularities of the rippled surface were rendered less conspicuous. Originally the material now exposed upon the rippled surface was mud. It was soft and easily impressed. At low water the surface was uncovered and exposed to the weather. Insects, birds, and other animals crossing the mud flat afoot left tracks. The footprints were covered up and preserved by later deposits so as to remain in the rocks, and to-day afford evidence of the character of the animals that lived when the rock was

RIPPLE MARKS ON SAND DUNES NEAR GOLDEN GATE PARK, SAN FRANCISCO, CALIFORNIA.

formed. The sandstone of the Connecticut Valley, from which specimens Nos. 17 and 18 were collected, have long been celebrated for the large fossil footprints it contains in certain localities. During the early portion of the Juratrias period amphibians and reptiles of large size traversed the muddy flats of the Connecticut Valley and left tracks in some cases nearly 2 feet in length. In places where the mud was exposed long enough to dry, reticulated cracks were developed. The succeeding flood filled the mud cracks with sand, and when the rock is split apart the filled mud cracks intersecting the ripple marks appear as in Pl. XII.

No. 19. Fossiliferous Sandstone.

(From Medina, Orleans County, New York. Described by J. S. Diller.)

Fossiliferous sandstone differs from other sandstone only in that it contains fossils. In this specimen from Medina, New York, commonly called the Medina sandstone, the sand, like that of the Potsdam sandstone, is almost exclusively quartz. The fossils it contains are either casts or shells shaped somewhat like a tongue, on which account the little mollusk was named *Lingula*. Lingula is one of the most ancient genera, ranging from the lower Cambrian to the present day. In the course of evolution it has been remarkably persistent, and, unlike most forms, has suffered comparatively little modification under the influence of a long series of geologic changes.

The fossils found in the sandstone are generally of animals which lived upon, or directly above, the sandy bottom of the sea. Rarely the fossils are of land animals or plants which have been brought to the sea by rivers and buried in the sand.

The fossiliferous sandstone at Medina is composed chiefly of quartz, the grains of which are rather angular. The preservation of the delicate shells indicates that the sand, at the time of its deposition, was not subjected to great attrition, else the fragile shells would have been ground to pieces. The cementing substance between the grains is chiefly carbonate of lime, probably derived in large part from the fossils.

This sandstone has a wide distribution through the eastern part of the United States, especially along the Appalachian Mountains, where it is evidently a shore deposit, passing into conglomerate, and containing ripple marks, rill marks, and other evidences of littoral origin. The Medina sandstone is associated with the Oneida conglomerate, and its distribution is more fully given on pages 70 and 71. Being a hard, siliceous rock, interstratified with shales, limestones, and other softer rocks, it more effectually resists the general degradation of the land than its associates, and in the course of long-continued exposure has come to be the principal mountain-forming rock in the immediate vicinity of its outcrop. The North Mountain, of Pennsylvania, the Massanutten, of Virginia, and the Clinch Mountain, of Tennessee, are good examples of mountains formed by the Medina sandstone. They are remarkable for their smooth, even crests, and give evidence of an earlier topographic cycle, when the land of that region stood at a much lower level with reference to the sea, having been, in fact, worn down by the streams during the long-continued period of degradation almost to a plain (peneplain). The even-crested mountains of hard rocks are the only remnants of this ancient peneplain.

NO. 20. GRAYWACKE.

(FROM HURLEY, IRON COUNTY, WISCONSIN. DESCRIBED BY W. S. BAYLEY.)

The graywackes differ from the sandstones in composition. Whereas the latter consist essentially of quartz grains (or of quartz and feldspar, as in the case of the arkoses) cemented by quartzitic, calcareous, or other cement simple in composition, the graywackes contain grains of many different minerals and small fragments of rocks, united by a cement of the composition of many slates. In the formation of the sandstones the rocks from which the sands were derived were broken down into their constituent mineral components, and these were sorted by the waters in which they were deposited. On the other hand, the rocks from whose detritus the graywackes were made were not so completely disintegrated. The sands contained not only quartz and other mineral grains, but also little particles of rock, all so intermingled that we can not believe that much sorting took place. When rock particles are not to be found in the graywackes, the distinction between these rocks and the sandstones must rest upon the cementing material, which in the former is dark in color and contains much chlorite and some mica.[1]

The specimen in the collection was taken from a low ledge on the south side of the Milwaukee, Lake Shore and Western Railroad, about three miles west of Hurley, Wisconsin. According to Irving and Van Hise, the rock belongs among the upper beds of the Penokee iron formation,[2] which is Huronian. It is not foliated—that is, it is not a schist—but it is heavily bedded, the different beds appearing as finer or coarser grained bands, in the latter of which rock fragments are quite conspicuous, while in the former the grains are so fine that the rocks seem to grade upward into black slates. All the beds have a low dip, a little east of south, and a strike north of east. The low dip of the rock over large areas indicates that it has not been subjected to severe orographic forces—a fact explaining its lack of foliation, and thus serving to distinguish it, together with all the other Penokee-Gogebic rocks, from the much squeezed, highly foliated rocks of pre-Huronian age in this region.

The specimen is an excellent representative of the typical graywacke, although but few rock fragments can be discovered in it. It

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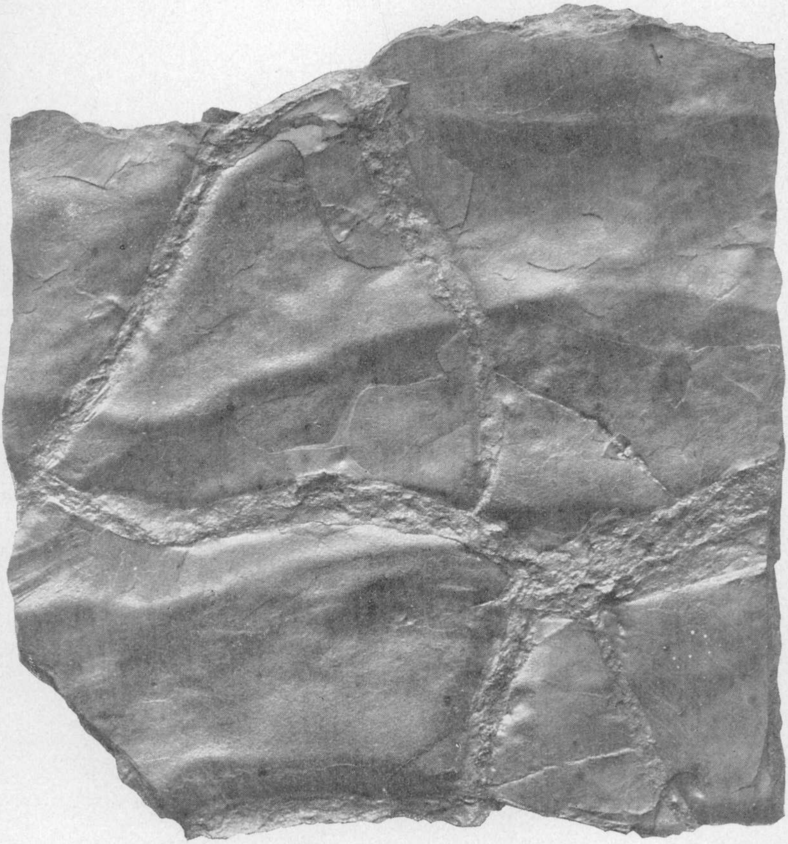
[1] Cf. Geikie: Text-Book of Geology, 2d ed., 1885, p. 162; and J. Roth: Allgemeine und Chemische Geologie, B. 11, p. 622.

[2] Tenth Ann. Rept. U. S. Geol. Survey, Part I, pp. 426 et seq.



RIPPLE MARKS CUT BY MUD CRACKS FILLED WITH SAND, FROM THE GRAND CANYON OF THE COLORADO, ARIZONA.

is a fine-grained gray rock of nearly uniform texture. In it may be detected a few grains of quartz that often appear black, small dull white grains of feldspar, and occasionally tiny black streaks that look like slate fragments. It splits quite easily parallel to its bedding, and breaks with a more or less conchoidal fracture in other directions. Its density is 2.687.

Under the microscope its coarser components are easily distinguished from the matrix or cement, which is not in very large quantity. The most numerous grains are clear fragments of quartz, some of which present the rounded outlines of waterworn grains, while others are subangular. They often contain rows of tiny vacuoles filled with liquid, and sometimes a few little specks of dust. Many of them have a wavy extinction, which is usually ascribed to deformation in the internal structure of the mineral showing it, as a consequence of pressure. A few grains are seen to be composed of several portions of different crystals, since their various parts extinguish in different positions. All these features are those belonging to the quartz of crystalline schists. Hence, we may conclude that some of the material of the graywacke was derived from rocks belonging to the crystalline-schist series.

Next to quartz in quantity are feldspar grains. Some of these are quite fresh, and consequently clear, grains of an unstriated variety that is probably orthoclase. Others show the bars of plagioclase, while a few are marked by the gridiron crossbarring of microcline. A few are as well rounded as those of the quartz, but most are more or less angular. The greater portion of the feldspar is highly altered. In natural light such grains appear cloudy, and often they possess a reddish tinge. Under crossed nicols they break up into a sort of mosaic of tiny particles of quartz and small needles and shreds of a brightly polarizing micaceous mineral that may be kaolin. In the most highly colored grains the pigment is discovered to be a red or reddish-brown iron compound intermingled with the other components of the mosaic. The shapes of the altered feldspar grains no longer resemble those of waterworn fragments. Decomposition has destroyed their original outlines, for now the kaolin needles extend into the interstitial cement, so that the margin formed by the replacing mosaic is rough and ragged.

The only other substances that are clearly seen to be grains are a few hornblendic pieces and fragments of dark rock. The pieces of hornblende are very few in number. They are irregular in their outline, as if broken, unworn pieces, and are strongly pleochroic, being yellowish green in a direction perpendicular to their cleavage, and dark green parallel to this. The rock fragments are dark, and sometimes nearly black. Under high powers they are found to consist of fine grains of quartz and of a dark substance, probably some mineral colored black by magnetite.

As a rule, all the fragments lie with their longer axes in one direction, which a little examination of the hand specimen shows to be in the plane of bedding.

The grains make up the larger part of the rock mass. Its most characteristic portion, however, is the material cementing these. This is present in but small quantity. It consists largely of chlorite, which gives it its greenish hue and the rock its dark color. The minerals that can be detected in it are chlorite, quartz, biotite, magnetite, muscovite or kaolin, and a very little hematite. The first two are the most common. Under high powers much of the quartz is found to be in small grains, while a good deal of the same mineral is intermingled with chlorite, etc., as a very fine aggregate of secondary origin. Professor Van Hise, who has studied the graywackes of the Penokee district[1] very carefully, believes that this quartz has come principally from feldspar, whose other product of decomposition is chlorite. In a few instances the origin of the quartz and chlorite may be told from the general shape possessed by their aggregates, which is that of feldspar grains, but in most cases the aggregates possess such indefinite outlines that nothing can be learned from them.

The true cement is the interstitial substance between the smallest recognizable grains. This represents what was originally clay. At present it is composed largely of tiny flakes of green chlorite—a little secondary quartz between the chlorite—and, embedded in this matrix, little particles of magnetite and pyrite, both of which are opaque, small round aggregates of a dark-brown translucent rutile, and occasionally a little flake of green biotite and tiny shreds of kaolin or muscovite. Since the same muscovite or kaolin shreds are observed surrounding some of the larger grains of feldspar, it is probable that this mineral in the cement is derived, like the larger pieces, from substances of the composition of feldspar in the original clay.

The entire cement is thus found to be crystalline. None of the original clay remains. The alteration is regarded by Van Hise, in the article alluded to above, as due entirely to the influence of circulating waters holding certain substances in solution, the most important being some magnesium salt. By the action of this salt on the material of the plagioclase and of the iron-bearing minerals in the original deposit an abundance of chlorite was developed, and at the same time the excess of silica in the feldspar was separated as quartz in the interstices between the chlorite flakes in the matrix.[2]

Such a change as this, produced by the partial solution of substances in a rock and their chemical reaction upon one another, is known as a metasomatic change. By it a clastic rock sometimes loses nearly all evidences of its original fragmental nature and becomes crystalline. If the metasomatic change is attended by pressure, the rock may have developed in it a foliation, and may thus give rise to a new rock, which, if its origin were not known, would undoubtedly be called a crystalline schist. Rocks of this nature have been described by Van

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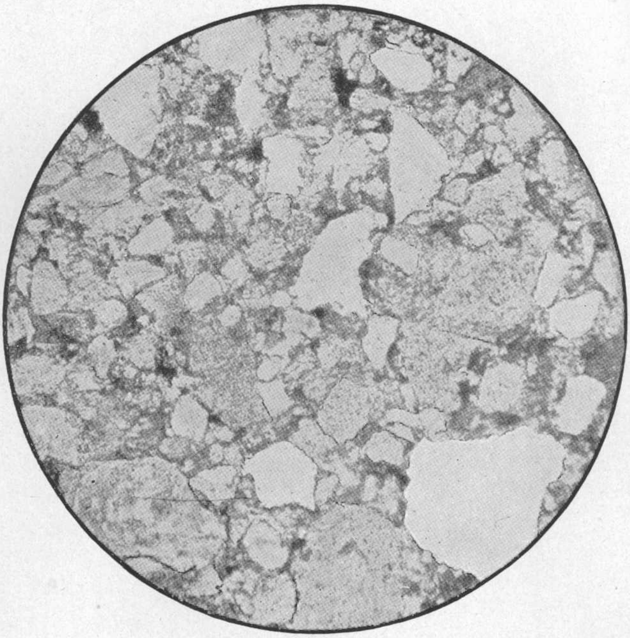
[1] Am. Jour. Sci., 3d series, Vol. XXXI, 1886, p. 453.

[2] The percentage of SiO_2 in oligoclase is about 62 per cent, while the proportion in chlorite is only about 28 per cent.



THIN SECTION OF GRAYWACKE FROM HURLEY, WISCONSIN, AS SEEN UNDER A MICROSCOPE IN ORDINARY LIGHT, × 33.

Hise,[1] and the chemical processes that have changed them from graywackes to mica-schists have been very carefully worked out.

Pl. XIII shows the fragmental character of the rock quite plainly. The lighter grains, both the rounded ones and the sharply angular ones, are quartz. The large clouded grains are altered feldspar. In the lower portion of the figure are two grains that have retained their waterworn outlines, while to the right of the center and a little above it is one whose original outlines have nearly disappeared through decomposition. The muscovite, biotite, and the fine components of the groundmass are not visible in the photograph.

The chemical composition of the graywacke, as reported by H. N. Stokes, is as follows:

Analysis of graywacke from Hurley, Wisconsin.

	Per cent.
SiO_2	76.84
Al_2O_3	11.76
Fe_2O_3	.55
FeO	2.88
MnO	trace
CaO	.70
MgO	1.39
K_2O	1.62
Na_2O	2.57
Loss (ignition)	1.87
Total	100.18

This is not very different from the composition of a feldspathic quartzite. Nor should we expect it to be different, for the original rock of which the graywacke is an altered phase was a plagioclase-quartz-clay rock, as we learn from its microscopic study.[2]

No. 21. SHALE.

(FROM CASHAQUA CREEK, LIVINGSTON COUNTY, NEW YORK. DESCRIBED BY J. S. DILLER.)

Shale is composed of sediment finer than sand. It usually splits or breaks most easily parallel to its stratification, showing that this line of weakness originated at the time of deposition. The deposit is chiefly clay with very fine sand, and the rock became shale by induration.

The rock from which specimen No. 21 was collected is best exposed on Cashaqua Creek, Livingston County, New York. On this account it was locally called the Cashaqua shale. It is light greenish gray, and rather solid for shale. It was obtained at a fresh exposure, where the

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[1] Cf. C. R. Van Hise, upon the Origin of the mica-schists and black mica-slates of the Penokee-Gogebic iron-bearing series: Am. Jour. Sci., 3d series, Vol. XXXI, 1886, p. 453.

[2] For other descriptions of graywackes see F. D. Adams: Appendix to Ann. Rept. Canadian Geol. Survey for 1880-81-82, Montreal, 1883, pp. 20-23; and Irving and Van Hise: Tenth Ann. Rept. U. S. Geol. Survey, pp. 426 et seq.

corrasion by the stream is rapid, so that the weathered portion of the shale has been removed and brought the solid rock to the surface. When exposed for a considerable time to the weather, shale becomes fissile, crumbles to small pieces, and is ultimately reduced to a tenacious clay, sometimes more or less sandy, ready to be carried away by the rains, rills, and rivers into the sea, and again deposited to initiate a new rock cycle. In the field the Cashaqua shale contains a few fossil shells and some flattened calcareous concretions, with traces here and there, but no continuous beds, of sandstone. On the Genesee River this shale is 110 feet thick. It gradually thins toward the west, appearing on Lake Erie with a thickness of 33 feet. To the east of Cashaqua Creek sandy layers become more and more abundant and the shale is gradually replaced by sandstone, indicating that the source from which the sediment of the shale was derived lay in that direction.

Under the microscope the specimens of shale from Cashaqua Creek are seen to vary considerably in the size of the particles of which they are composed. The component material may be conveniently divided into argillaceous and sandy. Both occur in the same specimen, and may be present in nearly equal amounts, or either may predominate, forming almost the whole of the mass.

The sharp, angular sand grains are chiefly quartz. It is generally clear and colorless, but occasionally contains liquid and other inclusions. Greenish grains of hornblende and chlorite are rather common. No fresh feldspar appears among the grains of sand; it has all disappeared in the process of decomposition and disintegration of the rock from which the sediment was derived. The space between the grains is occupied chiefly by argillaceous matter. It incloses scales of muscovite, numerous crystals of ferruginous carbonate of lime, and a multitude of minute prismatic crystals, the exact nature of which is not well understood. The muscovite is usually in very small scales and stripes intermingled with argillaceous material such as one sees ordinarily resulting from the alteration of feldspar. The mica in large part, and perhaps wholly, and also the clay, originated in the decomposing feldspar, although it is possible that the former may have been derived in part from a rock containing primary muscovite.

The small colorless or reddish and yellowish brown crystals are sometimes perfect rhombohedra, but more commonly they are round grains or groups of crystals. When sufficiently transparent the colors between crossed nicols are high. In acetic acid they effervesce like calcite, and when dissolved in hydrochloric acid the solution, upon the addition of ammonia, yields a precipitate of ferric oxide, showing that the carbonate contains iron. Its easy solubility suggests that it is not dolomitic. The mineral is apparently ferrocalcite. In weathered portions of the shale the ferrocalcite is reddish and yellowish brown, owing to the oxidation of the iron, and occasionally the iron oxide is in sufficient abundance to give a rusty tinge to the rock.

The sharp, angular cystals and grains of ferrocalcite are quite uniformly distributed through the whole mass of the rock, and were apparently deposited with the other sediment. It is evident, however, that they differ widely in their origin from the fragments of quartz and the greater portions of the sediments in which they occur. The grains of quartz are minute fragments of the rocks from which they were derived. They are not crystals, but their boundaries are not crystallographic lines. The fact that many of the ferrocalcite grains are perfect crystals indicates that they were deposited directly from solution in water. Whether their precipitation took place with the deposition of the sediment from suspension, or at a later date, may be learned from their relation to the associated material in the shale. In altered rocks carbonates frequently originate in the decomposition of other minerals, but in such cases there are usually more or less distinct traces of the decomposed mineral. In the Cashaqua shale there are no traces of decomposed minerals to indicate that the ferrocalcite originated that way. The complete absence of veins and other irregular accumulations of the material suggests that it was not deposited by waters circulating through the mass after the rock was formed. The regularity of its distribution and its idiomorphic character indicate that it was precipitated from solution in the ocean waters at the same time that the suspended sediments were, so that the chemical and mechanical sediments intermingled upon the bottom. It is known that mechanical precipitation tends to promote chemical precipitation, and it is possible that the association of the two sediments may be in some measure accounted for in this way.

The occurrence of ferrocalcite in this shale is interesting on account of its bearing upon the origin of extensive deposits of iron ore among the crystalline schists.[1]

The minute, brownish, prismatic crystals occurring in irregular abundance, frequently in small swarms, throughout the argillaceous material range in length from 0.01^{mm} to 0.005^{mm}. Generally they are so small that their effect upon transmitted light can not be observed, but the larger ones have a high index of refraction, giving strong color between crossed nicols, and have parallel extinction. They sometimes join in such a way as to suggest twinning, and occasionally are bent. These minute crystals, to which the Germans give the name "Thonschiefernadelchen," occur not only in shale, but more frequently in clay slate. They are referred to in the description of specimen No. 122, and are less abundant than in the Cashaqua shale. The exact nature of these minute crystals has been the subject of much investigation. On account of their small size it is difficult to isolate them for chemical determination, but Sauer, Cathrein, and Werveke have shown conclusively that at least in many cases the minute crystals are rutile.

The Cashaqua shale in New York is a member of the Portage group of the Devonian system of rocks, which has a wide distribution over the whole country between the Appalachian and Rocky mountains.

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[1] R. D. Irving: Am. Jour. Sci., third series, Vol. XXXII, 1886; pp. 255-272.

NO. 22. CARBONACEOUS SHALE.

(FROM DUG GAP, WALKER COUNTY, GEORGIA. DESCRIBED BY J. S. DILLER.)

This shale was collected at Dug Gap, near Lafayette, in the northwestern corner of Georgia. On account of its color it is sometimes called the black shale, or Devonian black shale, to indicate also its geologic age.

The upper portion of the shale, 3 or 4 feet in thickness, is usually dark gray in color, and often carries a layer of round concretions about an inch in diameter. The remainder of the formation, the portion from which the specimens were taken, is jet black from an abundance of carbonaceous matter, and when freshly broken it emits a strong odor like petroleum.[1]

To the unaided eye it is homogeneous and compact, but under the microscope it is minutely granular. The grains are chiefly angular particles of quartz, with minute globules and crystals of pyrite embedded in dark-colored material which is largely carbonaceous, whence the name carbonaceous shale. That this material is for the most part carbonaceous is indicated by the fact that when heated red-hot for a short time the dark color disappears, owing to the combustion of the carbonaceous matter. When highly heated for a longer time before the blowpipe it turns black again and becomes magnetic, due to the presence of iron.

The highly carbonaceous character of the shale is most clearly indicated by the following chemical analysis, made by L. G. Eakins in the chemical laboratory of the United States Geological Survey:

Analysis of shale from Dug Gap, Georgia.

	Per cent.
SiO_2	51.03
Al_2O_3	13.47
Fe_2O_3	8.06
CaO	.78
MgO	1.15
K_2O	3.16
Na_2O	.41
P_2O_5	.31
S	7.29
Fixed carbon	13.11
Volatile hydrocarbon	3.32
H_2O	.81
	102.90
O. for S	2.74
Total	100.16

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[1] In some States this black shale has been distilled for oil, yielding 30 to 40 gallons per ton.

The iron pyrites in the shale oxidizes and, according to Hayes,[1] frequently stains the weathered surface of the rock with iron oxide and sulphate and mineralizes many springs. The shaly structure is not prominent on fresh fractures, but is brought out somewhat by weathering.

Associated with the black shale locally in Tennessee are small nodules and beds of phosphate of lime, which is of economic importance as a fertilizer. Although only a few feet in thickness, this shale is perhaps the most persistent and uniform of all the Paleozoic formations of the South. It extends over the whole of middle Tennessee from the Tennessee River to the eastern edge of the Cumberland Plateau and southward across northwestern Georgia and northern Alabama, its outcrops indicating an original extent over at least 38,000 to 40,000 square miles.

This shale, on account of its distinctive and striking appearance, has attracted much attention from miners and has been prospected in many places for coal and various ores. Such exploitation, however, has always been attended by failure, as the shale contains nothing of present economic importance excepting the local deposits of phosphate of lime. Although it carries a large proportion of carbonaceous matter which burns when it is placed in a hot fire, the amount is not sufficient to constitute it a fuel, and no true coal is ever found associated with it. Besides the fertilizer it affords, this formation is of economic importance chiefly as a starting point in prospecting for the red fossil ore, like No. 52 of this series, which belongs below it at a uniform depth over considerable areas.

UNALTERED SEDIMENTARY ROCKS OF CHEMICAL ORIGIN.

No. 23. Siliceous Sinter.[2]

(From Yellowstone National Park. Described by Walter Harvey Weed.)

The hot springs and geysers of the Yellowstone are surrounded by large areas of siliceous sinter that often entirely cover the floor of the geyser basins. About the spouting vents this material has been built up into mounds and cones of unique forms and great beauty. The more quiet pools have built up more or less regular mounds of white sinter, which are in places as much as 20 feet in height above the surrounding level. Besides these deposits, the alkaline waters of the geyser regions have left deposits of silica wherever they have flowed, and many square miles within the park are covered by white and glistening deposits of this material.

Until the Yellowstone deposits were studied it was the generally accepted theory that the geyser waters reached the surface heavily

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[1] Geologic Atlas U. S., folio 2, Ringgold, Georgia-Tennessee. Also, Sixteenth Ann. Rept. U. S. Geol. Survey, Part IV, pp. 611-623.

[2] See Formation of hot-spring deposits, by W. H. Weed: Ninth Ann. Rept. U. S. Geol. Survey, 1890, pp. 628-663.

charged with silica, which by relief of pressure, by cooling, and by evaporation was precipitated out and deposited by the waters. Observation of the natural conditions under which the Yellowstone deposits are forming, together with experiments and a study of the chemical analyses of the geyser waters, showed that the silica brought to the surface by the geyser waters was rarely separated out and deposited by the first two causes, but that deposits are formed about the geysers and the margins of springs by evaporation, producing a true *geyserite.* A new mode of deposition was then recognized, namely, the separation of silica by plant life, by the algæ that are abundant in the hot waters of the region. It is by this agency that much the largest part of the sinter deposits of the region have been formed.

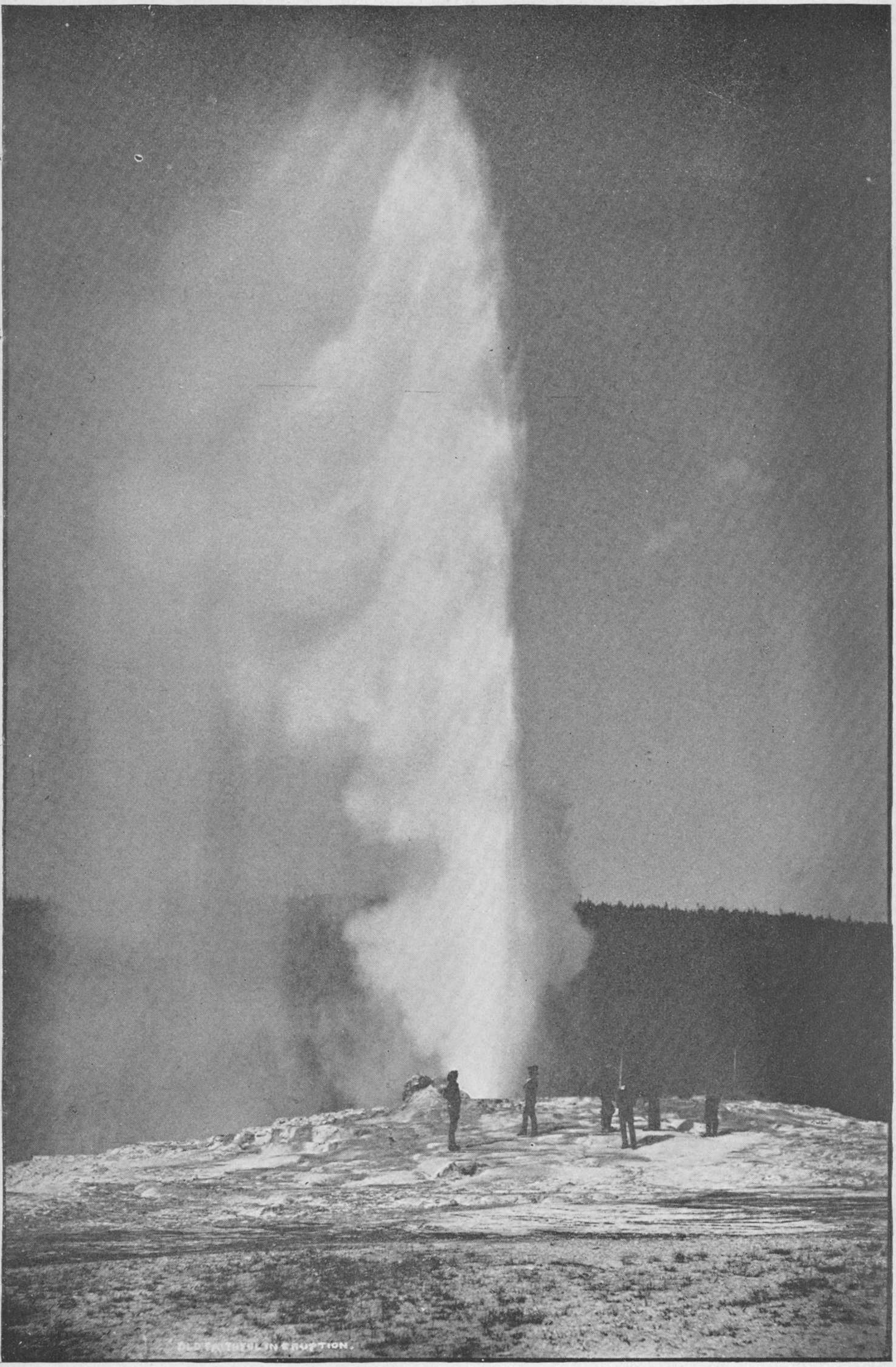
This algous vegetation is sure to be observed by every visitor to the region. Its varied tones of pink, yellow, orange, red, brown, and green adorn the slopes of geyser cones, flush the white silica of the little basins with their tints, and mark the waterways with their brilliant colors. It is ever present where the temperature does not exceed 185° F., often lining the great bowls of the cooler springs and pools with leathery sheets of brown or green. Where a constant overflow prevails, the channel is often filled by a vigorous growth in which an algæ mat is formed having the consistency of a firm jelly, and most beautifully colored. In whatever form it is found, and no matter how brilliantly tinted, this algous material, if removed from the water and dried in the hot sun of the region, rapidly loses its color, shrinks in size, and becomes an opaque white mass of silica, whose weight is not one per cent of its former state. Chemical analysis, made in the Survey laboratory by J. E. Whitfield, shows this dried material to be silica and water, viz:

Analysis of dried algous vegetation from geyser margin, Yellowstone National Park.

	Per cent.
SiO_2	93.37
H_2O	4.17
Organic matter	1.50

Experiments showed the writer that the growing algæ form a jelly of hydrous silica. It is of this material that the algæ filaments are formed, and the algæ slime of other waters is here a hydrous silica binding the threads together. The nature of this separation may be seen under the microscope, though the fresh hydrous silica is difficult to study, and the dried material becomes opaque. In most cases the glassy rods can be readily distinguished, and the inclosing paste usually shows globules and pellets of the dehydrated silica.

The specimen No. 23 is a sinter formed by algæ. It is light and porous, showing in part a fibrous structure, is soft, and resembles chalk in appearance because it soils the fingers with a white impalpable



OLD FAITHFUL GEYSER IN ACTION, YELLOWSTONE NATIONAL PARK.

powder. The specimens represent the lighter, truly algous form of siliceous sinter, such as is commonly formed by the gelatinous mats about the hot springs.

In thin section, when under low powers, the siliceous sinter usually appears as an indistinct aggregate of glassy silica. If, however, a power of 200 diameters be used, and the section is thin enough, the sinter is seen to be composed of a delicate network of minute fibers or threads which pass in and out, and are often composed of extremely minute globules of silica glass. In most cases the algous origin of the sinter is not apparent except under high powers. Generally the organic nature of the sinter can not be satisfactorily determined in thin section, owing to the fact that the plant rods are composed of hyaline silica. It is only in the minutest details that the structure may be recognized. In some specimens of the sinter we see extremely minute, thread-like particles of the silica held in a mat of small spheres of silica closely crowded together. In such cases it is not reasonable to assume that the former organic jelly made by the living plant has, upon drying, separated into such globular particles. It is rather more probable that the silica was itself in the globular form during the life of the plant.

The specimen represents the most common form of freshly formed sinter about the the geyser basins of the Yellowstone. The illustration, Pl. XIV, represents Old Faithful Geyser in action. The eruptions are of four or five minutes' duration, and take place every hour from an opening a couple of feet across in the summit of a mound built up of white siliceous sinter. The sinter forms a series of shallow terraced basins, in the cooler of which the algæ colors are noticed.

No. 24. VEIN.

(FROM PASKENTA, TEHAMA COUNTY, CALIFORNIA. DESCRIBED BY J. S. DILLER.)

Much of the rain that falls upon the earth sinks into it and circulates through the pores and fissures of the rocks beneath the surface. Soluble portions of the rocks are dissolved, and the water becomes charged with mineral matter. When this water again reaches the surface in springs it deposits the mineral matter held in solution, and thus siliceous sinter (No. 23), travertine (No. 29), etc., are formed. It may deposit its dissolved material beneath the surface, filling fissures in rocks, or form icicle shaped masses, as stalactites (No. 28), in caverns.

The fissures in rocks filled in this way with mineral matter are veins. They are illustrated by specimen No. 24, which was collected at Paskenta, in Tehama County, California, where they occur abundantly as stream pebbles brought down from the Coast Range. The vein in this case is quite uniformly white, and is composed of quartz and calcite. When placed in dilute hydrochloric acid it effervesces briskly, dissolving the calcite and leaving the quartz. The calcite is most abundant in the middle portion of the vein, while the quartz usually predominates upon the sides, showing that much of the quartz was deposited before the calcite. This relation is shown in fig. 10, illustrating a vein from which the calcite has been removed by acid. The quartz is often tooth-shaped, projecting into the vein.

Some veins are composed almost wholly of calcite, with but a trace of quartz here and there along the edges, while others are chiefly quartz. Generally, however, the two minerals are present in nearly equal amounts.

The rock fissures or openings which, when filled with mineral matter, become veins are produced in various ways. Some originate in the contraction of the rock while drying or cooling, others are due to solution, but the greater number that become veins are produced in connection with movements of the land in making mountains and continents. It is for this reason that veins are most abundant in mountain regions among rocks which have been upturned and metamorphosed.

Veins of quartz are perhaps more abundant than those of any other mineral, and those of calcite are next in number. Feldspar, barite, fluorite, hornblende, epidote, and pyroxene are other vein minerals, besides precious metals, such as gold and silver, and a large number of ores, which are sometimes of great economic value. Where native gold occurs it is usually found in quartz veins.

Pl. XV illustrates a vein of quartz 2 feet in thickness cutting jointed gneissoid rocks on the Potomac River near Washington, District of Columbia.

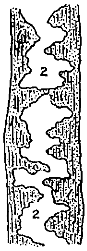


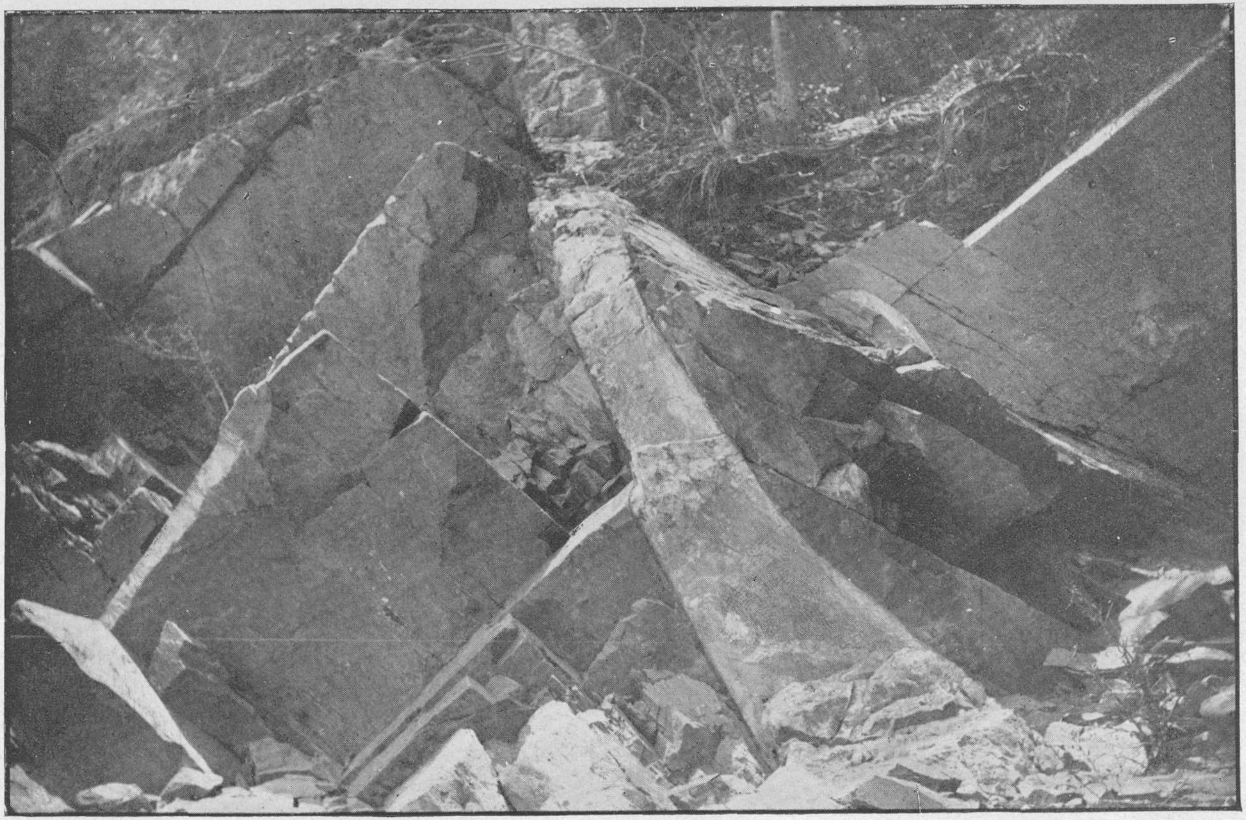
Fig. 10.—Section of vein composed of quartz (1) and calcite (2), from which the calcite has been removed by acid.

A vein containing ore is usually called a *lode* by miners, and the mineral matter associated with the ore in the vein is the *gangue*, while the rock containing the vein is the *country rock*. Veins when first formed are usually not far from vertical, but they may be displaced by subsequent movements and intersected by several series of later veins. They vary in breadth from a mere film to over a hundred feet, and occasionally have banded structure produced by the deposition of corresponding layers on opposite sides of the fissure until it is completely filled. When the filling is not complete the cavities are frequently lined with beautiful crystals similar to those found in *geodes*. Fibrous minerals are usually found in veins, and the fibers are perpendicular to the walls.

No. 25. Vein Quartz.

(From Castleton, Harford County, Maryland. Described by J. S. Diller.)

Of the various kinds of vein-forming minerals, quartz is the most common and important. Veins of quartz in altered crystalline rocks are sometimes 100 feet or more in width and may be traced across the country for miles. It occurs in sufficiently large masses to be considered as a rock. Although usually associated with metamorphic rocks, it originated, like siliceous sinter, by deposition from aqueous solution.



VIEW OF QUARTZ IN GNEISS NEAR CHAIN BRIDGE, DISTRICT OF COLUMBIA.

Specimen No. 25 is from a large vein at Castleton, Maryland. The rock is light colored, vitreous lustered, hard enough to readily scratch glass, infusible, insoluble in hydrochloric acid, and in fact has all the characteristic properties of the mineral quartz. Its structure is granular, but the grains being angular and interlocked, as in granite, they occupy all the space, and as all the particles are of the same material it does not appear granular to the naked eye. This structure is, however, well displayed under the microscope between crossed nicols, owing to the unlike optical orientation of the grains. The grains are transparent, although somewhat clouded by a multitude of minute liquid inclusions, usually less than 0.002 ^{mm} in diameter. These minute inclusions can be seen only with a high magnifying power, but are known to be liquid on account of the moving bubble which each one contains. If the section be gently heated, the liquid expands so as to occupy the whole cavity and the bubble disappears. The cause of the rapid motion of the bubble in these inclusions is not well understood.

Similar inclusions occur in the quartz associated with the calcite in the vein of specimen No. 24, as well as in the quartz of granite, gneiss, and schistose rocks generally.

The included liquid is usually water, but in some cases has been shown[1] to be carbon dioxide in a liquid state, and the two may occur together in the same cavity. Vein quartz is a water deposit from solution, and the included water was usually imprisoned in the cavities at the time the quartz was formed. Occasionally minute cubes of salt are found in these liquid inclusions.

The quartz at Castleton is mined and finely pulverized for use in the manufacture of pottery. In order to render it more pulverable it is highly heated in a kiln. It comes out snow-white and brittle, ready for grinding.

NO. 26. SILICEOUS OOLITE.

(FROM CENTER COUNTY, PENNSYLVANIA. DESCRIBED BY J. S. DILLER.)

The occurrence of silica in the form of sinter deposited by geysers is illustrated by specimen No. 23; that deposited in fissures as veins is represented by specimens Nos. 24 and 25. We now come to a form in which the silica appears in small spherules like fish roe, whence the name oolite. In this case the chief component of the oolite is silica, and it is designated siliceous oolite to distinguish it from the more common form of oolite, such as specimen No. 31, which is composed of carbonate of lime. The material was collected near State College, in Center County, Pennsylvania, where it occurs as bowlders associated with flint over an area of several square miles.

This oolite is remarkable for the uniformity in shape, size, and distribution of the spherules. On a fresh fracture their centers are usually dark, while their rims and the matrix which fills the interspaces and

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[1] G. W. Hawes: Am. Jour. Sci., 3d series, Vol. XXI, p. 203.

incloses the spherules are light colored. Both spherules and matrix are firmly coherent, so that a fracture passes directly through the spherules instead of around them. In some places the hand specimens show cavities which are lined with minute crystals of quartz. It is evident that if conditions had continued favorable for the development of quartz these drusy cavities would all have been filled.

The structure of the spherules may be readily seen in the hand specimen with a pocket lens. Their centers are usually dark, granular, and vitreous, and surrounded by a dense waxy envelope, which is in many cases beautifully banded, like agate. This relation is illustrated by the spherule in the center of the figures in Pl. XVI. The concentric structure shows that the spherules result from growth and not from attrition. At the center of many of them rounded grains of sand are found as a nucleus, about which the silica was deposited in successive layers. Some of the layers are granular quartz; others are fine, granular, or fibrous chalcedony. The black bands and clouding in the figures are brown oxide of iron.

The two large spherules cut through the middle by the left edge of the figures in Pl. XVI have each a round grain of quartz at the center. These grains are full of minute needles and liquid inclusions, like those of granitic quartz. The minute needles observed in these nucleal quartzes do not occur in the granular quartz of the concentric layers. As pointed out by O. E. Hovey, this nucleal quartz is occasionally surrounded by secondary growths of quartz optically continuous with the original grain.[1] In each of the two spherules alluded to the quartz is encircled by a rather coarsely granular band in which many of the longer diameters of the grains radiate from the center of the spherule. Some of the spherules are composed wholly of such grains, and the radial structure is plain. Others appear to be made chiefly of chalcedony. All the sections showing a nucleal grain are corresponding sections, and supposed to be through the middle of the spherule. When compared it is evident that the composition and structure of the spherules vary considerably. Occasionally the nucleal quartz is enveloped in a thick, dense layer of oxide of iron, and more rarely there are finely fibrous layers nearly midway between the center and circumference of the spherule. The outermost layers of the spherules, which form the borders of the interstitial spaces, are generally fibrous. This structure is well illustrated about the clear, triangular area toward the lower left-hand portion of Fig. *B* of Pl. XVI.

Oolite composed of carbonate of lime is of common occurrence, sometimes in large masses containing marine shells, and must be of marine origin. Its formation has been observed in lakes and springs, also. On the other hand, siliceous oolite is rare, and from the fact that, as in specimen No. 28, silica is known to replace carbonate of lime, it has been suggested that the siliceous oolite was originally calcareous.

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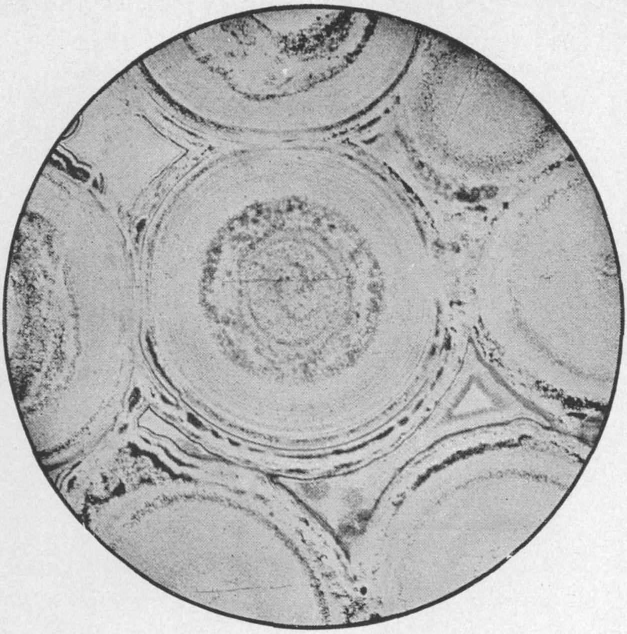
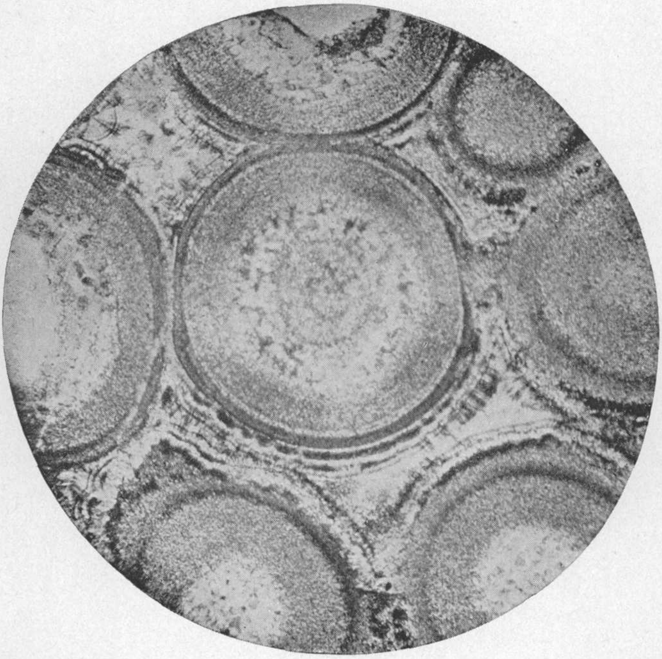
[1] Bull. Geol. Soc. America, Vol. V, p. 628.



A



B

THIN SECTIONS OF SILICEOUS OOLITE FROM CENTER COUNTY, PENNSYLVANIA, AS SEEN UNDER A MICROSCOPE, × 25.

A. In ordinary light. *B*. Between crossed nicols.

Pertinent to this view are the following chemical determinations taken from complete analyses published by Edwin H. Barbour and Joseph Torrey, jr.:[1]

Composition of oolite from near State College, Pennsylvania.

	Lime-silica oolite.	Silica-lime oolite.	Siliceous oolite.
Silica	3.7	56.50	95.83
Calcium carbonate or oxide	88.71	16.84	1.93

The lime-silica oolite and silica-lime oolite occur in the same hand specimen, but are said to be separated by a sharp line. Siliceous oolite and flint occur at the same locality. The same observers report organic remains in the siliceous oolite they describe, but none were observed in the specimens of this series nor in the material described by Hovey.

It does not admit of doubt that the nuclear quartzes filled with minute needles were originally grains of sand about which the concentric layers of silica were formed, but whether or not the concentric layers when first formed were calcareous or siliceous may yet be questioned. Dr. W. Bergt,[2] who has studied the material most carefully in the laboratory, and G. R. Wieland,[3] who has investigated it in the field, have advocated its direct deposition from hot siliceous springs and have described associated phenomena indicating such origin. Furthermore, similar deposits have been observed by W. H. Weed now forming about the siliceous hot springs of the Yellowstone National Park. They will be described by him in Monograph XXXII of the Geological Survey series, under the head of "Hot-spring deposits."

NO. 27. GYPSUM.

(FROM GYPSUM, OTTAWA COUNTY, OHIO. DESCRIBED BY J. S. DILLER.)

Gypsum, like quartz and calcite, occurs at times in such large masses as to be properly considered a rock. At Gypsum, Ohio, it is found near the middle of a great sheet of limestone of upper Silurian age. The specimens for this series were collected by Messrs. Marsh & Co.

Gypsum is generally fine-granular, or compact, and so soft as to be quite easily scratched with the finger nail, but, unlike limestone, does not effervesce in acid. Its normal color is white, though by admixture of clay, carbonaceous matter, and iron oxide, it becomes gray, brown, or reddish. The clear, transparent form of gypsum is selenite, and the compact, white form, frequently used for statuary and ornaments, is alabaster. Its composition is $CaSO_42H_2O$. When heated, the water

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[1] Am. Jour. Sci., 3d series, Vol. XL, pp. 248, 249. See also Petrology for Students, by Alfred Harker, p. 232.

[2] Gesellschaft Isis, in Dresden, 1892, p. 115.

[3] Am. Jour. Sci., Oct., 1897, 4th series, Vol. IV, pp. 262-264.

is readily driven off, and the resulting powder is the common plaster of paris of commerce.

Gypsum is usually found in beds or lenticular masses associated with clay and rock salt, or anhydrite, and it has been found locally in rocks of all ages later than the Silurian. This intimate association with rock salt clearly indicates its marine origin in many cases at least; for it is well known that in the manufacture of salt by evaporation from sea water gypsum is precipitated before the more soluble salt. Gypsum occurs also in irregular masses in limestone and is not associated with salt. It then appears to have resulted directly from the action of sulphuric acid upon the limestone, converting the carbonate into the hydrous sulphate of lime. Gypsum is rarely found forming incrustations in caves.[1]

Gypsum is used chiefly in the manufacture of plaster of paris and land plaster. The former has many applications in the arts, and the latter is a valuable fertilizer. Thin plates of selenite are used to secure certain optical effects in microscopic investigations, and from alabaster statuary, vases, and other ornaments are carved.

No. 28. STALACTITES.

(FROM LURAY CAVE, PAGE COUNTY, VIRGINIA. DESCRIBED BY J. S. DILLER.)

Limestone is one of the most soluble among the common rocks, and in certain regions, as for example Virginia and Kentucky, where circumstances are favorable, large caves are made in it by solution. The underground water in such regions contains much dissolved limestone, and when it seeps through the roof of a cave and evaporates the dissolved limestone is deposited in various shapes, depending chiefly upon the rate of supply. The most common and characteristic feature is the stalactite illustrated by specimen No. 28. A number of stalactites in position are shown in the accompanying Pl. XVII, a view of Marengo Cave, Indiana, taken by Mr. Ben Haines.

A drop of water with carbonate of lime in solution, upon reaching the roof of the cave where it is exposed, begins to evaporate and lose its carbonic acid by virtue of which it holds the limestone in solution. As a result the calcareous matter is deposited around the edge of the drop, and if the proper supply continues a tubular pendant will develop. While some of the small stalactites are hollow, they do not long remain so, for the hollow soon fills and the growth of the stalactite continues by the addition of successive layers upon the outside. A cross section of a stalactite shows it to be composed of one or more concentric bands, which are usually radial fibrous. Their color is generally yellowish, owing to the presence of iron oxide, but occasionally they are snow-white and translucent or beautifully colored by copper or other substances. Their chemical composition is $CaCO_3$, which generally crys-

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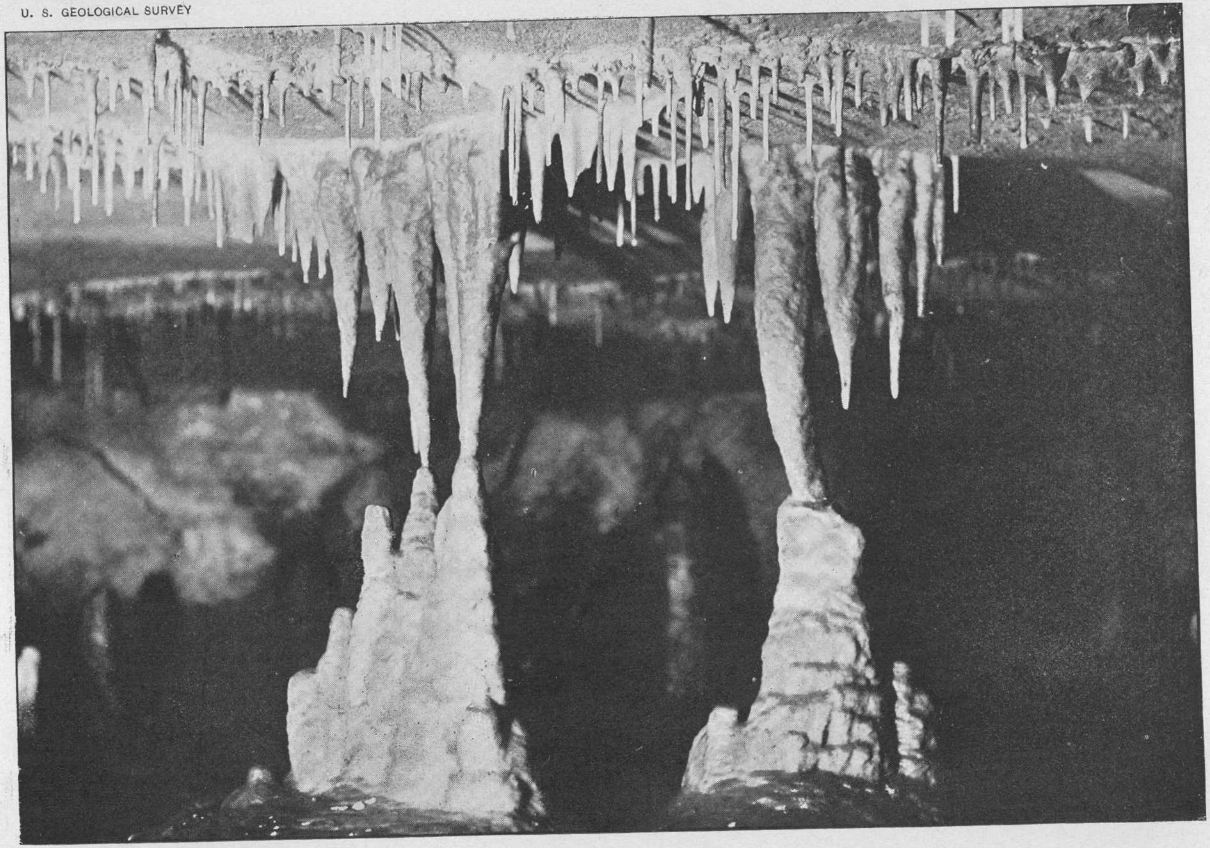
[1] See paper by G. P. Merrill, Proc. U. S. Nat. Mus., Vol. XVII, pp. 80-81.



DEPOSITS IN MARENGO CAVE, INDIANA.

tallizes in the hexagonal system as *calcite*, but occasionally in the orthorhombic system as *aragonite*.

In Pl. XVII stalactites are seen hanging like icicles from the roof of a cave. When the supply of water is greater than can be evaporated from the stalactites, some of it drops to the floor and forms a stalagmite which grows upward as the stalactite grows downward, and if the process be continued long enough the two will meet and form a column, as shown in the plate. Variations in the rate and distribution of the supply give rise to many beautiful as well as grotesque forms. Luray Cave, of Virginia, from which specimen No. 28 was collected, is remarkable for the abundance and varied character of its deposits. Part of these are illustrated in Pl. XVIII, from a photograph taken by Mr. C. H. James, of Philadelphia. All caverns are not so beautifully ornamented. Mammoth Cave, of Kentucky, although remarkable for its size, contains a very small amount of cave deposits such as are shown by the two illustrations.

The formation of stalactites has been described and illustrated by G. P. Merrill in Proc. U. S. Nat. Mus., Vol. XVII, pp. 77–80.

NO. 29. TRAVERTINE.

(FROM MAMMOTH HOT SPRINGS, YELLOWSTONE NATIONAL PARK. DESCRIBED BY WALTER HARVEY WEED.)

Among the many interesting natural phenomena that claim the attention of the visitor to the Yellowstone National Park, the geysers and hot springs rank first in general interest. Their novelty and beauty are sure to attract universal admiration, while the vast quantities of hot water that flow from the ground are convincing evidence of the nearness of internal heat. These steaming fountains and boiling pools are usually surrounded by snowy white borders of mineral matter deposited by the hot waters.

At the Mammoth Hot Springs the deposit consists of carbonate of lime; this forms the unique marble terraces and pulpit basins of those springs. The total area covered by travertine at this place is over a thousand acres, and the greatest thickness is about 250 feet. When first seen the main mass of the deposit is striking from its whiteness, resembling an immense snow bank, filling a narrow valley environed by dark-green, pine-clad slopes. This deposit of travertine forms benches or terraces, the largest one, on which the hotel stands, being 83 acres in extent. While the deposit is white, or if old and weathered a light gray, the hot-spring bowls and overflow basins, and especially the slopes wet by the streams of hot water, are brilliantly tinted with red, yellow, orange, green, and brown. These colors are due to a low form of plant life—algæ—whose presence is not easily recognizable, owing to the covering of travertine. The illustration shows the general character of the terraced basins that are built up on the overflow slopes.

The illustration, Pl. XIX, shows the hot-water basins that cover the slopes, like irregular steps. They are formed by the more rapid deposition about the edges of pools of hot water; and the crenulated border produced by the rippling of the water, together with the presence of algæ, causes an overflow that builds up stalactitic masses that hang like a fringe down the sides of the basins.

The occurrence of plant life in these hot waters has a special significance, as the travertine deposits are built up chiefly by the activity of these little plants, which abstract carbon dioxide from the hot waters, thus causing the precipitation of the carbonate of lime held in solution. The specimen shows the fibrous variety of travertine formed by the encrusting of the yellow, silky skeins of algæ filaments growing in the hottest waters near the orifices of the springs. This deposit forms fan-shaped masses (fig. 11), which eventually choke up the spring.

The specimen shows a beautiful fibrous structure, and is apparently compact, but the transverse section shown by the ends of the specimen prove the rock to be cellular. The freshly formed rock is soft and friable, but becomes indurated and compact with age, the change being unaccompanied by any variation in chemical composition. While freshly formed and wet, the travertine retains the brilliant colors of the algæ, but these gradually fade upon drying and the death of the plant life, and the deposit becomes chalky white. The older deposits have a gray surface, due to the organic matter from the algæ present in the rock.

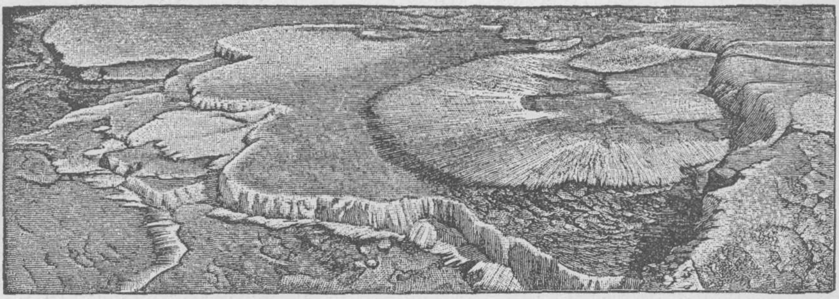
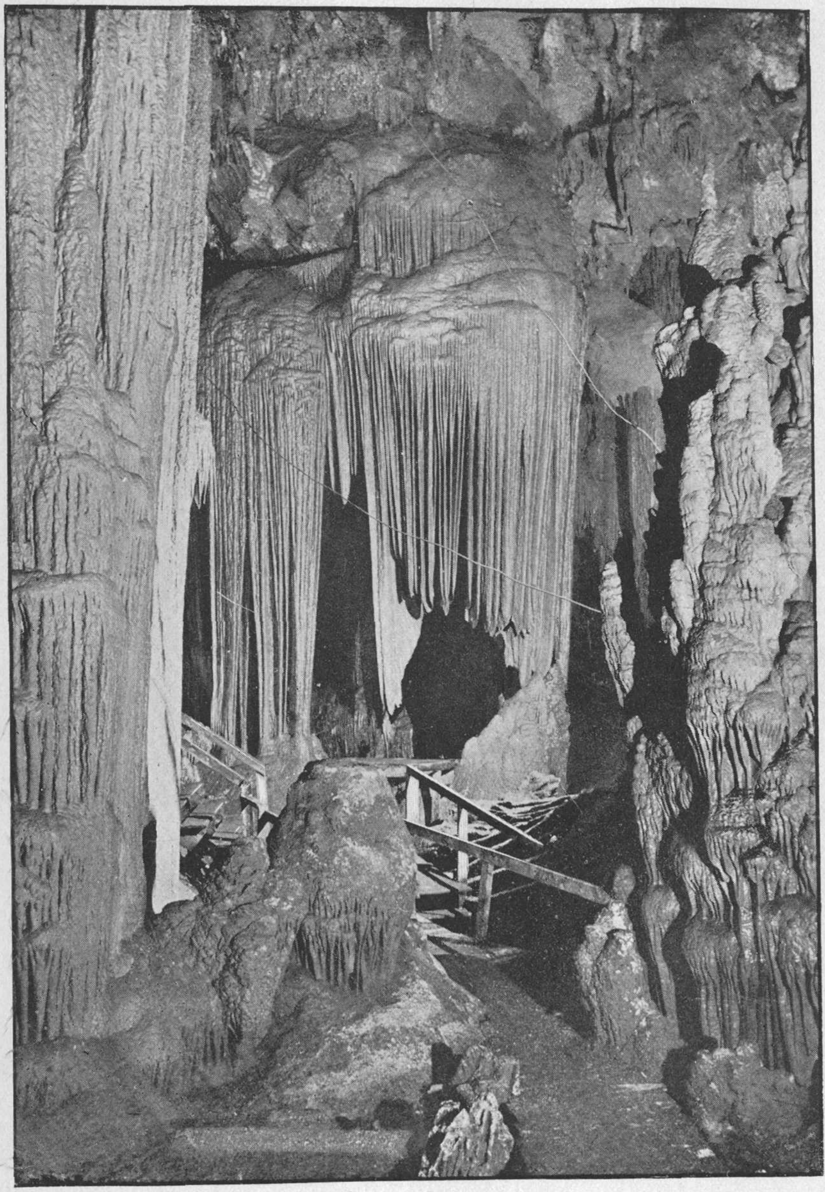


FIG. 11.—Travertine fan, Mammoth Hot Springs, Yellowstone National Park.

Though the specimen of travertine described is a hot-spring deposit, this rock is also formed by cold-spring waters which are highly charged with carbonate of lime. The beautiful cave onyx and other cave deposits are similar in composition, but they are formed more slowly and are therefore of different physical character.

In thin section under the microscope the organic origin is not disclosed, but fresh specimens may be dissolved in dilute acid, which will reveal the algæ sheaths and threads. The following analysis, made in



DEPOSITS IN LURAY CAVE, VIRGINIA.

the laboratory of the United States Geological Survey by J. E. Whitfield, shows the material to be a nearly pure carbonate of lime:

Analysis of travertine from vent near Blue Springs, main terrace, Mammoth Hot Springs, Yellowstone National Park.

	Per cent.
SiO_2, silica	0.06
$Al_2O_3 + Fe_2O_3$	0.14
SO_3, sulphuric acid	0.70
CaO, lime	55.02
$CaCO_3$, lime carbonate	[a] (96.02)
MgO, magnesia	0.06
NaCl, sodium chloride	0.20
K_2O, potash	[b] 0.08
CO_2, carbonic acid	42.25
H_2O, water	1.06
C, carbon	0.24
Other constituents	....
Total	99.81

[a] If all the CO_2 be supposed to be combined with lime.
[b] Potassic chloride.

The striking feature of the analysis is the remarkably low percentage of carbon when it is remembered that the travertine is formed of lime-incrusted algæ threads.

The waters of the Mammoth Hot Springs are so heavily charged with carbonate of lime in solution that this substance is deposited by other agencies than plant life, but they are insignificant in comparison with it. This is taken advantage of in the preparation of coated articles of metal and glass—often sold to tourists—the articles being prepared by exposing them to hot-water spray.

In thin section under the microscope the travertine shows tangled fibers, which are surrounded by a furry growth of calcite spicules, which are in general at right angles to the fibers. Under high powers with crossed nicols these rods appear brownish gray in color, and the spaces between the fibers are filled with a finely cryptocrystalline aggregate of calcite. In many of the sections, where the rods are thickly crowded, the lace-like arrangement is not so apparent and the calcite aggregate is wanting. The calcite spicules which surround the rods are but rudely radial in appearance, and sometimes appear felted, but generally resemble delicate frostwork. This microscopic structure quite accords with what we know of the origin of the travertine. The rods are the coatings of the algæ threads, which in the section are probably merely shells and contain no recognizable organic matter.

No. 30. OOLITIC SAND.

(FROM PYRAMID LAKE, WASHOE COUNTY, NEVADA. DESCRIBED BY J. S. DILLER.)

Among the Needles on the shore of Pyramid Lake in Nevada, according to Prof. I. C. Russell, the short beaches are made up of oolitic sand, represented by specimen No. 30. Although most of the grains are well rounded, there are many subangular ones. In size they are very irregular, ranging from 1^{mm} to 6^{mm} in diameter. The smaller, when cemented, give rise to oolite, but the larger ones produce pisolite. Among the well-rounded grains are occasional shells of a small snail.

The middle portion of each spherule is minutely granular and enveloped by series of concentric fibrous granular layers. Each spherule is a concretion. Some have grains of sand or minute shells at the center as a nucleus, about which the carbonate of lime accumulated. Occasionally the nucleus is large and complex, including one or more concretionary grains, each having its own concentric banding. Most of the spherules, however, are without such foreign nucleus. They appear to have started by the segregation of the more or less flocculent particles of the precipitate itelf, forming globular accumulations upon which the further precipitation continued with variations, giving rise to successive rings of growth. This subject will be considered more at length under "Concretions" (Nos. 33 to 36).

The spherical form of the grains and the uniform thickness of the concentric layers indicate that the grains were in motion while the successive coats were formed. Professor Russell[1] remarks that "this material is evidently now forming, and in places has been cemented into a compact oolite by the deposition of a paste of calcium carbonate between the grains, and forms irregular layers several inches in thickness that slope lakeward at a low angle." The formation of oolitic sand on the shore of Pyramid Lake is limited to the immediate vicinity of the Needles, where warm calcareous springs rise near the shallow margin of the lake.[2]

Similar sand, but much finer, is now forming locally upon the shores of Great Salt Lake. The waters of Pyramid Lake and Great Salt Lake differ widely in chemical composition, and it is evident that the conditions under which oolitic and pisolitic sand may be formed vary considerably.

Dr. A. Rothpletz has shown[3] that the oolitic sand of Great Salt Lake is of vegetal origin. It is due to certain algæ having the power to secrete carbonate of lime. When the grains of sand are dissolved in weak acid, there remain the dead and shriveled bodies of such algæ, and in the lake these granules are usually covered, at least in part, with

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[1] Mon. U. S. Geol. Survey, Vol. XI, p. 168.

[2] Ibid., p. 61.

[3] Botanisches Centralblatt, Nr. 35, 1892; translated by F. W. Cragin in Am. Geologist, Nov. 1892, Vol. X, p. 279.

TERRACES OF MAMMOTH HOT SPRINGS, YELLOWSTONE NATIONAL PARK.

a bluish-green algæ mass. In Pyramid Lake, however, no such masses have been reported in connection with the oölitic sand, and the evidence does not appear to indicate that it is of vegetal origin. To settle this matter, if possible, specimens of this oolitic sand from Pyramid Lake were referred to Prof. W. G. Farlow, of Harvard College, who reports that they contain "nothing like Glœocapsa and Glœothece." He adds: "I find no trace of vegetable structure except the rare occurrence of Leptothrix-like threads broken up into fragments. These are so rare and so imperfectly shown that I can only regard them as accidental impurities, coming, perhaps, from the outside. There is nothing like the mass of algæ found in the Salt Lake material."

No. 31. Oolitic Limestone.

(From Bedford, Lawrence County, Indiana. Described by J. S. Diller.)

The oolitic limestone, or oolite, from Bedford, Indiana, represented by specimen No. 31, is composed chiefly of oolitic grains, among which there is great variety in form, but a smaller range in actual size. They are generally less than 1^{mm} in diameter, and can not be studied to advantage without a microscope. They do not have the usual concentric banding, like the grains of siliceous oolite (No. 26) and oolitic sand (No. 30), and are much more irregular. Discoidal and elongated forms predominate, possibly for the reason that under their conditions of growth the environment was not symmetrical in all sections, and development along different radii proceeded unequally. Much of the variation in shape, however, is due to the fact that the grains are fragments of coral, molluscan shells, worm tubes, and numerous other more or less rounded forms.

Each rounded oolitic grain is enveloped by a coat stained more or less deeply by oxide of iron. Many of these grains are completely crystalline, and, all parts being in parallel position, they extinguish at the same time when rotated between crossed nicols. Some of these grains, as shown by the distribution of their iron oxide, were evidently once organic, and, besides being optically continuous within, they are in some cases continuous upon the outside with the clear granular calcite of the matrix. It is evident that such grains have grown by additions of calcite upon the outside, in just the same manner as the quartz has grown in many slightly altered sedimentary rocks.[1] The matrix is usually more crystalline and clearer than the grains which it incloses, and is often optically continuous about several grains.

Mr. George H. Girty has examined this limestone microscopically, and furnishes the following remarks concerning the fossils it contains:

> Protozoa are very abundantly represented by the foraminiferal genus Endothyra. Most of the forms observed can probably be referred to *Endothyra baileyi* Hall, a common fossil in the St. Louis limestone of the Mississippian series. A trace of sponges

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[1] See descriptions of Nos. 15 and 118.

has been noticed, and corals, belonging chiefly to the genus Zaphrentis, occur sparingly. Fragments of echinoderm plates and spines constitute, perhaps, the greater portion of the organic remains of this rock. Brachiopods and bryozoa are not well represented, and the articulates are represented by ostracods and trilobites.

In the oolitic sand (specimen No. 30) of Pyramid Lake there are usually a few shells of a small fresh-water gastropod; but in the oolite from Bedford, Indiana, the organisms of various kinds are marine and so abundant as to indicate a rich fauna. This commingling of fossils and oolitic grains is illustrated in the formation of oolites upon the seashore to-day. Oolitic sand and oolite, as shown by Dana,[1] are of common occurrence on the beaches of coral islands. Coral rock is broken off and ground up to calcareous sand by the force of the waves that break against the coast. These sands, worm shells, etc., are thrown by the tides and waves upon the beach. The water of such calcareous shores gets much carbonate of lime in solution, and as the sand dries, after the tide recedes, the dissolved material is deposited, thus forming successive coats about the grains, filling the spaces between them, and, if the grains are not frequently moved, ultimately cementing them together to form oolite or pisolite, according to the size of the grains. Dana observed that such "beach deposits consist of regular layers, commonly from an inch to a foot in thickness, and are generally consolidated up to a line a little above high-tide mark. In all instances observed the layers dip at an angle of from 6° to 8° down the beach. The dip is nothing but the slope of the beach itself, and arises from the circumstance that the sands are deposited by the incoming waves or tides on such a sloping surface."

Such deposits are forming on the Florida Keys. Much of the drift sand of that region is consolidated into true oolite, containing numerous traces of organic remains, wholly unlike those of the oolite at Bedford, Indiana.

As shown by Rothpletz[2] and Wethered,[3] it is probable that algæ and other low forms of life which secrete carbonate of lime may have contributed much in the formation of oolite. The fragments of coral and other grains of calcareous sand in water containing much carbonate of lime in solution would, under especially favorable conditions, afford nuclei for the growth of algæ and girvanellæ, forms which are known to have played an important rôle in the formation of certain oolitic granules. The more we learn of sedimentary rocks precipitated from solution the more clearly we perceive the importance of the work of such organisms in the process.

The Bedford oolitic limestone is extensively quarried at many points in a belt extending southeast from Gosport by Bloomington, Bedford, and Salem to near the Ohio River. The belt has a length of about 90 miles and an irregular breadth averaging nearly 5 miles. The rock

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[1] Coral and Coral Islands, 3d edition, pp. 153, 156, 206, and 392.

[2] Botanisches Centralblatt, Nr. 35, 1892; translated by F. W. Cragin in American Geologist, Nov., 1892, Vol. X, p. 280.

[3] Quart. Jour. Geol. Soc. London, May, 1895, vol. 51, p. 196.

varies in thickness from 25 to 100 feet, and is massive, showing only traces here and there of stratification. Upon a weathered surface these lines are more distinct and cross bedding is occasionally visible. The dip is gentle toward the Mississippi Valley. Joints are common, but not abundant, and the water thus gaining access to the rock mass has in places given rise to great caverns. Where weathered, the limestone is buff colored, but in the deeper parts of the quarries it is blue. The difference in color is thought to be due to a change in the oxidation of the iron and the loss of carbonaceous matter upon exposure. When first taken from the quarry the rock is soft and easily carved, but hardens upon exposure.

Oolitic limestones of great extent are rare, although a local development of oolitic structure in extensive limestones is not uncommon. Its formation depends, apparently, upon the large local supply of carbonate of lime along the shore, but this must be combined with mobility of deposit in order to produce spherical deposition.

On account of the abundance of oolite at a certain horizon among the rocks of the Jurassic system in Europe, this portion of the system is called the Oolite. It must be understood, however, that as a name for a group of rocks in the Jurassic system it includes many other rocks besides oolite properly so called.

Oolite is generally carbonate of lime, but occasionally it is siliceous, as in specimen No. 26, or ferruginous, as in specimen No. 52. In the second case, however, the oolitic structure was originally calcareous; and it is possible, but not probable, that the same was true in the first case. Rarely oolite is made of pyrite. Mr. G. P. Merrill has an excellent example from the Black Hills. The student will find an excellent paper on the Bedford oolitic limestone in the Twenty-first Annual Report of the Department of Geology and Natural History of the State of Indiana, for 1896, pp. 291–427. The paper includes a bibliography of oolites.

No. 32. LIMONITE.

(FROM LOWMOOR, ALLEGHANY COUNTY, VIRGINIA. DESCRIBED BY J. S. DILLER.)

Of the various substances accumulated by deposition from solution in water, limonite is among the most common. When heated before a blowpipe in the reducing flame it becomes magnetic on account of the iron present. In composition it is a hydrated oxide of iron, expressed by the formula $2Fe_2O_33H_2O$. Its streak is usually yellowish brown, like iron rust, which is practically the same substance. Another name for it is brown hematite, to distinguish it from red hematite (No. 121), which has a red streak and contains no water.

The simplest form of limonite is represented by specimen No. 32, in which it occurs as a stalactite. Carbonate of lime frequently occurs in the form of well-developed stalactites, but such forms of limonite are rare, although it is frequently seen in small shapes which are somewhat stalactitic or botryoidal. The mode of occurrence, origin, and structure of the stalactite of which specimen No. 32 is a fragment are in a general way exactly analogous to those of specimen No. 28, which is composed of carbonate of lime.

The stalactites of limonite were collected by Mr. G. L. Welch from the roof of a limestone cavern within a mile of Lowmoor. That there were some stalactites of carbonate of lime in the same cavern is indicated by the fact that in a few of the specimens the limonite is completely inclosed by calcite, and the limonite core is discovered only when a cross section of the stalactite is examined.

It is not quite correct to say that this stalactite is limonite, for it is in some cases largely carbonate of iron (siderite), and a few of the stalactites in the series are coated by carbonate of lime, like specimen No. 28, although the middle portions of such are limonite or siderite.

The structure of specimen No. 32 is well shown at the ends. The brown concentric layers differ in texture; some are very compact and more or less waxy or dull, while others, upon a fresh fracture showing cleavage faces, have a somewhat vitreous luster when seen in the proper position; still other bands are spongy or pulverulent. Upon applying a drop of hydrochloric acid it is found that the lustrous layers effervesce vigorously, while the others are not affected. The lustrous layers are siderite, the others are limonite. By a study of the soft ocherous layers it is found that the limonite, in many cases, grades into the siderite in the same layer, the oxide being the exposed portion, while the carbonate is within, where not so exposed to the influence of atmospheric agents. This relative position at least suggests, if in fact it does not demonstrate, that the limonite is derived from the carbonate by oxidation. As shown by T. Sterry Hunt[1] this change is accompanied by a considerable loss of volume, and we are enabled to understand why limonite derived from the carbonate is so porous.

The compact layers of limonite which usually form the outer coating of the stalactite, and occur also within, sometimes alternating with the layers of siderite, do not appear to be derived from the carbonate. Their structure is not porous, and precludes the idea that they were derived directly from the carbonate, but indicates rather that the change took place before the deposition. It is possible that in all cases the iron may have been in solution as a carbonate, but was oxidized before actual deposition, so as to show no loss of volume.

At Lowmoor there are large deposits of limonite, and it occurs in the form of an extensive bed, averaging 15 feet in thickness. It is of Devonian age. This is but one of many similar examples throughout the Appalachian region.

The conditions necessary to the accumulation of iron upon the earth's surface are well illustrated in many places to-day, and deserve special consideration. By the decomposition of rocks containing ferriferous minerals the iron is usually liberated in the form of ferric oxide, which, being insoluble, remains behind, coloring the residual material red-

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[1] Mineral Physiology and Physiography, p. 262.

dish. To render it soluble it must be reduced to a ferrous state, and this is accomplished by acids, chiefly carbonic acid, resulting from the decomposition of vegetal matter. Ferrous oxide readily combines with carbonic acid to form carbonate of iron, which is soluble in water, containing an excess of carbonic acid, and it is thus that the accumulation of large bodies of iron is rendered possible.

Ferrous carbonate when exposed to pure air loses carbonic acid and takes oxygen, thus returning to the insoluble ferric oxide. This reaction forms a precipitate and deposits limonite. The process is illustrated about many chalybeate springs where the reddish ferric oxide accumulates.

The precipitation and deposition of carbonate of iron, such as that which is associated with the limonite in specimen No. 32, could not take place with full exposure to pure air. There must be present some reducing agent—as, for example, carbonic acid—to prevent its oxidation. As shown by Le Conte,[1] the condition most favorable for its deposition is the presence of a large amount of decomposing organic matter—for example, a peat bog, where there is an excess of carbonic acid. This subject will be reverted to in considering fossiliferous iron ore, specimen No. 52.

Limonite is a valuable ore of iron, and when pulverized is used also as a polish and for paint.

NO. 33. CONCRETION (CALCAREOUS). (CLAYSTONE.)

(FROM HARTFORD, CONNECTICUT. DESCRIBED BY J. S. DILLER.)

In studying the oolitic sand (p. 102) it was noted that each grain is essentially a concretion, i. e., it is nodular in shape and composed of material which accumulated by systematic additions upon the outside. It began to form at the center, and gradually grew outward.

Specimen No. 33 is a concretion, and, like the grains of oolitic sand, is composed of carbonate of lime, but it was formed under very different conditions. On account of its composition it is sometimes called a *calcareous concretion*, and in consideration of the fact that it occurs in clays, it is frequently designated *claystone*.

It was obtained from the bank of the river at Hartford, Connecticut, where many of them have been washed out of the adjoining clay bank. Their mode of occurrence at other localities was described and their great variety of form illustrated as early as 1841, by President Edward Hitchcock.[2]

In form there is great variety, including spherical, discoidal, annulated, and cylindrical. Most of the forms represented in this collection are discoidal, and show traces of the planes of stratification in the clay where they were found.

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[1] Elements of Geology, p. 137.

[2] Final report on the Geology of Massachusetts, Vol. II, pp. 407-417, pls. 15, 16, 17, and 18.

The stratification planes are marked directly through the claystones, and they have their greatest extension parallel to the stratification, which is horizontal. That the concretions did not exist at the time the clay was deposited, but originated in place later, is clearly indicated by their mode of occurrence and structure. The lines of stratification in both clay and claystone were marked out by differences of size, color, or composition of the particles at the time the clay was deposited. At a later period the carbonate of lime, of which the greater portion of the concretion is composed, was deposited by waters circulating through the porous layers of the sandy clays.

Why the circulating waters bearing calcic carbonate should deposit it in such shapes is not always clear, but it appears from the general form that the precipitating influence must have emanated from the center. Many calcareous concretions contain fossils, and the decomposing organic matter furnished the surrounding atmosphere with the precipitant that developed the concretion from the center outward. The form of growth, however, is determined largely by the relative porosity of the various layers. The greatest development takes place along the most porous layers, where precipitation is most free. As the concretion grows, it loses organic matter at the center, and this process may be carried on until the latter has entirely disappeared in such a way as not to preserve its original form. No record of the fossil will remain. Many concretions have no visible traces of organic matter, and its absence may be explained in this manner.

Excepting the conditions which mark the planes of stratification, claystones are often homogeneous throughout, but in other cases they possess concentric banding like that so well shown in the siliceous oolite, specimen No. 26.

For further information on the subject of claystones, the student is referred to Monograph XXIX, United States Geological Survey, by Prof. B. K. Emerson, where he will find the matter discussed under the heading "Concretions."

No. 34. CONCRETION (FERRUGINOUS, CONTAINING A FOSSIL).

(FROM MAZON CREEK, GRUNDY COUNTY, ILLINOIS. DESCRIBED BY J. S. DILLER.)

The rocks along Mazon Creek, Grundy County, Illinois, from which specimen No. 34 was collected, according to Mr. Frank H. Bradley,[1] consist of very sandy clay shales and sandstones, in some places becoming nearly pure clay shales with many fossiliferous nodules of carbonate of iron. These nodules contain many species of ferns, as well as numerous fossil insects, occasional crustaceans, fish scales, and shells of mollusks. It appears that in this case most, if not all, the concretions have organic nuclei, and in this respect they are strongly contrasted with the claystones of Hartford. It should be remembered, however, that

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[1] Geol. Survey of Illinois, Vol. IV, p. 196.

in the shales of Mazon Creek there are numerous fossils, but in the clays of Hartford fossils are rare or entirely absent.

The ferruginous sandy shale, which contains the concretions (specimen No. 34) irregularly scattered through it, is 25 feet in thickness and overlies the main coal bed of that region.

In form and size the concretions vary according to the inclosed organism. A small fern leaflet may be contained in a concretion less than an inch in diameter, while another concretion, inclosing a piece of calamite, may be a foot in diameter. Generally, however, the concretions are flattened in one direction and elongated oval in another.

As with the calcareous concretions, the plane of greatest extension is the plane of stratification. Traces of stratification may be seen in the banding or shaly structure of the concretion.

The fossil vegetal fragments contained in these concretions have been studied, described, and figured by Leo Lesquereux,[1] who remarks:[2]

> Peculiar species of plants and animals or their fragments seem to have been selected as the nuclei of the nodules. They contain, for example, an abundance of leaflets of various species of Neuropteris . . . which are either rare or have not yet been found in the shale at Morris, while these shales are rich in [other] remains scarcely or not at all preserved in the concretions.

He states further:[3]

> The pinnæ or leaflets of ferns are always found in them in a flattened position, their axis or rachis extending through the center of the elongated nodule, with the divisions on both sides; the surface of the pinnules, slightly swollen, as when in their living state, is marked by recognizable hairs or fruit dots, with distinct veins and veinlets, and their appendages, like the scales, are seen in the various modifications which they present in living specimens; for example, long, straight, flat, diverging, or primary rachis, and becoming shorter, ruffled and curled on their upper divisions. The small organs of plants appear, therefore, in a better state of preservation than in the shales. With small animals like crustaceans, scorpions, insects of a fleshy and very delicate texture, the preservation of form is still more remarkable. They are found entombed in the middle of the nodules just as if they were in life, or as if they had been transformed into stone while still living. The fruits or nutlets are not flattened. By the section of the nodules, which generally break into two equal halves by hard strokes on their edges, the middle and internal part of the fruit is exposed to view, while the outside surface is immersed in the stone. The numerous cones also of Lepidodendron found in these concretions are equally well preserved, either in whole or in part, by horizontal cross sections. Some specimens not only show distinctly the pedicels of the sporanges and the blades in their natural position, but even sporanges with their seeds have been found in them, without perceptible alteration. In the cross section of these Lepidostrobi the sporange cells form a central row, which is surrounded by the blades in the form of a star.

Aside from the inclosed organism, part of whose carbon usually remains in the fossil, the concretion is composed chiefly of carbonate of iron. When dissolved in dilute hydrochloric acid, upon the addition of ammonia the solution becomes at first greenish, then reddish, precipitating an abundance of ferric oxide. There is but little calcium and

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[1] Geol. Survey of Illinois, Vol. IV, pp. 375-508, and numerous plates.

[2] Op. cit., pp. 482-483.

[3] Ibid., p. 482.

magnesium in the solution, and it is evident that the iron, being in the ferrous state, as shown by the greenish color of the solution, is present in the nodule in the form of a carbonate. The presence of the iron is most simply shown by the fact that a small fragment of the concretion heated in the reducing flame becomes magnetic. It is interesting to note this occurrence of carbonate of iron in connection with organisms where carbonic acid was probably present to prevent the oxidation of the iron at the time of deposition.[1]

NO. 35. CONCRETION (MARCASITE).

(FROM THATCHER, LAS ANIMAS COUNTY, COLORADO. DESCRIBED BY J. S. DILLER.)

These concretions of marcasite were obtained, according to Mr. G. K. Gilbert,[2] from the lower layers of the limestone at the base of the Timpas formation.[3] The limestone has a light-gray color, which becomes creamy white on weathered surfaces. It is compact and fine grained, and in the eastern portion of the district its texture becomes somewhat coarser, its color paler, and the fractured surface resembles chalk.

> As the limestone is broken up and removed by the action of the weather, the more resistant nodules are freed from the matrix, so as to lie loose on the surface. They are of a dark-brown color, and of oval or cylindrical form, with a diameter of about half an inch. Their surfaces are not even, but are set with angular projections, the ends of crystals.[4]

In Pl. XX, taken from Gilbert's report, the variation in form and size of the nodules is illustrated upon the natural scale.

That the crystals referred to above are marcasite is known by their form in connection with the fact that, when pulverized and heated in a closed tube, they yield a sulphurous odor and become magnetic, thus indicating that they are composed of sulphur and iron. From the shape of the projecting crystals it appears that their axes, although at right angles, are of unequal length, thus showing that the mineral is marcasite and not pyrite, which has nearly the same color and composition but differs in form of crystallization.

The structure of the concretion is radial and connected directly with the arrangement of the pointed crystals upon its surface. Although all the concretions are rusty brown outside, when broken open some of them are found to be brass-yellow within, and the radial structure distinct. In most of the nodules, however, the marcasite has completely changed to limonite, and the structure is not well marked. No nuclei were observed.

The chemical composition of marcasite is sulphur 53.4, iron 46.6, represented by the formula FeS_2. When exposed to the air, it usually decomposes, forming limonite, which at first only coats the nodules but

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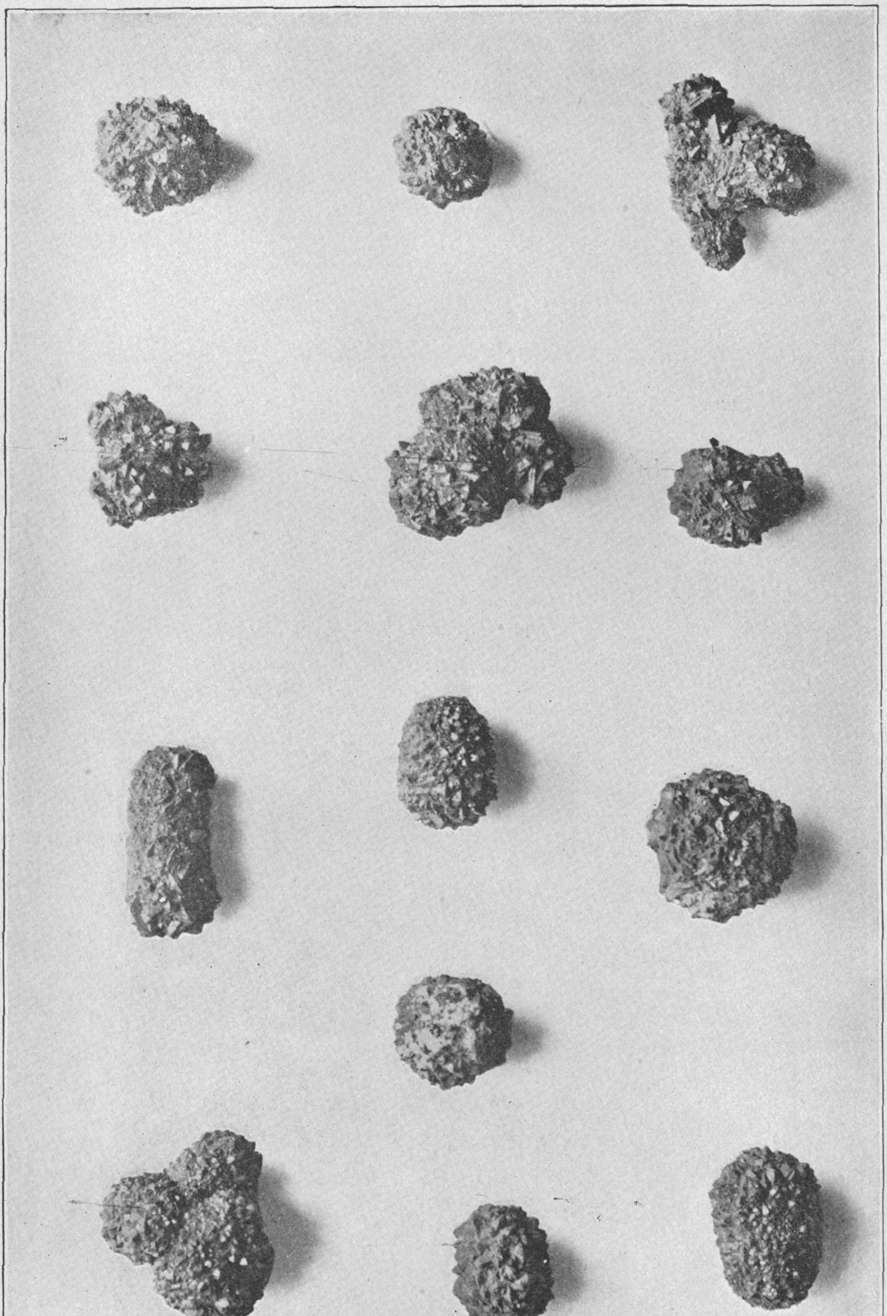
[1] See also description of Limonite, specimen No. 32, and Fossiliferous Iron Ore, specimen No. 52.

[2] The underground water of the Arkansas Valley in eastern Colorado: Seventeenth Ann. Rept. U. S. Geol. Survey, Part II, 1896, p. 566.

[3] The Timpas formation is the upper portion of the Niobrara (Cretaceous) group of that region.

[4] Gilbert, op. cit., p. 566.



CONCRETIONS OF MARCASITE FROM THATCHER, COLORADO.

Natural size.

in time completely replaces the marcasite. When the replacement is complete the crystals are pseudomorphs of limonite after marcasite. In the process of decomposition sulphuric acid is set free and may attack the surrounding minerals, thus contributing to the effects of weathering. Sulphate of iron is frequently formed, and the nodules fall to pieces. This is especially likely to be the case if the air is damp. The nodules found loose upon the weathered surface of the limestone are chiefly limonite, but according to Mr. G. W. Stose, who collected some of the specimens, those found firmly embedded beneath the surface of the limestone are marcasite, and when broken exhibit the radial structure much better than those changed to limonite.

In the case of the concretions Nos. 33 and 34 of this series, it is evident that they were formed after the deposition of the argillaceous strata in which they are contained; but the concretions of marcasite from the Timpas limestone do not indicate so clearly their origin. In some other cases, however, fossils which were originally calcareous are found completely replaced by marcasite or pyrite. Such replacements were not found in the strata from which specimen No. 35 was collected.

Nodules of marcasite or pyrite are perhaps most frequently found in limestone, but they are of common occurrence also in shales and sandstones.[1]

No. 36. Geode.

(From Warsaw, Hancock County, Illinois. Described by J. S. Diller.)

Geodes, like concretions, are nodules, but differ widely in their mode of growth. A concretion begins at the center and increases in size by additions upon the outside. On the other hand, a geode begins upon the outside as the lining of a cavity, and grows by successive additions upon the inside of the cavity. As in specimen No. 36, the cavity is usually well studded with crystals.

The geodes at Warsaw are contained in a bed of the Keokuk group, of lower Carboniferous age, and it has been said that there is no other locality known in the West where a few hours of labor of a good collector will be rewarded by so large a variety of finely crystallized specimens. The occurrence of these geodes in the field has been studied by Mr. A. H. Worthen,[2] and their structure and mineralogic composition have been described by Prof. George H. Brush.[3]

Mr. Worthen says:

> The geodes occur disseminated through the shale and shaly limestone, sometimes so thickly dispersed through it that the individuals press against each other as they lie embedded in the matrix; and again, are so sparsely disseminated that several cubic feet of the shale will afford not more than a single specimen. They are most abundant at Warsaw, in the lower part of the bed, which also affords nearly all the large-sized individuals. The general form of those filled with siliceous minerals is

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[1] The formation of sandstone concretions, by G. P. Merrill: Proc. Nat. Mus., Vol. XVII, p. 87.

[2] Geol. Survey of Illinois, Vol. I, pp. 89-98.

[3] Op. cit., pp. 90-96.

> globular, and many of them are solid spheres of quartz, the interior of which is generally crystalline, with a thin crust of chalcedony coating the exterior surface.
>
> Through the middle of the geode beds there is a band of shale, which, at Warsaw, is from 8 to 10 feet thick, in which nearly all the geodes are lined with calcareous minerals, and these present less regularity of form than those lined with quartz. Many of them are flat disks, nearly or quite solid, but always containing calcite, and frequently fine crystals of blende.

Mr. Worthen states also that in Hancock County a siliceous geode was found filled with liquid bitumen, and at St. Francisville, Missouri, others were observed to be partially filled with clear water.

The collection of thirty-three geodes studied by Professor Brush was specially selected, and his report describes the variations. The geodes of this series of rock specimens, although generally quite uniform, are somewhat varied, as were those described by Professor Brush, from whose report the following is quoted:

> You will observe that, in every case I have examined, the outer layer of the geode is siliceous and is of that form of silica which is called *chalcedony*, although sometimes this outer siliceous rim is extremely thin. The next in the order of superposition is *crystalline quartz*. In every geode which contains crystalline quartz this rests directly on the chalcedony. In some instances a second layer of chalcedony rests on the quartz crystals (Nos. 11, 14, and 22), and in one instance a second series of quartz crystals rests on the second layer of chalcedony. *Calcite* occurs in great beauty and variety of form, sometimes resting directly on the chalcedonic crust, and sometimes resting on the lining of quartz. In no instance where calcite and quartz occur in the same geode have I found the quartz resting on calcite; they all indicate that the calcite is subsequent in formation to the quartz. The calcite crystals are worthy of special crystallographic study.
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> The occurrence of pyrites shows that in some cases its formation was simultaneous with that of calcite, while in other instances it was apparently subsequent to it. The elongated crystals of tarnished pyrites are quite remarkable and might easily be confounded with rutile; but they show a yellow color and a cross fracture, and a blowpipe examination reveals their real character.
>
> *Blende* seems to have been simultaneous in formation with the calcareous layer of the geodes in which it occurs, for in two instances I have observed it embedded in the calcareous layer without resting on the chalcedonic base.
>
> *Gypsum*, observed in minute crystals in only two instances, is subsequent in formation to the second layer of chalcedony in the geodes in which it occurs. *Pearl-spar, dolomite*, or *brown-spar*, as it might very appropriately be called, occurs in several geodes, and is almost always of subsequent formation to the calcite. In a few instances, however, calcite crystals appear resting on a dolomite base, and this leads me to call attention to the occurrence of calcite of at least two distinct periods of formation, as shown by the form and color of the crystals (Nos. 20 and 21). The dolomite in the geodes seems to be peculiarly liable to decomposition by the oxidation of the iron. An analysis of it shows it to contain a large percentage of carbonate of iron with the carbonates of lime and magnesia.
>
> *Aragonite* was found in but one instance, and then resting on dolomite. Geode No. 32 contained a considerable amount of a loose white powder, which, on chemical examination, proved to be a hydrous silicate of alumina; and it is exceedingly curious that the crystals of calcite in what must have been the lower part of the cavity, contain, disseminated through them, this same silicate, as, upon solution in acid, they leave behind an insoluble white powder, similar in character to that found loose in the geode. Moreover, the crystals differ in form from those lining the upper portion of the cavity.

Geode No. 4 is one of the most interesting of the suite, being almost filled with asphaltum, and having isolated quartz crystals embedded in the asphaltum.

The geodes in this series are composed of a thin crust of chalcedony, here and there showing indistinct banding parallel to the surface of the geode. Inside of the chalcedony is a thick layer of crystalline quartz with granular or radial structure about the inclosed cavity, which is bristling with the pyramidal points of quartz crystals. Superimposed upon the faces of the quartz crystals, here and there in some of the geodes, are a few crystals of dolomite, calcite, pyrite, or other minerals, but they form a very subordinate portion of the whole mass.

That geodes originate in cavities there can be no question, but the way in which the cavity was produced is often a matter of doubt. The form of the geode is in some cases conclusive evidence that the cavity was produced by dissolving and removing a shell or other fossil. The shape of the geodes in this series does not clearly indicate any organism, but it has been suggested that the geodes of the Keokuk limestone of Iowa and Illinois (including those of Warsaw) "occupy the centers of sponges that were at some time hollowed out by siliceous solutions, like the hollowed corals of Florida, and then lined with crystals by depositions from the same or some other mineral solution."[1]

Among the most interesting geodes are those occasionally found in fossiliferous shales, as at Yaquina Bay, on the coast of Oregon, where, after the calcareous shells are removed, leaving a cavity, the mold is filled with translucent quartz by successive additions upon the walls of the cavity. In most cases the cavities are completely filled, but in others the cavity is only partially filled with quartz, the remaining portion containing water with a movable bubble, whose motion may be observed through the translucent quartz.

Similar small geodes are occasionally found in amygdaloids, where the original vesicles in the lava are not completely filled. The same term is also applied to crystal-lined cavities in veins, without reference to their form.

No. 37. SILICIFIED WOOD.

(FROM GALLATIN BASIN, GALLATIN COUNTY, MONTANA. DESCRIBED BY J. S. DILLER.)

The occurrence of silicified wood is illustrated in Pl. XXI, prepared from a photograph taken by Prof. J. P. Iddings upon the slopes of the Lamar River. The trunks of the two trees are shown standing erect where they grew. They were buried by the accumulation of sand and gravel of an ancient geologic flood, which gave birth to the Tertiary conglomerate. At the time of their burial they were not silicified, but, while under the ground, the circulating siliceous waters effected a complete change in their composition. The wood was removed particle by particle, and in the position of each was placed a particle of silica, so

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[1] Manual of Geology, 4th edition, by J. D. Dana, pp. 97, 98.

that ultimately the wood was all removed and the whole trunk was completely changed to silica; yet the replacement occurred in such a way as to preserve with wonderful detail, not only the remarkable cellular structure of the original wood, but also the peculiar markings upon the walls of the cells. Thin sections have been made of specimen No. 37, and fig. 12 shows its cellular structure, as seen under a microscope. The cells of the wood are filled with silica, slightly different in appearance from that which replaces the vegetal matter, and it is this difference that marks the cellular structure so distinctly. It has been studied by Mr. F. H. Knowlton, who describes it as follows:

Pityoxylon pealei.—Annual ring very pronounced, 2.10 $^{\mathrm{mm}}$ broad; cells of summer wood large, thin-walled; cells of fall wood thick, much compressed; cells of summer wood with a single series of large, scattered punctations; medullary rays in a single series of two to about twenty long cells, marked radially with one to three small-bordered pits in the width of each wood cell; resin tubes rather numerous, of large size.

The fossil wood contains in places much amorphous silica, but at other places is generally cryptocrystalline, with here and there small radial fibrous groups with negative optical properties, indicating that it is chalcedony.

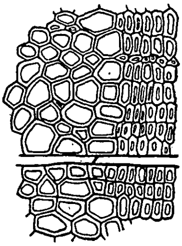


FIG. 12.—Cells of silicified wood as seen under a microscope.

The special lesson to be learned from this specimen is the excellent example it affords of the replacement by substitution of one substance for another, in connection with fossilization by casting.

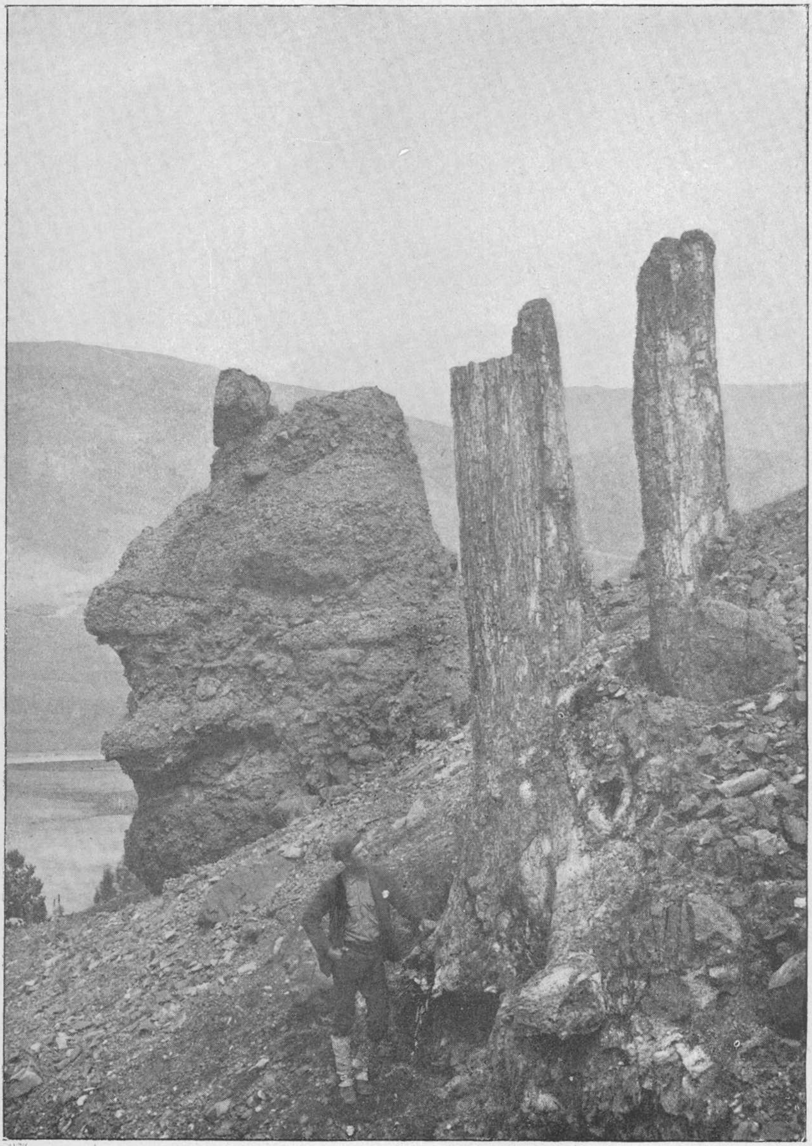
The double character of the process may be illustrated by an experiment. If wood be repeatedly soaked in a solution of sulphate of iron until its cells are filled, and then burned, its structure will be preserved in the remaining ferric oxide in the form of a cast. The place formerly occupied by the wood will be vacant. In silicified wood, however, there is the cast of silica as before, and also the replacing silica which occupies the position of the organic matter. Such perfect replacement by silica may occur also in the animal kingdom. The internal structure of a spirifer, as well as the delicate parts of other mollusks, may be replaced and preserved in the greatest detail by silica.

Silicified wood is of common occurrence in many of the sandstones and conglomerates of all ages, especially in those later than the Jurassic. These rocks usually contain much quartz, and, being porous, afford special facilities for the circulation of underground waters, through whose agency the silicification of the wood is effected.

NO. 38. SILICIFIED SHELL.

(FROM CHARLESTOWN, CLARK COUNTY, INDIANA. DESCRIBED BY J. S. DILLER.)

This shell, *Spirifer oweni*, is one of the Devonian forms found in the hydraulic limestone, or cement stone, which extends northeastward from Louisville, Kentucky, to Charlestown, Indiana. The shell was origi-



FOSSIL TREES, YELLOWSTONE NATIONAL PARK.

nally carbonate of lime, but is now quartz, the carbonate of lime having been removed and the silica deposited in its place. This has been done in such a way as completely to preserve the external form of the shell, but the internal structure is lost. It appears that a perfect impression of this shell was made in the material by which it was inclosed at the time the rock was formed. The shell was then removed by solution in the water circulating in the rocks, thus leaving a mold which was afterwards filled with silica, producing a cast. The method of fossilization by molds and casts is common and of much importance in the geological record. Molds of shells are perhaps more frequently seen in the Oriskany sandstone than in any other formation.

Casts may be of other substances than silica, and when of a comparatively stable substance, like oxide of iron, the fossil may be preserved although the rock inclosing it may undergo great change. One of the most striking examples of this kind is in a mica-schist of Scandinavia, where the original sediment was so metamorphosed as to have been completely crystallized, and yet the forms of large trilobites it contains are perfectly preserved in the casts of oxide of iron.

There are three principal types of fossilization illustrated by specimens in this series. In the first type, represented by specimen No. 6, the organism is simply buried and remains wholly or partly unchanged; in the second type, represented by specimen No. 38, the organism has been completely removed and its mold or cast preserves its external form only; in the third type, represented by specimen No. 37, the organism is completely removed and replaced by mineral matter in such a way as to preserve not only the external form but also its delicate internal structure.

UNALTERED SEDIMENTARY ROCKS OF ORGANIC ORIGIN.

No. 39. CHALK.

(FROM WHITE CLIFFS OF LITTLE RIVER, SEVIER COUNTY, ARKANSAS. DESCRIBED BY J. S. DILLER.)

Of the various rocks deposited by water, limestone is among the most important. It is composed essentially of either carbonate of lime or carbonate of magnesia, or both. Its various forms are quite fully illustrated in this series by the following specimens: Chalk (No. 39), Patellina limestone (No. 40), coquina (No. 42), shell limestone (No. 43), cherty limestone (No. 44), compact limestone (No. 46), lithographic limestone (No. 47), hydraulic limestone or cement rock (No. 48), amorphous marl (No. 49), and shell marl (No. 50) among the unaltered rocks, and crystalline limestone (No. 115), marble (No. 116), and dolomite (No. 117) among the metamorphic rocks.

Chalk is a white earthy limestone which is so soft as to be easily marked by the finger nail, and is composed of fine calcareous sediment derived chiefly from the shells of foraminifera. When pure, its chemical composition is almost wholly carbonate of lime.

Although well known for centuries in England, its occurrence among the rocks of the United States was not appreciated fully until 1887,[1] when it was described by Mr. R. T. Hill, who has shown[2] that there are several distinct beds of this material, having wide vertical and areal distribution, in the Cretaceous rocks of Texas and neighboring States. The specimens for this series, which are a little harder and less porous than typical chalk, were collected from the uppermost of the various chalk beds of the Texan region at White Cliffs, on Little River, in Arkansas, where, according to Mr. Hill, a great bed of the purest white chalk occurs in section 35, T. 11 S., R. 29 W. He says:

> These cliffs have long been a landmark of the region, are about 150 feet in height, perpendicular, and as white and almost as pure as the celebrated chalk cliffs of Dover, England. Their remoteness from the lines of travel is the probable explanation of their having so long been overlooked by American geologists.
>
> The chalk of these cliffs scales off rapidly in great conchoidal flakes, and owing to the irregularity of this process, its face, instead of being a continuous plane, is composed of many acute and reentrant angles, resembling the bastions of a fortress. The summit of the cliff is covered with gravel, but, measuring from the top of the hill a short distance from the margin, the present thickness of this chalk is found to be about 135 feet from the summit to the bed underlying it. This chalk has a low southeastern dip.

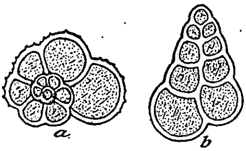


FIG. 13.—Globigerina (*a*, ×100) and Textularia (*b*, ×140) from the chalk of White Cliffs, Texas.

> The regularity of this bed throughout its exposure—about one-fourth of a mile—and its reappearance a few miles to the east and across the Saline watershed shows that it is not a local bed, but the remnant of a great and extensive horizon, worn away by the denudation through Tertiary and Quaternary times of the deposits of the Red River embayment.

In the large fragments from which specimen No. 39 was prepared fossils were rather common and conspicuous, although but few traces of them can be seen in the hand specimen. Camptonectes, Inoceramus, Baculites, and *Ananchytes ovalis* are the fossils reported by Hill from this bed, but it appears that generally "the chalk is almost free from fossils." This statement, however, refers only to fossils which can be seen by the unaided eye, for if properly prepared and examined under the microscope the chalk is found to be composed almost wholly of material derived from the shells of minute organisms. Some of the shells are complete, more are broken, but most are reduced to a fine powder. In fig. 13 are represented two of the most common forms which occur in specimen No. 39. These have been studied by Mr. George H. Girty, who reports as follows:

> The chalk sections which I have examined seem to be scantily supplied with recognizable organic fragments. The latter consist of foraminifera, with an occasional coccolith. The foraminifera can be referred to the genera Globigerina and Textularia, of which the former seems much more common.

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[1] Am. Jour. Sci., 3d series, Vol. XXXIV, 1887, p. 308.

[2] Ann. Rept. Geol. Survey Arkansas for 1888, vol. 2, pp. 87 and 88.

The chemical analysis[1] of the chalk from White Cliffs is as follows

Analysis of chalk from White Cliffs, Sevier County, Arkansas.

	Per cent.
Insoluble matter and silica	3.49
Alumina Ferric oxide	1.41
Carbonate of lime	94.18
Carbonate of magnesia	1.37
Loss on ignition and water	0.55
Total	101.00

It contains some iron, which here and there tinges it yellowish. The insoluble matter and silica are readily accounted for by the presence of spiculæ of sponges and other siliceous organisms, which may be seen under the microscope. Mr. Hill reports that in the field it does not contain nodules of flint. In this respect it is like the "chalk without flints" of Europe, and differs from the "nodular chalk" or "chalk with flints," so well exposed in the cliffs at Dover, England. Although flints do not occur in the chalk at White Cliffs, they do occur in the Caprina limestone near Austin, Texas, from which specimen No. 41 was collected.

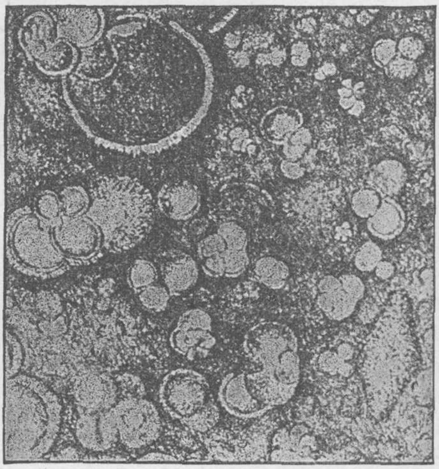

FIG. 14.—Globigerina ooze from Indian Ocean, at a depth of 1,800 fathoms.

Much light has been thrown upon the origin of chalk by the deep-sea soundings of the *Challenger* expedition.[2] From the sea floor, at depths of between 2,500 and 17,000 feet, where not too cold, the dredge brought up a white ooze, consisting largely of the shells of foraminifera and other organisms having calcareous tests, intermingled with a small amount of radiolarian and other siliceous shells.

In fig. 14 is shown the appearance of globigerina ooze as seen under the microscope. It is composed chiefly of the calcareous shells of members of the family Globigerinidæ, but with these are a few lozenge-shaped and other siliceous shells.[3] This is so strikingly similar to chalk in its structure and composition that its deposition practically illustrates the origin of chalk.

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[1] Ann. Rept. Geol. Survey Arkansas for 1888, vol. 2, p. 220.

[2] Report of the scientific results of the exploring voyage of H. M. S. *Challenger*, 1873 to 1876; Deep-Sea Deposits, 213–223.

[3] Ibid., upper one-third of fig. 4, Pl. XII.

The organisms whose remains now form the chalk lived in the sea under various circumstances. The larger animals lived upon the bottom, where they died and their shells contributed to the accumulating chalk.

The minute foraminifera, of whose tests the chalk is chiefly composed, lived not upon the bottom, but far above it, near the surface of the ocean. The species of foraminifera caught in the surface nets of the *Challenger*,[1] are the ones whose dead shells have sunk to the bottom to make up a large part of the globigerina ooze.

It is evident that these minute organisms must have drawn from the ocean water the carbonate of lime of which their shells are composed. The same is true of corals, mollusks, and all other marine organisms whose skeletons or shells are calcareous and whose remains play such an important part in the formation of limestones.

Notwithstanding the fact that chalk is one of the rarest of sedimentary rocks, globigerina ooze is one of the most widely distributed of the marine deposits forming at the present day.

Chalk is very porous, so that it will absorb in some cases an amount of water equal to about one-third its own bulk. On this account beds of chalk are great reservoirs of underground water, and in some places, as in the vicinity of London, such beds yield a large supply of water by means of artesian wells.

Chalk has wide application in the arts, industries, and agriculture. It is calcined to make lime, producing a superior quality of that material for chemical and structural uses. In the semihumid portion of its extent, where the material indurates through a process of interstitial hydraulic setting, it is sawn and extensively used as a building material. By saturating chalk with siliceous solutions to give it hardness, and mineral stains to give it color, ornamental marble of great variety and beauty is manufactured in Europe. Its most remunerative application, however, is its use in the process of making hydraulic and Portland cements. For this purpose it is mixed in definite proportions with clay and silica. It is the use of chalk that has enabled Europe to control the supply of superior Portland cement in the United States, and Hill has pointed out the fact that the neglect to utilize the extensive deposits of chalk in our own country amounts to a serious commercial loss. When pulverized, washed, and elutriated it is known as *creta preparata*, and is extensively used for toilet and fine abrasive purposes, as well as for medicinal purposes. It is also used in the manufacture of carbonate of soda and carbonic acid. On wet clay soil it is a valuable fertilizer, and for such purpose it is extensively used in parts of England, and could be most profitably so employed upon the noncalcareous lands of the southern coastal region of the United States.

The white crayons used for marking purposes were formerly made of chalk, but now they are composed chiefly of artificially produced sul-

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[1] Challenger Reports; Deep Sea Deposits, p. 213.

phate of lime, with a small admixture of lime carbonate. The lump chalk used by carpenters and other tradesmen is the natural chalk as removed from the ground.

NO. 40. PATELLINA LIMESTONE.

(FROM AUSTIN, TEXAS. DESCRIBED BY J. S. DILLER.)

The specimens of this series were collected on Bull Creek, 5 miles west of Austin, Texas. It is a light-colored, earthy limestone, which to a considerable degree resembles the chalk of Arkansas, although it belongs to a much older horizon. According to Hill,[1] it forms a stratum 10 feet or more in thickness near the middle of the Glen Rose beds, in the basal portion of the lower Cretaceous.

The typical Patellina limestone differs from the chalk (No. 39) chiefly in hardness and in the macroscopic fossils present; but the material also occurs in nature as beds of pulverulent chalk, or marl. As in the case of chalk (No. 39), there are a number of mollusks present in this limestone, but few, if any, of them appear in the hand specimens.

It is composed largely of a small, flat-conical foraminiferal shell, *Patellina texana* Roemer,[2] and on this account, at the suggestion of Mr. Hill, has been called the *Patellina limestone.* While *Patellina texana* is the only foraminifer in the limestone visible to the naked eye, in a thin section of the rock under the microscope the finer material is seen to be composed chiefly of foraminifera similar to those of chalk, illustrated in figs. 13 and 14, and might well be called *chalky limestone.* Its conditions of formation must have been in general quite like those of chalk.

NO. 41. FLINT.

(FROM AUSTIN, TEXAS. DESCRIBED BY J. S. DILLER.)

Flint nodules are of common occurrence in the upper chalk beds of England, but, as noted under the description of chalk (No. 39), they do not occur in the equivalent of that horizon in Texas. The specimens of the series were collected from the lower-lying Caprina limestone (Shumard) of Hill's section,[3] 2 miles west of Austin, Texas.

> In this chalky limestone are well-defined layers of exquisite flint nodules, occupying, apparently, persistent horizons in localities. These flint nodules are oval and kidney shaped, ranging in size from that of a walnut to about 2 feet in diameter. Exteriorly they are chalky white, resembling in general character the flint nodules of the English chalk cliffs. Interiorly they are of various shades of color, from light opalescent to black, sometimes showing a banded structure. These flint nodules are beautifully displayed *in situ* in the Deep Eddy Canyon of the Colorado, above Austin, where they can be seen occupying three distinct belts in the white chalky limestones. . . .
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> The fact that these are the only flint horizons, so far at least as is known to the writer, in the whole of the immense Cretaceous deposits of the United States is very

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[1] Paleontology of the Cretaceous formation of Texas: Proc. Biol. Soc. Washington, Vol. VIII, 1893, pp. 14, 20, and 21.

[2] Illustrated in Dana's Manual of Geology, 4th ed., 1895, p. 834.

[3] Geol. Survey Texas, Bull. No. 4, p. xix.

interesting, and especially since they occur about the middle of the Lower Cretaceous series instead of at the top of the upper series, as in England. It was from them that the Indians made their flint implements, and the ease of their lithologic identity will be of value to the anthropologist in tracing the extent of the intercourse and depredations of former Indian tribes inhabiting this region.[1]

These flints have been distributed in later geologic epochs over a wide area coastward of the present outcrops of the Caprina limestone.

The specimens illustrate the light-colored exterior of the flints as well as the extremely compact texture and the perfect conchoidal splintery fracture of the darker interior. Pl. XXII, taken from a photograph, shows a section of one of these nodules in which the concentric banding, as well as the planes of original stratification, are distinctly marked. When highly heated in a flame, the dark-colored flint becomes white, indicating that the color is due to the presence of organic matter. Mr. Hill reports a nodule containing a small cavity filled with liquid; others are found with fossils (Requienia and Monopleura) as nuclei, but these occurrences are exceptions. The nodules are generally without nuclei. Nevertheless, they contain a large number of fossil fragments, which are visible only with the aid of a microscope.

Mr. J. A. Merrill[2] has made a special study of the fossils in the flint nodules of the Lower Cretaceous of Texas, and not only described the forms, but considered the conditions of their preservation and the origin of the nodules. He examined a number of slides of specimens in this series, and reports three species of monactinellid and three tetractinellid forms of sponge spicules, besides the remains of foraminifera, echinoderms, and shell fragments.

The large number of the siliceous organisms found in the flint, both of this country and of Europe, leave scarcely any doubt as to the source of the silica of which they are formed. It was originally taken, at least in large part, directly from the sea water by siliceous organisms, especially sponges, for their skeletons and shells, in much the same way as the carbonate of lime is secured from the same water by organisms having calcareous parts. In globigerina ooze calcareous and siliceous organisms are found intermingled, and the Texas material contains a similar association of forms. The organisms found by Mr. Merrill in the flint of Texas are foraminifera, sponges, mollusks, and fish scales. The foraminifera were principally globigerina whose shells are well known to have been originally calcareous. In the flints, however, the calcareous matter is completely replaced by silica, and it is evident that the flint is not made wholly by an accumulation of siliceous organisms, but in part, at least, by the replacement of calcareous organisms by silica brought in solution. Spicules of sponges and other organisms are found in all stages of preservation. A few are well preserved; more are partially destroyed, while the greater number have either almost or entirely disappeared under the attack of mechanical attrition and solvents.

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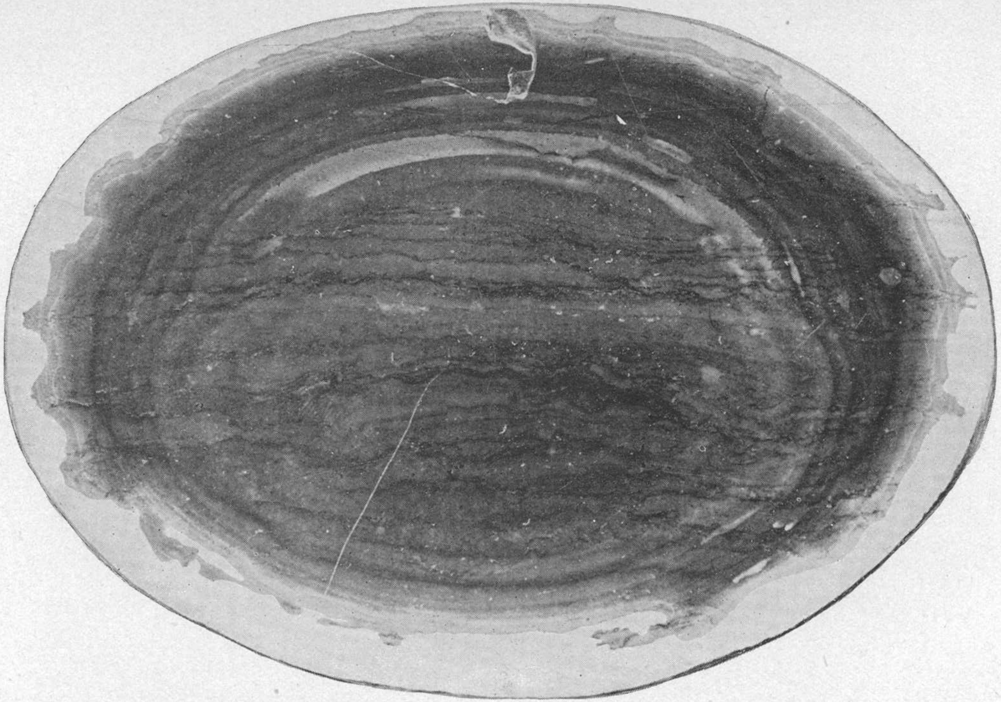
[1] Hill, Geol. Survey Texas, Bull. No. 4, p. xix.

[2] Bull. Mus. Comp. Zool. Harvard College, Vol. XXVIII, No. 1, pp. 1-26. See also a Review of the general work by Mr. Wayland Vaughan, in Jour. Geol., Vol. IV, p. 112.



SECTION OF A FLINT NODULE FROM AUSTIN, TEXAS.

Although the forms of some of the sponge spicules are well preserved, the siliceous material of which they are now composed is not amorphous, as it was originally, but so arranged, or perhaps we may say rearranged, as to be crystalline. The silica of the flint is in two forms, crystalline and amorphous. The first is practically insoluble, but the second is soluble in caustic potash. By far the larger portion of the silica in the flint is in a crystalline condition. Mr. George Steiger, by treating specimen No. 41 with a 10 per cent solution of caustic potash for one hour over a water bath, found that 15.39 per cent of the flint was dissolved. It is generally very fine microgranular, but occasionally it is radial fibrous like chalcedony. However, it is optically positive, while chalcedony is negative. Even that of the sponge spicules and other fossils, which was originally amorphous, is now crystalline. Perhaps this structural change may have resulted directly from the removal of the spiculin originally associated with the silica in the sponge spicules. However this may be, it is certain, as already noted, that there is much actual replacement by silica in the fossils of flint nodules.

It has generally been supposed that originally the silica was rather uniformly distributed throughout the bed, and that the flint nodules were formed in much the same manner as claystones by concretional action. A somewhat different view is suggested by Sollas,[1] advocated by Merrill,[2] and commented upon by Vaughan[3]—that each nodule represents a separate sponge bed, in which many generations of sponges have lived and died in all stages of development.

In the local accumulations thus produced Sollas and Merrill see the origin of the nodules, but in support of a somewhat different view Vaughan refers to a fact noted by Murray—that sponge spicules collect around shells. That flint nodules, sometimes at least, have nuclei has been shown by Hill, and the weight of present opinion appears to favor the view that flint nodules are largely concretionary.

Flint nodules are extensively imported from England into the United States, where they are ground and mixed with kaolin for the purpose of making potter's clay, such as is used in the manufacture of porcelain and other finer grades of china. The material is also valuable, especially in Texas, for road making, and is extensively used for track ballast.

No. 42. Coquina.

(From St. Augustine, Florida. Described by J. S. Diller.)

Coquina is a very porous limestone, composed almost exclusively of shell fragments cemented together by carbonate of lime. It is a *shell limestone*, but on account of its peculiarities is generally known throughout this country by the local Spanish name of *coquina*.

According to Mr. R. Dietz,[4] it forms a considerable portion of Anas-

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[1] Annals Mag. Nat. Hist., 5th series, Vol. VI, pp. 441–443.

[2] Bull. Mus. Comp. Zool. Harvard College, Vol. XXVIII, p. 22.

[3] Jour. Geol., Vol. IV, p. 114.

[4] Jour. Acad. Nat. Sci. Philadelphia, Vol. IV, 1824, p. 73.

tasia Island, and occurs in horizontal layers, which easily separate, forming slabs. The layers are from 1 inch to 18 inches in thickness. The fragments of shells composing them vary in size, and occasionally entire shells are found. In general, the material is finest near the surface. When first removed from the ground the rock is soft and may easily be cut into any desired shape, but upon exposure to the air it becomes indurated. On this account it is a good building material, and has been extensively used in the construction of the fort, the quays, and other structures at St. Augustine.

The shells are chiefly, if not wholly, of species now living along the adjoining coast. In the coquina studied by Dietz they belong principally to the genus Arca, but Dr. W. H. Dall says that they vary greatly from place to place, according to the locally dominant species.

The shell fragments are all arranged with their largest surfaces parallel to the plane of stratification. The space between them is partially filled with clear quartz sand, and the whole is cemented by calcite, and in such a way as to give the rock, when examined under a small lens, a crystalline appearance. The quartz is easily loosened and isolated by dissolving a small piece of the coquina in acid. Some of the grains thus liberated are well rounded, but generally they are sharp, angular, and clear, as if near their original source. Numerous minute rutile needles occur in some of them, as in the quartz of granitic rocks. The sand drifts southward along our Atlantic coast, and it is probable that the sand in the coquina has been carried from far northward, for the beach of Florida exposes no rocks from which it could have been derived.

Dr. Dall tells me that coquina is now forming at many points along the coast of Florida. The shallow-water shells washed up by the waves to the beach, when placed about high-tide level, are alternately wet and dry. The water laving the shell beach gets a large amount of carbonate of lime in solution, and as it dries, after the waves recede, the lime carbonate is deposited upon the fragments, gradually binding them together and forming a more or less solid shell rock—coquina.

The loose shell-beach material is mixed with cement to make an artificial building stone, quite extensively used in St. Augustine. The trimmings of buildings made of this material are of coquina.

NO. 43. SHELL LIMESTONE.

(FROM ROCHESTER, NEW YORK. DESCRIBED BY J. S. DILLER.)

This limestone, like coquina, is composed of shells, and is therefore a shell limestone. It differs from coquina, however, in being compact and containing almost exclusively the shell of one species, formerly called *Atrypa hemispherica*,[1] but now known as *Anoplotheca hemispherica*.[2] As the limestone is composed almost entirely of Anoplotheca, it is sometimes called *Anoplotheca limestone* by paleontologists.

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[1] Geology of New York, by James Hall, 1843, pp. 64 and 73.

[2] Paleontology of New York, Vol. VIII, by James Hall, 1894, p. 136.

This bed of limestone is only 3 or 4 inches in thickness along the Genesee River near Rochester, and lies within the upper green shale of the Clinton group. The sediments associated with it are all fine, and, although of littoral origin, evidently do not belong to beach deposits. The shells are so well preserved as to retain their pearly appearance, and but few of them are broken. They accumulated upon the sea floor at a favorable spot, where not disturbed by the influx of ordinary sediments or the beat of waves.

The relation of the strata in that region is illustrated in Pl. XXIII. At the base of the exposure shown in the figure is a mass of shale, which is overlain by a thin-bedded limestone, near the bottom of which is a bed of iron ore (No. 52). The limestone above the ore, having a thickness of 14 feet, forms the middle falls of the Genesee. As its most abundant shell is a Pentamerus, it is referred to as the Pentamerus limestone. Immediately above the Pentamerus limestone, which is well shown in the figure, is the mass of green shale containing the thin bed of Anoplotheca limestone from which specimen No. 43 was obtained.

NO. 44. CHERTY LIMESTONE.

(FROM BUFFALO, NEW YORK. DESCRIBED BY J. S. DILLER.)

The bed of limestone from which specimen No. 44 was taken extends from near the Hudson westward through the State of New York into Canada, Ohio, Indiana, and other States of that region. At many places in New York it contains a large amount of siliceous material called chert or hornstone. The limestone containing it is *cherty limestone.* It was formed during the Corniferous[1] period of the Devonian era. Fossils, especially corals, are so abundant in some places that the limestone looks like the reef-rock of modern coral reefs. The fossils are often silicified, forming chert.

The chert occurs irregularly distributed throughout the mass of limestone, as in specimen No. 44, or it may be arranged in layers, nodular sheets, or series of separate nodules in the same plane, alternating with layers of limestone. In such cases the limestone layers are generally thicker than those of chert, although the relative proportions of chert and limestone vary greatly from place to place. In general, the occurrence of chert in limestone is analogous to that of flint and chalk.

The limestone, being soluble under conditions of weathering, is gradually carried away, leaving the exposed surface of the limestone rough with chert. As weathering progresses the surface in places becomes paved with angular fragments of chert.

In hand specimen No. 44 the bluish-gray compact chert and the dark limestone are distinctly separable. In some specimens the chert predominates, in others the limestone. Their boundaries are almost always sharply defined, although in some places there is gradation

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[1] From the Latin "cornu," horn.

from one to the other. Both effervesce in acid, but the soft, dark portion, which will hereafter be referred to as the limestone, effervesces much more freely than the hard, flinty chert.

That the limestone is crystalline, at least in part, is indicated by the minute glistening grains, visible under a small hand lens. When viewed in a thin section under a microscope it is found to be irregularly granular, containing numerous perfect crystals of calcite, ranging from 0.005^{mm} to 0.03^{mm} in diameter. Most of the calcareous material is dark or brownish, owing to the presence of carbonaceous matter, which disappears upon ignition, leaving the limestone white. Clear, colorless calcite occurs in veins, but more commonly in single crystals or variously shaped patches, irregularly intermingled with the clouded material.

Embedded in the limestone are occasional angular grains of clear quartz. They occur in chert also, but are much less common.

The chert effervesces rather feebly in acid, owing to the presence in it of some carbonate of lime, but when that is dissolved away nothing but the hard, horny siliceous material is left. Under the microscope it appears cryptocrystalline, with here and there more coarsely crystalline, clear areas, having confused radial fibrous structure, some of which appears to be optically negative, as chalcedony.

Scattered throughout the chert is much carbonate of lime, often in sharp rhombohedral crystals. These crystals are completely enveloped by the chert, as if they were formed before the chert was deposited, or at least before it had hardened so as to prevent the development of crystals of calcite. This matter will be more fully considered under "Chert," as illustrated by specimen No. 45, which was taken from the same bed of cherty limestone as that which occurs at Buffalo, but at a different locality.

No. 45. CHERT.

(FROM LEROY, GENESEE COUNTY, NEW YORK. DESCRIBED BY J. S. DILLER.)

The chert at Leroy, New York, according to Hall,[1] occurs in the Corniferous limestone of the Devonian group, where it is arranged in irregular bands between layers of compact gray or blue limestone. In a thickness of about 50 feet of the Corniferous limestone there are at least twelve horizons of chert, ranging from a few inches to several feet in thickness. Westward the proportion of chert in the limestone diminishes, and in some places the chert nearly disappears.

Chert, illustrated by specimen No. 45, is a highly siliceous material of light-gray color. When freshly broken some of it effervesces for a little while, showing the presence of a small amount of carbonate or lime; but a fragment long exposed to the weather does not effervesce, the carbonate of lime having been removed in solution. Upon exposure it

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[1] Geology of New York, part 4, 1843, p. 167.

breaks up into small angular pieces, which accumulate in the soil at the surface.

The chert contains shells, corals, and other fossils which were originally composed of calcareous matter, but are now completely silicified. In addition to these fossils, it contains numerous organisms which were once siliceous. Mr. George H. Girty, who examined the thin sections of this chert, states that "sponge spicules and fragments of the spicular skeleton of sponges of both the hexactinellid and lithistid orders are not uncommon, although they frequently are much broken. The hexactinellid elements are chiefly flesh spicules ornamented with numerous sharp nodes."

The structure, as revealed by the microscope, is cryptocrystalline, and on the whole considerably finer than that of the chert in specimen No. 44. The minute grains are rarely greater than 0.001^{mm} in diameter, and there is comparatively little variation in size. Radial fibrous chalcedony, such as occurs in specimen No. 44, was not seen in the body of the chert, but does occur in a few remarkably well-developed veins. These veins are made up of several bands of fibrous chalcedony, with a final filling of granular quartz in the middle. Here and there throughout the chert are small areas of amorphous silica, and there may be much in the cryptocrystalline mass, where it can not be so readily distinguished.

The chert, excepting that which replaces calcareous organisms, is remarkable for the abundance of sharp rhombohedral crystals, like those of calcite, it contains. There is some variation in the forms of the crystals, but in general they are rhombohedral and average about 0.02^{mm} in diameter. A few minute crystals of other substances besides carbonates, as well as irregular grains of quartz, are present.

The siliceous material of the Corniferous limestone, illustrated by the specimens Nos. 44 and 45, is sometimes called *hornstone.* There appears to be no distinct line of division between flint, hornstone, and chert. The term "flint," although used in a comprehensive sense to include chert, so that chert may be defined as impure flint, is applied chiefly to the more purely siliceous rock which occurs in chalk. Flint is often, but not always, rather dark colored. A special characteristic of flint, according to Griswold, seems to be that a considerable part of the silica is in the amorphous soluble form of opal.

In New York the siliceous material of the Corniferous limestone was formerly called "hornstone,"[1] and the name is still used to some

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[1] Geikie applies the term "hornstone" (Text-Book of Geology, 3d ed., p. 154) to "an exceedingly compact siliceous rock, usually of some dull tint, occurring in nodular masses or irregular bands or veins. The name has sometimes been applied to more flinty forms of felsite." In the United States, certain more or less flinty rocks which result from the alteration of sediments in contact with igneous rocks have been called hornstone. It is what the Germans call "hornfels." Hawes described such in New Hampshire, Am. Jour. Sci., 3d series, 1881, Vol. XXI, p. 27; Emerson in New Jersey, Am. Jour. Sci., 3d series, 1882, Vol. XXIII, p. 303; and Kemp in Trans. New York Acad. Sci., Vol. XI, pp. 70, 128. It thus appears that the term "hornstone" has been used to designate rocks of widely different origin, and the needs of science would be better subserved by dropping it altogether, and using the terms *flint* and *chert* for rocks like specimens Nos. 41 and 45, and *hornfels* for those like specimen No. 130.

extent,[1] but with growing infrequency,[2] while the term "chert" is coming into more general use to designate impure flint, especially when it is calcareous.

Much has been written concerning the origin of flint and chert, and it is evident that all have not been produced in the same way. Some observers consider that the silica of chert is derived from sponges and other siliceous organisms, while others consider that by some chemical reaction the silica was precipitated directly from sea water to make the chert.

The presence of siliceous organisms[3] in many cherts leaves no doubt that their silica, at least in large part, was derived from siliceous organisms.

Oolitic structure (specimen No. 26) occurs in some cherts, and has been regarded as indicating the replacement of carbonate of lime by silica. The silicified corals and mollusks (specimen No. 38), so common in the chert of the Corniferous limestone, afford positive evidence of this replacement, and since we often find in the same specimen of Corniferous chert both sponge spicules and replaced calcareous fossils, the traces of its history are essentially the same as those noted under flint (specimen No. 41). In fact, the chert (specimen No. 45) differs from flint chiefly in containing numerous crystals of carbonate of lime. These crystals can not be regarded as remnants of the calcareous organisms. They crystallized in place before they were enveloped in hard chert to interfere with their development. Irving and Van Hise,[4] after an extensive study of the cherty limestone and the cherty carbonates of the Penokee iron-bearing series of Michigan and Wisconsin, conclude: "First, that the chert was mainly deposited simultaneously with the iron carbonate with which it was so closely associated; and, second, that it is probable that the chert is of organic origin, although we have no positive proof that it is not an original chemical sediment, while it may in part be from both sources."

The acids resulting from the decomposition of organisms affect the solubility of silica, and, as suggested by Julien,[5] may cause its precipitation. This would account for the silicification of organisms, both vegetal and animal, so common in the various formations.

The evidence of the formation of chert by direct precipitation from sea water without the intervention of life is negative. Although there are cherts in which no trace of life has been found, it is possible that such traces have been obliterated by more pronounced activity of the same agents which in other cases only partially destroy them.

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[1] See Dana, Manual of Geology, 4th ed., 1895, p. 583.

[2] See "Hornstone" in Century Dictionary.

[3] W. J. Sollas, Annals Mag. Nat. Hist., 5th series, Vol. VII, 1881, p. 141; G. J. Hinde, Geol. Mag., 1887, p. 435; J. A. Merrill, Bull. Mus. Comp. Zool. Harvard College, Vol. XXVIII, pp. 1-26.

[4] Tenth Ann. Rept. U. S. Geol. Survey, Part I, p. 397.

[5] Proc. Am. Assoc. Adv. Sci., 1879, p. 396.

NO. 46. COMPACT LIMESTONE.

(FROM GREASON, CUMBERLAND COUNTY, PENNSYLVANIA. DESCRIBED BY J. S. DILLER.)

This limestone is one of the most extensive and most ancient, as well as the most important, economically, in the United States. It occurs in the great limestone belt extending from western New England through the corner of New York, New Jersey, Pennsylvania, Maryland, and Virginia into Tennessee, and represents widespread, long-continued, comparatively uniform conditions of the sea in Cambro-Silurian time. On account of its softness and solubility by long exposure to atmospheric agents it has wasted away more than the harder rocks adjacent to it. The latter rocks form mountains, while the limestone appears in the intervening valley. Lebanon and Cumberland valleys of Pennsylvania and the Great Valley of Virginia have this limestone as their fundamental rock. The soil in these valleys is rich, and furnishes the basis of one of the greatest agricultural regions of the country.

The limestone is compact, with numerous minute glistening particles, visible with a hand lens. Its dark color is due to impurities, probably carbonaceous, at least in part, for when highly heated the dark color disappears. In dilute hydrochloric acid it effervesces freely, but not so vigorously as pure calcite, and after the carbonate of lime is completely dissolved there remains a very fine, dark sediment. Under the microscope the structure of this limestone is found to be what would be termed *microporphyritic*. It contains a multitude of minute rhombohedral crystals of calcite, about 0.05 to 0.06^{mm} in diameter, embedded in a very fine-granular matrix, which is chiefly carbonate of lime, but contains in addition nearly all the various impurities found in the limestone.

Many of the crystals are very sharply defined and contain traces of the impurities in the matrix. Occasionally the material is arranged in bands, of which the darker and more carbonaceous usually contain the largest number of well-developed crystals. In places over very small areas they have so grown as to mutually interfere and interlock in a way suggesting the crystalline structure of marble. In the lighter-colored bands the microphenocrysts are less abundant, and occasionally the fine-granular groundmass prevails.

After the carbonate of lime is removed by acid, much of the fine residual material is doubly refracting, but in general it is too fine for a definite mineralogic determination. The chemical analysis of the whole rock, however, shows that the residual material must be composed chiefly of quartz, with silicates of alumina, magnesia, and iron.

The chemical analysis, made by E. A. Schneider, is as follows:

Analysis of limestone from Greason, Pennsylvania.

	Per cent.
SiO_2	7.00
Al_2O_3 Fe_2O_3	3.62
Insoluble residue, undetermined	.45
CaO	39.26
MgO	9.00
CO_2	38.82
Organic matter	.75
H_2O (105°)	.18
Total	99.08

Specimen No. 46 contains no fossils, although there are beds of the same belt in that region containing an abundance of marine shells, and there can be no doubt in such cases that a considerable part of the limestone is of organic origin. For this reason, in the classification of the limestones of this series it was placed among those of organic origin. There is reason to believe, however, that it may be of chemical origin, and occasion will be taken at this point to consider the evidence concerning such a view.

The principal evidence furnished by the limestone itself is to be found in its porphyritic structure. The relative age of the groundmass and the minute crystals so conspicuous under the microscope (microphenocrysts, which produce the porphyritic structure) may be best understood by considering a porphyritic igneous rock, such as dacite-porphyry (specimen No. 90), where the phenocrysts of quartz and feldspar are clearly older than the groundmass by which they are enveloped; that is, these crystals were formed before the groundmass solidified. This is shown especially by the corrosive action of the magma upon the quartz crystals. At the time the large feldspar crystals developed the inclosing material was soft, so as not to interfere with their symmetrical growth and structure. The same must have been true of the minute crystals of calcite in the limestone. They must be the oldest solid portion of the mass. Although it may have accumulated about the same time, it was not lithified until the crystals of calcite were fully developed.

This microporphyritic structure of the limestone is not a local modification in the rock; it belongs to the whole mass, and may not be attributed to metamorphism, either local or regional, for both are absent. The associated layers of shale and fossiliferous limestone are unaltered. It appears as if the crystals of calcite developed directly in the solution from which they drew their carbonate of lime, and that they are the fundamental portion of the original mass.

The conditions under which large masses of limestone originate by chemical deposition are not well understood, and there is much difference of opinion concerning the early history of such rocks. This subject has been recently discussed by Mr. Bailey Willis,[1] and from his paper the following quotations are taken. The conditions favorable to chemical deposition are—

(*a*) Evaporation from an inclosed sea.

(*b*) Precipitation of lime and magnesia from ocean waters, charged by solution from the land, through evaporation, through reaction of salt water on fresh, and through varying atmospheric conditions at the surface of the sea.

(*a*) *Evaporation from an inclosed sea.*—When a limited body of water, such as a lake, is subjected to a change of climate, so that evaporation exceeds precipitation of rain, the volume will shrink, outflow will cease, and the solution of salt will be concentrated. If the process is sufficiently continued, the solution will become saturated, first for one salt, then another, and they will be deposited in the order of their insolubility. This process is important as an indication of climatic variation in the past. It has been fully described by Gilbert, Russell, and Chatard for Pleistocene lakes and the chemical relations, and these studies suggest the conditions to which appeal must be made to explain the less exact facts known in ancient formations of the kind.

(*b*) *Precipitation from brackish waters.*—The chemical precipitation of lime and magnesia from sea water is a much mooted question. There are two lines of evidence relating to it which are apparently opposed. On the one hand, the scientists who have described material obtained by soundings on modern limestone deposits have recognized only organic remains. The *Challenger* in the open oceans, remote from great rivers; the Coast Survey vessels in the Caribbean, the Gulf of Mexico, and off the Atlantic coast; the Norwegian expedition in the North Atlantic, and English vessels in the Indian Ocean have found calcareous oozes of various kinds and rocky limestone formations, but in every case the calcareous matter is described as composed wholly of the tests of pelagic organisms, many of them of microscopic size. It is known that carbonates of lime and magnesia are to a greater or less extent soluble in waters containing carbonic acid, and that the proportion of these carbonates dissolved in ocean waters is small. According to Dittmar, the salts in solution in ocean waters contain 0.345 per cent of carbonate of lime and 3.600 per cent of sulphate of lime,[2] and the ocean is capable of dissolving all the lime poured into it by rivers.[3] This view being accepted, it follows that pelagic organisms, which possess the power of secreting solid carbonate of lime from solution, alone can cause lime deposits. Chemical precipitation is, according to this view, impossible, or, if it occurs, is followed by speedy re-solution, and all limestones deposited under conditions of the existing oceans are of organic origin.

On the other hand, there are many limestones, deposited at different periods of geologic time, from Algonkian to the present, including some now forming, which consist of more or less clearly crystalline calcite, devoid of organic structure. If this calcite was originally built into organic forms they have been entirely obliterated. Such limestones do indeed contain fossils which sometimes exhibit more or less crystalline texture, but the occurrence of these organic forms in the holocrystalline matrix only raises the question, If the mass was originally all organic and has undergone secondary crystallization after lithifaction, why was the process so complete in the matrix and relatively so ineffective in structures whose delicate anatomy can still be traced even to microscopic details? Thin sections of limestone which show a mass of interferant crystals suggest that this was the primary

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[1] Jour. Geol., July-August, 1893, Vol. I, No. 5, pp. 500-517.

[2] Report on the Scientific Results of the Voyage of H. M. S. *Challenger*; Physics and Chemistry, Vol. I, p. 204.

[3] Op. cit., p. 221.

structure of the rock, and organic remains appear to be foreign bodies which are accidentally of the same substance as the matrix. If this view be correct, then only the alteration of the organic carbonate is the measure of the alteration of the rock-mass, and it is a fair inference from the original crystalline structure that the limestone may have been produced by chemical precipitation.

In explanation of this contradiction it may be suggested that broad shallow seas resemble inclosed bodies of water rather than the open ocean, so far as concentration of their dissolved salts is concerned; and that observations on organic deposits have been made in the ocean, whereas it is not improbable that many limestones were deposited in relatively shallow seas. If oceanic waters enter a broad basin which is so nearly inclosed as to impede their outflow, they may circulate until more or less concentrated by evaporation, much as they would be in a completely inclosed water body. Under such conditions limestones may have a chemical origin.

It is not proposed here to argue that limestones are prevailingly of one origin or the other, but only to show that the assumption of organic origin for all the calcareous deposits of the stratified series is too sweeping. To this end it is desirable to consider the chemical and mechanical conditions which affect the precipitation of carbonate of lime, to estimate the solubility of the carbonate in salt water, to review the conditions under which lime is contributed to, and distributed in, the sea, and to describe several cases of modern limestone formation by precipitation. . . .

As to the chemical and mechanical conditions which affect the precipitation of carbonate of lime, chemists describe two under which bicarbonate of lime held in solution may be decomposed, liberating carbonic acid and precipitating the neutral carbonate: First, by diminution of the tension of the carbonic acid in the atmosphere; second, by agitation of the solution.

Theoretically, either one of three things may occur to the neutral carbonate of lime if it be thrown out of solution by either one of these processes, which we may admit are active on some portions of the salt-water surface. The carbonate may be redissolved, or deposited as a calcareous mud, or built into organic structures. We may discuss these alternatives in turn.

The solvent action of sea water has been the subject of direct observation in the ocean and of experimental determination. . . .

The pelagic pteropods and foraminifera, living at the surface, sink on dying and are slowly dissolved. If the water be too deep, the carbonate of lime never reaches the bottom; only the insoluble residue gets there. The limits below which the calcareous remnants are not found are about 1,500 fathoms for pteropods, thin shells exposing large surfaces to solution, and 2,800 for globigerina, smaller shells, relatively more massive. . . .

The solvent power of sea water is very moderate and may be satisfied, so far as carbonate of lime is concerned, by two sources—by organic tests in suspension, and by chemical precipitate. The lime used by organisms is derived from the solution to which it is partly returned by re-solution, but another part is deposited, and the sea thus suffers constant loss. This loss is supplied by the streams from the land. If this terrigenous supply is less than the amount of organic deposit, the sea will become less alkaline and will more efficiently dissolve calcareous tests, until the solvent is satisfied. If the land contribution is continuously equal to the amount organically subtracted, there will be equilibrium. If the land yields more carbonate of lime than that which is being locked up in organic limestones, the alkalinity of the sea will gradually increase until there is chemical precipitation. This condition is favored by the entrance of lime-bearing fresh water into a sea free from active currents and exposed to evaporation which balances the inflow.

After reviewing the conditions under which lime is carried from the land and distributed in the sea, Willis finds that—

> The lime brought down by rivers, though measurable by hundreds of thousands of tons per annum, is so widely diffused in the vast volume of the ocean that it escapes recognition.

There are several instances of modern limestone formation which, though local, illustrate the processes of chemical deposition on a large scale. A reference to this may close the suggestion concerning limestone deposition by other than organic means.

Chemically deposited limestone is forming in the southern part of Florida, probably over extensive areas. It occurs in the Everglades, and the precipitation is in two forms:

> First, from the mass of the water as a flocculent mud; second, from the lower layers of the water in contact with limestone as crystals forming an integral part of the solid rock.

The limestones formed upon the shores of the Pleistocene lakes Bonneville[1] and Lahontan,[2] of Utah and Nevada, as well as the one now developing at the mouth of the Rhone, are referred to as examples of limestones formed under the conditions considered in the preceding discussion.

> These conditions are favored at the mouth of the Rhone by the salinity of the Mediterranean and the absence of strong currents.
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> The examination of a few thin sections of limestone of different ages, from Cambrian to the present, shows that they have three principal types of structure. There are those which resemble the Everglades limestone in that they consist of more or less coarsely crystalline calcite, yet include unaltered organic remains. Of these the Trenton limestone and the marbles of corresponding age in Tennessee, which occur interstratified with unaltered calcareous shales, are the most striking examples examined. Cambrian limestones and the Knox dolomite show similar crystalline structure. The second type, the precipitated sediment which forms the muds of the Everglades and which was deposited in Lake Bonneville, is represented by specimens composed of exceedingly fine grained, apparently pulverulent, material; the best of these are from the Knox dolomite and the Solenhofen lithographic stone. The third variety of limestone consists of the thoroughly crystalline marbles, which contain no unaltered material, and which occur in such field relations that they are known to be completely metamorphosed. Extended study is required to determine the nature of deposition of the first and second types. They may have been organic and have suffered moderate alteration only, but there is a reasonable presumption that they did to some extent crystallize in place from sea water, and were, to a still greater extent, precipitated from the outspread fans of fresh water radiating from rivers' mouths, whence they spread as fine silt over the bottom of the sea. . . .
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> In discussing the solubility of shells in sea water it has been pointed out that the layer of organic matter which accumulates at the sea bottom contains a solvent formed by the evolution of carbonic acid in the process of decay. Through this layer all substances must pass before they can become part of a lithified stratum. If they are plant tissue or flesh they will become more or less oxidized; if they are calcareous tests they will be more or less completely dissolved, and if there be any chemically precipitated lime arriving on the sea bottom it, too, would be dissolved in this menstruum. The earlier forms of dredge which scooped into the sea bottom

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[1] Mon. U. S. Geol. Survey, Vol. I, by G. K. Gilbert.

[2] Mon. U. S. Geol. Survey, Vol. XI, by I. C. Russell.

brought up a mass of ooze, formed of fine particles, burying organic forms. The later forms of dredge, arranged to skim the surface of the bottom, bring up shells and organisms remarkably free from mud. Now, it may be conceived that the layer of mud on which the creatures live, die, and with sunken organic remains decay, grades from the fresh surface of recent accumulations downward into a much more completely decayed and dissolved mass, and that this rests upon a surface of limestone. In the upper part of this unconsolidated stratum carbonic acid may most abundantly be evolved; in its lowest part the more concentrated solution of lime may accumulate. Then it is conceivable that lithification by crystallization of the carbonate of lime from the more concentrated solution is constantly proceeding on the limestone surface. If this conception be correct, the formation of limestone by organic means involves the re-solution and crystallization of more or less of the calcite in the primary formation, and only those organic forms can remain unchanged which resist the solvent action. If they are delicate, as the trilobites' branchia from the Trenton limestones, described by Walcott, they give evidence that they were rapidly buried and protected.

It is thought by some that limestones are evidences of organic life at whatever period of sedimentary history they were deposited, but it has here been shown that the source of all lime in the sea is the land, and that under conditions existing in certain localities both crystalline limestone and calcareous mud are now forming chemically. It has also been shown that lime converted into organic forms is subtracted from that which would otherwise go to saturate the sea water. If, then, in any early age of the earth's history, lime-using organisms were not present to subtract and deposit lime from sea water, and if the atmospheric agencies worked then as now, the contributions from the land must have continually added to the alkalinity of the sea until chemical precipitation occurred. Such a process must have been limited to seas rather than extended to oceans, because the conditions of delivery of lime from the land were then, as now, localized. With the development of marine life and the increased demand for lime for organic use, and with the corresponding deposition of organic limestone, the sea water must have become less alkaline, and the conditions of chemical precipitation must have been still more restricted. In time it might occur that pelagic organisms should demand so much lime for circulation from the water to calcareous algæ, to herbivorous, and then to carnivorous forms, and so back into solution, that lime could escape from solution by precipitation only under exceptional conditions. If it be true that the oceanic oozes, the muds of the Caribbean, the mud flats of Florida, and similar calcareous deposits in different seas the world over, be wholly organic, then marine life has locked up more lime than the continents could concurrently supply, and the balance is now turned against chemical precipitation. But it has not always been so.

No. 47. LITHOGRAPHIC STONE.

(FROM FLINT RIDGE, GREENWOOD COUNTY, KANSAS. DESCRIBED BY J. S. DILLER.)

Lithographic stone is a limestone characterized by its very fine, uniform texture, structure, and composition—so fine and compact, indeed, that it will receive very delicate markings by the engraver's tools, as well as by etching with acids in lithography.

The best lithographic stone comes from the neighborhood of Solenhofen, near Munich, in Germany, where the rock is extensively quarried. Besides the uniformity of texture and composition which makes it equally resistant throughout to the engraver's tool, it is soft enough to be easily engraved and possesses a degree of porosity which renders it properly absorbent, so that it will receive and retain the greasy preparations used by the lithographer in transferring and printing.

Specimen No. 47 is a poor example of lithographic stone, although it is one of the best that could be readily obtained in this country. It lacks uniformity of texture and composition, and for this reason is not good for lithographic purposes. Under the microscope, in a thin section, it is seen to contain not only very fine-granular carbonate of lime, but also numerous angular particles of quartz, which, although usually less than 0.02^{mm} in diameter, render it worthless for lithography. The minute particles would turn the engraver's tools aside, and in etching would not be affected by acid, like the surrounding carbonate of lime. It contains also numerous small patches of clear calcite, which modify the absorption of the stone.

When a bit of this stone is dissolved in acid, a large amount of residual material is obtained that is composed chiefly of quartz. When similarly dissolved, the Solenhofen stone, used in printing the United States Geological Survey maps, leaves a considerable insoluble residue of dark argillaceous matter with some minute grains of quartz, although chemical analysis has shown that in many cases it is composed almost wholly of carbonate of lime. All the other substances it contains put together rarely make as much as 4 per cent of the whole mass.[1] A simple means of testing the lithographic qualities of a stone which to the naked eye appears so fine grained and homogeneous as to promise to be of use for lithographic purposes, is to examine a thin section under the microscope. If the stone is of value, it will appear homogeneous in composition and have a very fine texture.

Good lithographic stones have been much sought for in this country, but thus far with but little success. Stones have been found in several of the States within the Mississippi Valley region, but so far as known none of them have proved very satisfactory. Some rocks have been discovered yielding small stones, but none of these have come into extensive use. It is possible, however, that good lithographic stone may yet be found in this country. A paper by Mr. G. P. Merrill[2] on lithographic limestone will be found useful to students and others interested in this subject.

No. 48. HYDRAULIC CEMENT ROCK.

(FROM AKRON, ERIE COUNTY, NEW YORK. DESCRIBED BY J. S. DILLER.)

Hydraulic cement rock is a limestone containing nearly half as much clay as carbonate of lime. It affords a quicklime, the cement from which, when properly prepared, will harden under water to a stone-like mass. On this account the rock is often called by geologists[3] *hydraulic limestone*. It occurs interstratified with other limestones of

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[1] Paper and Press (Philadelphia, January, 1896), Vol. XXII, p. 90.

[2] The Mineral Industry, by R. R. Rothwell, 1893, vol. 2, p. 453.

[3] Mr. U. Cummings, general manager of the Standard Cement Company, who kindly obtained the specimens of hydraulic cement rock for this series, informed me that the term *hydraulic limestone* is in the trade applied to a limestone that contains only about half as much clay as the *cement rock*, and that the lime derived from it will not make a cement that will harden under water.

various compositions, and, in places, contains fossils of marine origin. The cement made from it is of great importance for building purposes.

Hydraulic cement rock is usually of a gray color, and has a more or less fine-granular crystalline structure. Under the miscroscope it is seen to contain a large number of angular grains of quartz, and here and there a grain of fresh feldspar. Some of the feldspar is microcline, and so fresh as to be clear and show distinctly the characteristic crossed striations. The microscope reveals numerous circular spots or pellets, which are fine-granular, and contain much of the argillaceous material.

When dissolved in acid the rock leaves a large amount of gray residual material, which, under the microscope, is found to be chiefly argillaceous, with much quartz, some feldspar, and a trace of a few other minerals. These represent the sediment deposited in the limestone while forming.

The chemical analysis given below, by George Steiger, shows the large amount of impurity present; and that the greater portion of it is quartz, with much clay, is evident. It seems hardly proper to call these materials impurities, for the value of the rock, as a source of cement, depends upon their presence in the limestone.

Analysis of cement rock from Akron, New York.

	Per cent.
SiO_2	9.03
TiO_2	.16
Al_2O_3	2.25
Fe_2O_3	.85
FeO	.52
MnO	none
CaO	26.84
MgO	18.37
K_2O	.85
Na_2O	none
Water 100° −	.21
Water 100° +	.77
P_2O_5	.03
CO_2	40.33
Total	100.21

The property of hardening under water, possessed by hydraulic cement, is attributed to a chemical union of the clay (silica and alumina) with the lime and water. Mortar made of ordinary quicklime will harden only upon evaporating to dryness, and is therefore of no value for many of the most important structures.

The hydraulic cement rock represented by specimen No. 48 belongs to what is called the Water-lime group in the upper Silurian system of New York, where it is extensively used for making cement, especially in Ulster County. Large quantities of cement rock are quarried also in Indiana and Kentucky, and to a less extent at various points in

Georgia, Illinois, Kansas, Maryland, Missouri, New Mexico, Ohio, Pennsylvania, Texas, Utah, Virginia, West Virginia, and Wisconsin. The total product of hydraulic cement in the United States in 1895 was nearly eight million barrels, and the output is rapidly increasing.

Portland cement, which is of the same character as the hydraulic cement already referred to, is made in England by mixing 70 per cent of chalk with 30 per cent of fine mud from the Thames. It is now being made quite extensively in this country from a nonmagnesian argillaceous limestone.

Information concerning the production of cement in this country is published annually by the United States Geological Survey in the report on the Mineral Resources of the United States, and special mention may be made to the report for 1891, pp. 529 to 538, the report for 1894 (Part III of the Sixteenth Annual Report), pp. 576 to 585, and the report for 1896 (Part V of the Eighteenth Annual Report), pp. 1179-1182.

No. 49. Amorphous Marl.

(From Cortland, Cortland County, New York. Described by J. S. Diller.)

A belt of limestones and highly calcareous rocks extends across the State of New York from the Niagara to near the Hudson. During the Glacial period much material from this belt was carried in the drift southward, so that there is a broad belt in which the springs and other waters rising in the drift carry much carbonate of lime in solution.

Upon the loss of the carbonic acid by means of which the carbonate is held in solution, as well as by means of plants and animals, much of the carbonate is precipitated, forming calcareous tufa or marl. The calcareous tufa generally contains traces of the vegetation which grows upon the bottoms of the lakes and streams or upon the adjacent slopes. On the other hand, the marl generally contains shells. Marl is an earthy calcareous rock in which the carbonate of lime is intermingled with much clay, sand, or other earthy material. The proportions may vary from a small percentage to over one-half of the whole mass. James Hall[1] says that "in nearly all situations the muck swamps are underlain by a deposit of calcareous marl. This is usually very finely pulverulent, and, though cohering when wet, is very friable when dry."

Specimen No. 49 is of this character. A few small shells of both univalve and bivalve mollusks occur in it where the specimens were collected, but as they are not in large numbers the marl appears amorphous, although in other portions of the mass shells are locally abundant. It contains 94.32 per cent of carbonate of lime, and is almost completely soluble in dilute hydrochloric acid, leaving a whitish residue composed chiefly of more or less rounded grains of quartz.

The calcareous material is very fine-granular, the particles averaging apparently less than 0.01^{mm} in diameter, while the associated quartz

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[1] Geology of New York, Part IV, 1843, p. 360.

grains are generally about six times as large. Both are crystalline, although neither shows crystallographic outlines. The carbonate of lime closely resembles that obtained by pulverizing the contained shells, and suggests that it may have originated by their disintegration. Professor Hall remarks:[1]

> In the greater number of the marl beds the remains of fluviatile testacea are very abundant, though it is only in a few situations where they have formed any large proportion of the deposit. The shells appear to have flourished in immense numbers, probably from the facility with which they obtained calcareous matter, and other favorable circumstances; but still it is plain that the formations of this kind are generally due to calcareous springs or to the percolation of rain water through the surrounding rocks, which, from its excess of carbonic acid, dissolves the calcareous particles in the soil or the harder strata.

No. 50. SHELL MARL.

(FROM NEAR ROCHESTER, NEW YORK. DESCRIBED BY J. S. DILLER.)

A few miles east of Rochester, New York, is a small place which until recently was a swamp, but is now dry land and cultivated. Originally it was a small lake, which was gradually filled by sediments washed from the adjacent slopes, and became first a swamp and then arable land. In the lake lived numerous mollusks, whose remains were buried in the mud of the lake, converting it into marl. As the shells may still be plainly seen, the material is shell marl. In some cases the shells are so abundant as to form the greater portion of the mass, but in specimen No. 50, although numerous, they form but a small portion of the whole. When the marl is placed in dilute acid it effervesces vigorously for a short time only, and the greater portion of the material, which under the microscope is seen to be composed of sand and argillaceous matter, with traces of fibrous vegetal remains, is left as a residue.

No. 51. DIATOM EARTH. (INFUSORIAL EARTH, OR TRIPOLITE.)

(FROM WHITE PLAINS, CHURCHILL COUNTY, NEVADA. DESCRIBED BY J. S. DILLER.)

Diatom earth, sometimes called tripolite (or tripolyte[2]), and more frequently infusorial earth, is a soft earthy material like chalk (No. 39), volcanic dust (No. 58), or kaolin (No. 149), but differs from all of these in being composed chiefly of extremely minute siliceous plants, or diatoms. The diatoms were once included under the general term "infusoria," hence the name *infusorial earth*. Tripolite, or tripoli, takes its name from the country in Africa, where similar material occurs. In that case, however, instead of being composed of diatoms, it appears to be derived from the leaching of a siliceous limestone.

The shells of organisms in lacustrine waters of limestone regions, as we have already seen, are calcareous, for there large masses of calcareous rocks give carbonate of lime to the waters of the lakes. In

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[1] Geology of New York, Part IV, 1843, p. 361.

[2] Dana's Manual of Geology, 4th edition, p. 81.

regions where the prevailing rocks are rich in silica the shells of organisms which flourish in the waters are siliceous. The most common of such siliceous organisms are diatoms, a very minute species of plant, of which there are many forms. A few of these are illustrated in Dana's Manual of Geology, fourth edition, pages 164 and 894. Occasionally they are so abundant that their dead shells, falling to the bottom of the water in which they lived, accumulate and form large deposits. Such deposits are common in the volcanic regions of the Northwest, where the streams carry much silica from decomposing lavas and are occasionally interrupted and ponded by outflows of new coulées. Several excellent examples of such ponding, produced by the recent outflows of lava forming dams in the bed of the stream, occur along Pit River and Klamath River, in northern California. In such cases there was developed above the dam a temporary lake in which diatoms flourished and gave rise to small local deposits, now exposed on the banks of the river, which by long-continued corrasion has cut a canyon through the lava and drained the lake. The diatom earth of White Plains, Nevada, forms a bed of larger extent. It is of Miocene age, and has been tilted with the associated volcanic rocks.[1] Its mode of accumulation is illustrated by Shaler.[2] Although diatom earth is often of lucustral origin, it is produced also in the warm waters of the siliceous springs of the Yellowstone National Park, where, as Weed has shown, beds 3 to 6 feet in thickness cover many square miles.[3]

Diatoms flourish in the surface water of parts of the ocean, especially in the South Atlantic, where they are so abundant as to becloud it and where they serve as food for whales. Their remains sink to the bottom and form great accumulations of diatom ooze.[4] Their tests, unlike the calcareous ones of foraminifera, are insoluble and may sink to the bottom of the deepest ocean.

Diatom earth is found in many parts of the world, and is extensively used for polishing. It has been used also as an absorbent in the manufacture of explosives, and as a packing about steam boilers. The "silver white" of commerce is diatom earth.

In the United States it occurs at many localities, of which two may be mentioned. Near Richmond, Virginia, it forms a bed 30 feet thick and 100 miles in extent; and near Monterey, California, there is a bed of it 50 feet in thickness, but of unknown extent. There are many other localities. The output for 1896 in this country was 2,796 tons, valued at $16,042.

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[1] U. S. Geol. Expl. Fortieth Par., Vol. I, Systematic Geology, p. 421; Vol. II, Descriptive Geology, p. 770.

[2] The origin and nature of soils: Twelfth Ann. Rept. U. S. Geol. Survey, Part I, 1891, p. 316, fig. 22.

[3] Botanical Gazette, Vol. XIV, No. 5, p. 117, 1889.

[4] Reports of the Challenger Expedition, Deep Sea Deposits, p. 208.

No. 52. FOSSILIFEROUS IRON ORE.

(FROM ROCHESTER, NEW YORK. DESCRIBED BY J. S. DILLER.)

The rocks of the Clinton series, exposed along the Genesee River, near Rochester, are illustrated in Pl. XXIII. The main mass is a thin-bedded limestone of the Clinton series in the upper Silurian system, but near its base, plainly visible in the figure, is a bed of iron ore—red hematite—illustrated by specimen No. 52. At this point the ore bed has a thickness of 14 inches. Twenty miles to the east it attains its greatest thickness, 24 inches. Westward from Rochester the ore bed extends only a short distance, for it does not reach the Niagara River. To the south, however, in the Appalachian region, it has a remarkable distribution. Sometimes there is only one bed, as at Rochester; then again there may be three beds, ranging from 1 foot to 10 feet in thickness. They can be traced from New York through Pennsylvania, Virginia, Kentucky, and Tennessee into Alabama. They occur also in Wisconsin.

The ore is usually fossiliferous, as is specimen No. 52, and is sometimes called "red fossil ore." At other times it is oolitic, and is referred to as the oolitic iron ore; also as the Clinton ore, on account of its age and place of best exposure. The fossils are chiefly broken crinoids and bryozoa.

The rock is made up of flattish or elongated grains, many of which are fragments of shells, but when seen in the hand specimen all appear to be oxide of iron. Under the microscope, however, these fossil fragments are, in most cases, found to be only partially made up of iron ore. In some cases there is a fine coating of the oxide, such as may be seen about the grains of beach sand, as well as about the grains of many sandstones and quartzites, but generally it is thicker than a mere coating, and in many cases it completely replaces the carbonate of lime of the original fossil. Some of the grains look oolitic, but in a thin section no concentric or radial arrangement, suggesting concretionary structure, was observed. At many other places, however, as shown by Smyth,[1] the oolitic structure is well developed. In specimen No. 52 the cement binding the ferruginous grains together is calcite and silica. They may be intermingled or may occur separately, but in either case the cement contains but little oxide of iron. The silica is occasionally radial-fibrous and optically negative, like chalcedony.

By dissolving a fragment of this ore in hydrochloric acid, after the carbonate of lime has completely disappeared it is found that the ore is intimately associated with much silica, which is not easily recognized before the carbonates are removed. Upon close examination of a thin section a considerable part of the carbonate of lime in the fossil fragments is seen to be replaced by silica.

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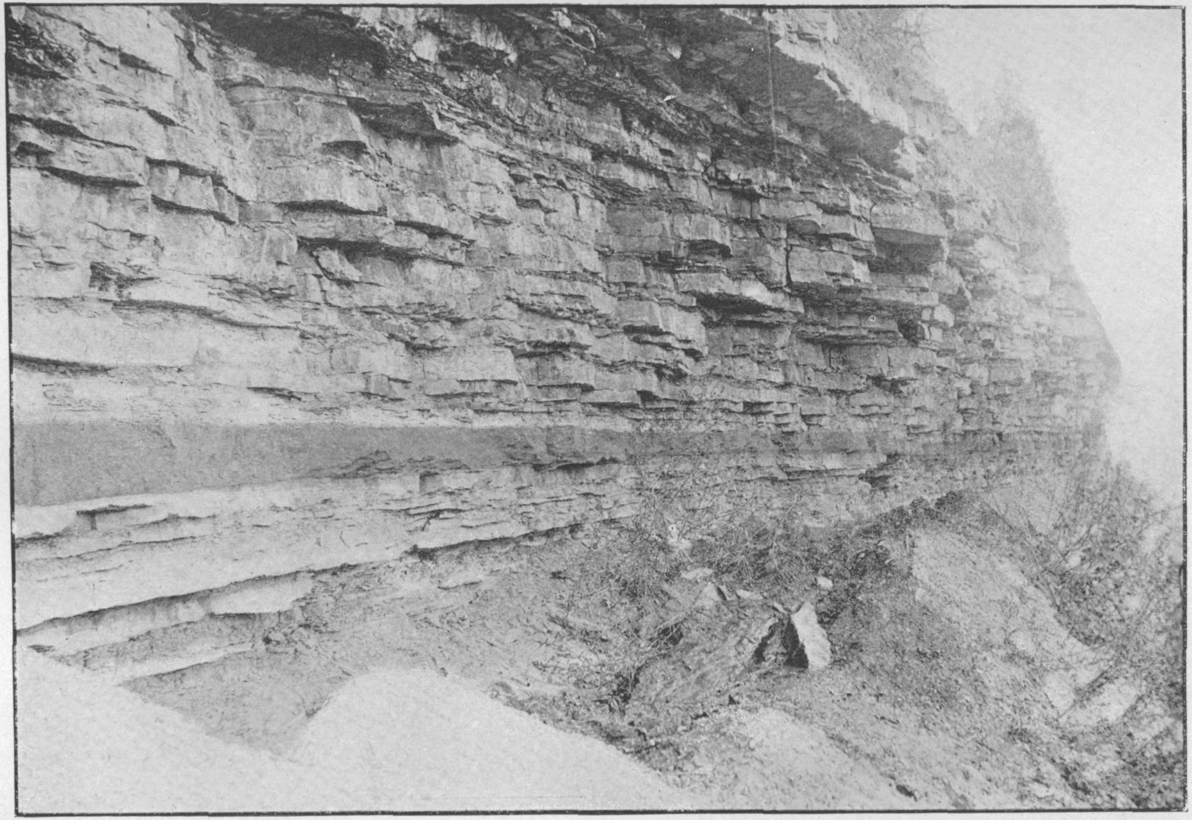
[1] Am. Jour. Sci., June, 1891, 3d series, Vol. XLIII, p. 487.



BED OF FOSSILIFEROUS IRON ORE BETWEEN BEDS OF LIMESTONE, ROCHESTER, NEW YORK.

When this rock is long exposed, at or near the surface, to atmospheric influences and drainage, it is softened by the removal of much of the carbonate of lime cement, and thus the proportion of oxide of iron is greatly increased, making the rock a valuable ore of iron. Below drainage the carbonate of lime is not removed, and the rock is harder and of less value for the iron it contains; but as it affords the necessary flux for more siliceous ores, it may still be used for its iron. It is important, however, to note that the ore in both cases is the anhydrous oxide of iron—that is, red hematite—and not the carbonate, or limonite, as might be expected from its association with carbonate of lime.

This ore has been extensively used of late years in the Southern States, especially at Birmingham, Alabama, and at various points in Tennessee. Originally it was considerably used in Tennessee, not only as a source of iron, but also in dyeing, and it has been known in that region for many years as the "dyestone ore."

The fossiliferous and bedded character of this ore, and its extensive distribution, are altogether exceptional, so that its origin is a matter of much interest. James Hall[1] regarded it as derived from pyrite, in part at least, through the action of thermal waters, but this view has long since given place to other hypotheses.

The facts that the oxide of iron in the bed replaces bryozoa and other calcareous fossils, and that below the drainage level the rock is largely carbonate of lime, have led to the view that the ore originated entirely by the replacement of limestone after the strata were tilted up into their present position. This view was advocated by A. F. Foerste,[2] and especially by James P. Kimball.[3]

The type locality of the rocks of the series to which the iron ore belongs is at Clinton, New York, where, instead of one bed, there are three beds of ore, and, as pointed out by C. H. Smyth, they are associated with shales, sandstones, and conglomerates, whose ripple marks and mud cracks clearly indicate the littoral condition under which they were deposited along the borders of an interior sea that once filled the Mississippi Valley, and at an earlier stage of its history deposited the great mass of limestone noted in the description of specimen No. 46 (p. 127). The abundance of marine life furnished the material for the coquina-like accumulation of shells, and the streams of the adjacent lands brought the oxide of iron to tide-washed, salt-water flats, where, in the association of the two, the deposit of iron originated.

According to Dana,[4] "The beds were evidently made over tide-washed, salt-water flats, where trituration is gentle. They indicate a wonderful degree of uniformity in continental level over a wide area."

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[1] Geology of New York, part 4, p. 61.

[2] Am. Jour. Sci., Jan., 1891, 3d series, Vol. XLI, p. 28.

[3] Am. Geologist, Dec., 1891, Vol. VIII, pp. 356-357.

[4] Dana's Manual of Geology, 4th ed., p. 539.

The oolitic structure of the ore, as shown by Newberry,[1] favors the view which regards the ore as an original deposit instead of a subsequent replacement of the limestone.

C. Willard Hayes has recently examined many of the Clinton iron-ore mines of Tennessee,[2] Georgia, and Alabama with special reference to data concerning the origin of the ore, and he reports[3] that he has never found it passing into a nonferruginous limestone. "While it is true that the proportion of iron to lime in the unweathered ore varies in some cases rather rapidly, it is quite as apt to vary along the strike as upon the dip, showing that the variation is original and not connected with depth below the surface." His observations lead him to conclude, as did Newberry and Smyth, that the iron ore is an original constituent of the bed, and is not due to later replacement.

No. 53. PEAT.

(FROM NORTH CAMBRIDGE, MIDDLESEX COUNTY, MASSACHUSETTS. DESCRIBED BY GEORGE OTIS SMITH.)

Peat is of recent origin, and the processes of its formation can be observed by anyone who has opportunity to visit a swamp. It is generally formed by the accumulation of moss-like plant matter that has been preserved from the usual decay by moisture which prevented the free access of air. Classified by origin, peat may be termed phytogenous and sedimentary; with respect to composition, it is essentially carbonaceous. The specimen of this collection well exhibits the character of peat in its dry, compact form, in which it is used as a fuel. In color, it is dark brown or black; in texture, somewhat earthy, but with almost all of the characteristics of matted plant fibers. In its natural condition peat varies much in degree of compactness and the amount of water it contains.

Peat is a sedimentary deposit in stagnant or almost stagnant water. Thus the plant remains are usually deposited in close proximity to the place of growth, and often the growing plants are in contact with the underlying peat, which simply represents past generations of the same species. Peat-forming conditions obtain in countries of humid temperate or subarctic climate. The places of peat accumulation are small lakes, marshes, or bogs, where the moisture favors both the growth of mosses and water plants and the preservation of their remains.[4] The drainage modifications which have resulted from the glacial invasion have favored the existence of such swamps and bogs in the northern parts of this country; but in Ireland peat bogs attain the greatest extent, one having an area of over 100 square miles, with the deposit of peat almost 50 feet thick.

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[1] The genesis of our iron ores, by J. S. Newberry: School of Mines Quart., Nov., 1880, Vol. II, pp. 13–14.

[2] Geologic Atlas U. S., folio 8, Sewanee, Tenn.

[3] Letter, June 10, 1896.

[4] Professor Shaler gives the best description of these marsh conditions, in his paper on Fresh-water morasses of the United States: Tenth Ann. Rept. U. S. Geol. Survey, 1890, pp. 255–339.

Specimen No. 53 was collected in North Cambridge, Massachusetts, where it occurs in a small basin eroded in brick clay similar to No. 8 of this collection, and of inter-Glacial age.[1] The shallow pond has been filled during post-Glacial time by this deposit of plant remains, which is from 3 to 4 feet thick. In the lower part of this deposit the peat is compact and composed of finely comminuted material, which grades upward into a vegetal mat, on the surface of which the peat-making plants are growing in some places. The origin of the compact peat is thus clearly shown.

Many varieties of peat have been distinguished, classification being based upon the kind of peat-forming plants, or upon the physical and chemical characters of the peat itself. The amount of carbon present varies from 50 to 62 per cent, but usually there is little increase over the amount contained in peat moss, Sphagnum. The principal use of peat is as a fuel, but it is far inferior to other fuels; and it is also used as an absorbent and as a fertilizer.

NO. 54. CANNEL COAL.

(FROM WALLINS CREEK, HARLAN COUNTY, KENTUCKY. DESCRIBED BY GEORGE OTIS SMITH.)

Coal, like peat, is composed essentially of carbon derived from vegetal matter accumulated under conditions in which water played an important part. It may therefore be regarded as a phytogenous sedimentary rock, but it is unlike peat in all its physical and chemical characters, and far superior to it in economic importance. Coal is not believed to have been deposited as coal, hence its origin needs to be discussed under two heads—the conditions of accumulation and the character of subsequent change. Peat has been defined as simply preserved plant débris, and is essentially an unaltered rock; but in the case of coal the changes subsequent to deposition have been considerable. This alteration has consisted of changes in structure or texture and in chemical composition. Thus, the coal specimens might be described later as altered rocks were it not for their natural relation to the peat just described.

That coal represents old deposits of vegetal matter is well proved by both its megascopic and its microscopic structure. Distinct plant impressions are often seen on coal. Logs are found changed to coal, and its inner structure in many cases is fibrous or cellular. The microscope reveals even delicate spores as constituents of coal. The fossil leaves and other plant remains, which are so abundant in the associated shales and sandstones, strengthen the proof of its organic origin. Concerning the conditions of accumulation of this mass of plant débris, two rival hypotheses may be mentioned, but a complete discussion of them would involve the consideration of the most complex of geologic phenomena.

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[1] The glacial brick clays of Rhode Island and southeastern Massachusetts; Chap. III, The clays about Boston, by C. F. Marbut and J. B. Woodworth: Seventeenth Ann. Rept. U. S. Geol. Survey, Part I, 1896, pp. 989-998.

The one hypothesis gives to coal a growth-in-place origin, the other a drift or transport origin.

The growth-in-place origin involves a comparison of Paleozoic coal beds and recent peat deposits. The hypothesis extends peat-forming conditions over vast areas, and pictures a luxuriance of vegetation hardly to be comprehended from our knowledge of present conditions. Such a view is supported by the presence of the underclay, supposed to represent the soil which supported this growth, and also by the frequent occurrence of roots (Stigmaria) in this clay and of tree trunks in the sandstone above the coal. An accumulation as great as that represented in the coal beds seems to imply tropical vegetation; yet the process was one of preservation as well as of production of the organic matter. The climate that would promote the latter might prevent the former, since, as has been stated in the description of peat, accumulation of vegetal matter takes place to-day only in humid temperate and subarctic climates.

The drift origin of coal deposits involves sedimentation processes differing somewhat from those which have produced other sedimentary rocks. Sedimentation of this character would take place in the quiet waters of marginal lagoons, into which abundant vegetal matter drifts. Along the margins of these lagoons marsh vegetation would flourish, and here subaerial decay and subaqueous preservation might proceed side by side. The invasion of currents bearing mud or sand into portions of the lagoons would occasion the deposition of shale or sandstone; and thus the splitting of a coal bed may be explained as a simple phenomenon of sedimentation.

The two hypotheses have much in common. Both involve base-level conditions, luxuriance of vegetation, and slow subsidence of the area of accumulation. They differ in that growth-in-place necessitates subsidence of an oscillatory character to explain the alternation of coal beds and subaqueous sediments, while the sedimentation of drift material needs only slow subsidence, possibly somewhat intermittent. Both hypotheses are ably supported, the latter receiving more attention from later workers on the subject. It is reasonable to believe, moreover, that the coal deposits, with so great a distribution both geologically and geographically, have not all had exactly the same origin, and that even in the same coal field both hypotheses may be necessary to explain all the phenomena.

The subsequent alteration of these deposits of carbonaceous débris has resulted in the destruction of much of the organic structure and in quite marked chemical changes. Peaty fermentation doubtless initiated such changes, while later geological processes contributed to the metamorphism. It must be noted that the metamorphism has been selective, the associated shales and sandstones remaining unaltered. This is explicable from the readiness with which hydrocarbon compounds respond to changes in their physical environment. Increase of temperature and of pressure attending the folding and faulting of the rocks of the coal formation has caused the chemical changes which constitute the difference between woody fiber and coal. The alteration, in short, consists of a decrease in volatile or gaseous constituents and a corresponding relative increase in carbon. The principal physical change has been a corresponding loss of volume, and from compression there have resulted various structures more or less characteristic of the different varieties of coal. These changes have been slow, but the degree of alteration attained in some of the Tertiary coals shows that time is not the most important factor. Coal beds are found in formations of the Paleozoic, Mesozoic, and Tertiary ages, but the Carboniferous coals are the most important, and the coal specimens described below are all of this age.

Cannel coal is black in color, with a rather dull luster, compact and homogeneous in texture, and with a flat conchoidal fracture, although often with a fissility approaching that of shale. Its specific gravity is lower than that of most bituminous coal, but higher than that of lignite or brown coal. Chemically, cannel coal is characterized by its richness in volatile hydrocarbons—a quality which makes it preeminently a gas coal. Its name, cannel, or candle, was given because of the readiness with which it burns with a bright flame, so that pieces were used as candles by the poor people in England.

Cannel coal is more clastic in character than other coals, and is composed of carbonaceous material thoroughly macerated. Fossil fishes and remains of other aquatic animals are often found associated with cannel coal, showing its sedimentary origin. The proportion of impurities or ash is larger than in other coals, and cannel coal thus grades into carbonaceous shale by increase in amount of clayey material.

The specimens of this collection came from the Carboniferous area of southeastern Kentucky. Here the measures lie in a broad syncline, with a gentle fold as its southeastern limit, and an overthrust fault bounding it on the northwest. Analyses of cannel coal from the same part of the basin show a rather low percentage of carbon, with ash amounting to over 25 per cent.

NO. 55. BITUMINOUS COAL.

(FROM GEORGES CREEK, ALLEGANY COUNTY, MARYLAND. DESCRIBED BY GEORGE OTIS SMITH.)

This coal is intensely black, with a velvet or pitch luster and a cubical or uneven fracture. A block of bituminous coal usually shows a banded structure, with some of the bands dull, others bright and glistening. The hardness of this coal is less than that of anthracite, hence its common name, soft coal; and it soils the hand, thus differing from cannel coal. Its specific gravity varies from 1.2 to 1.5. Chemically, it varies considerably in the proportion of carbon and volatile constituents, but is intermediate in composition between anthracite and lignite.

Bituminous coal ignites easily, burns with a yellow flame, and gives off much smoke. The rapidity of its combustion fits it for general use in the industries, while certain varieties are especially adapted for the production of gas and coke.

The Georges Creek Basin, from which locality this specimen was collected, is situated in western Maryland. It is a shallow basin of Coal Measures, containing several valuable beds of coal. The "Big Vein," which occurs near the top of the 1,200 feet of Carboniferous rocks here exposed, is correlated with the Pittsburg coal bed, the most valuable of the Appalachian field. It forms the lowest member of the upper Coal Measures, and its structure persists over large areas, showing wide prevalence of nearly uniform conditions at the time of its deposition.[1] The coal represented by specimen No. 55 is a high-grade coal, standing well in the market.

No. 56. ANTHRACITE COAL.

(FROM GILBERTON MINE, SCHUYLKILL COUNTY, PENNSYLVANIA. DESCRIBED BY GEORGE OTIS SMITH.)

As will be observed from an examination of this specimen, anthracite coal is black, but with a bluish or brownish tinge. Its luster is adamantine to submetallic and its fracture is plainly conchoidal. It is dense and brittle, and no megascopic structure can be distinguished, yet the microscope sometimes reveals traces of plant remains. Anthracite is the hardest and heaviest of all the coals, with a hardness of 2 to 2.5 and a specific gravity of 1.4 to 1.7. Its chemical characteristic is the high proportion of carbon, which ranges from 85 to 92 per cent in the Pennsylvania anthracite and is known to reach even 95 per cent in the anthracite of Wales. Because of the decrease in volatile constituents, anthracite ignites with more difficulty than does bituminous coal, and burns with a small bluish flame and no smoke, but affords more heat, pound for pound, than any other coal.

The locality from which this anthracite was collected is in the Western Middle Anthracite Field of Pennsylvania.[2] The eastern basin of this field is a long and narrow spoon-shaped syncline, subdivided by anticlines into many smaller basins. Overturned strata are quite common, and the coal beds of this area are steeply inclined, the average dip being not less than 35° to 40°. Such close folding has tended to crush the coal, thus increasing the proportion of waste.

The chemical and physical characteristics of anthracite are such as seem due to a greater degree of alteration than that attained in the other coals. It has been suggested that there were differences in the original vegetal deposits, since beds of anthracite have been found between or even above beds of bituminous coal. However, these rela-

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[1] The stratigraphy of the bituminous-coal fields is described by I. C. White in Bull. U. S. Geol. Survey No. 65.

[2] Described in the Final Report of the Pennsylvania Geol. Survey, vol. 3, Part I, Chap. CXXI.

tions are exceptional, and it is well known that in the same bed bituminous coal may grade into anthracite, and in many cases this change is seen to be the result of contact metamorphism. Perhaps the best instances of alteration are found in the Cretaceous coals of the Anthracite-Crested Butte area in Colorado.[1] The noncoking bituminous coals are found in regions of least metamorphism, the coking coals in the localities of more advanced alteration, and the anthracite only in areas of great regional metamorphism or in the neighborhood of large bodies of porphyrite.[2]

If the metamorphism of coal beds is more profound, the coal becomes graphitic, as is the case in the anthracite of Rhode Island.

In short, there is a complete gradation in chemical composition from wood which contains about 50 per cent of carbon to graphite, which is pure carbon. Intermediate members of this series are the peat and the coals which have already been described. The group is a natural one, the members having an origin essentially the same, but with present characters dependent upon the degree of subsequent alteration.

UNALTERED IGNEOUS ROCKS.

No. 57. Dike.

(From Williamsons Point, Lancaster County, Pennsylvania. Described by J. S. Diller.)

By the activity of forces not fully understood, fissures (great and small) are produced in the rocks at and near the earth's surface and filled from below with molten rock material. Such rock-filled fissures are *dikes*. They are common in volcanic regions, and illustrate one of the forms of connection between the volcanic effusions upon the surface and the highly heated interior of the earth in which the lavas originate. They are generally nearly vertical, as in Pl. XXIV, breaking through sedimentary as well as igneous rocks, and occasionally show a marked columnar structure perpendicular to the walls of the dike, like that of specimen No. 103. Specimen No. 57, which includes the whole thickness of the dike, shows the cross fractures distinctly. This jointing was determined by the cooling influence of the adjacent rocks.

Dikes range in size from a few inches to several hundred feet in thickness and from a few rods to miles in length. Igneous rocks such as form dikes are generally harder than the adjoining rocks, so that they are able longer to withstand the destructive influence of weathering, and give rise to ridges which may be traced for miles. The same dike may not continue for many miles, but the group to which it belongs may be more or less continuous for long distances. In connection with

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[1] Geologic Atlas U. S., folio 9, Anthracite-Crested Butte.

[2] Eldridge, descriptive text of folio 9.

the Triassic formation of the Atlantic coast, they extend with interruptions from Massachusetts to North Carolina.

The material of large dikes cools more slowly than that of small dikes, and becomes more coarsely crystalline. Small dikes, like specimen No. 57, are usually fine grained. Large dikes are in general more coarsely crystalline in the middle than upon the borders, where they come in contact with the country rock and are sometimes glassy. A number of volcanoes may be in line on the same fissure, affording escape at certain points for the rising magma. In other places the outflow upon the surface appears to have taken place all along the fissures in sheets, as observed by Russell,[1] Le Conte,[2] and others.

Dikes may occur in radial groups about a volcano. Volcanoes sometimes become plugged up, and the great pressure of the molten material within bursts the mountain asunder. The fissures afford an escape for the magma, and dikes are produced. This arrangement is well marked in the Highwood and Crazy mountains, as well as other mountains in Montana[3] and about the Spanish Peaks of Colorado.[4] Mount Etna affords an illustration of such a group in connection with an active volcano. Upon its slopes are numerous minor vents arranged in lines radiating from the main crater.

Like joints, dikes may occur in parallel or intersecting systems. Where they intersect, their relative age can be determined; the newer cut across the older.

Many kinds of igneous rocks, both plutonic and volcanic, occur in dikes. Some forms are known only in dikes, and for this reason have been placed in a separate group by some authors.[5]

The most common of all dike-forming rocks is probably diabase, the group to which the small dike illustrated by specimen No. 57 belongs.

GRANITE-RHYOLITE FAMILY.

No. 58. VOLCANIC DUST (RHYOLITIC?).

(FROM GALLATIN VALLEY, GALLATIN COUNTY, MONTANA. DESCRIBED BY J. P. IDDINGS.)

This fine dust forms a deposit about 20 feet thick within Neocene lake beds of the Gallatin Valley, Montana,[6] where it has been studied by A. C. Peale. The major part of these lake beds consist of volcanic dust, similar but less pure, and presumably brought into the lake basins by waters from the neighboring slopes, where it has been deposited by the wind. The purer material occurring in these beds is considered to

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[1] Bull. U. S. Geol. Survey No. 108, pp. 11 and 22.

[2] Am. Jour. Sci., 3d series, Vol. VII, p. 167.

[3] Highwood Mountains of Montana, by Walter H. Weed and Louis V. Pirsson: Bull. Geol. Soc. America, vol. 6, p. 392. See, also, Geologic Atlas U. S., Little Belt folio, by W. H. Weed.

[4] Geologic Atlas U. S., Spanish Peaks folio, by R. C. Hills.

[5] "Ganggesteine" of Rosenbusch: Mikroskopische Physiographie der Massigen Gesteine, 1887, p. 6.

[6] Peale, A. C.: Geologic Atlas U. S., folio 24, Three Forks, Montana, 1896.

DIKE OF ANDESITE CUTTING ANDESITIC BRECCIA, ABSAROKA RANGE, WYOMING.

have been deposited directly from the air. It occurs in beds 2 to 5 feet thick, separated by thin calcareous layers, the thickness of the whole being 20 feet.

When examined with a microscope, it is seen to be made up of minute fragments of colorless glass, whose angular shapes in some instances, and thread-like form in others, together with the presence of air pores, which are spherical, elliptical, and tubular, indicate plainly that the fragments are broken pumice. The size of the fragments is very small, the largest being about 0.4^{mm} in diameter, the average diameter being about 0.2^{mm}.

A very small percentage of the fragments are pieces of crystals, and these appear to be feldspar, hornblende, and pyroxene, and possibly some quartz. But quartz and unstriated feldspar may be easily confused when in angular fragments, unless cleavage is pronounced. This small percentage of crystals as compared with glass may be due to the original paucity of crystals in the magma exploded into dust, or it may be the result of a partial separation of the material during its transportation through the air, by which means the denser and more compact particles settled nearer the vent from which the eruption took place than the lighter and more attenuated ones. Hence it can not be assumed that the material found in this deposit necessarily represents the composition of the lava before explosion. The glass itself is absolutely free from microlites and is perfectly colorless in the thin bits forming the dust.

The chemical composition of the dust is shown by the following analyses:

Analyses of volcanic dust and of rhyolite.

	I.	II.	III.
	Per cent.	*Per cent.*	*Per cent.*
SiO_2	68.68	74.59	75.19
Al_2O_3	12.69	13.78	13.77
Fe_2O_3	1.14	1.23	.61
FeO	1.17	1.27	1.37
MnO	trace	trace	trace
MgO	1.14	1.23	.09
CaO	1.11	1.21	.68
Na_2O	1.23	1.34	3.83
K_2O	5.58	6.06	3.33
Li_2O	....	....	.02
SO_3	....	....	.29
Ignition	7.99	....	.65
Total	100.73	100.71	99.83

Analysis II shows the percentage when the loss upon ignition is left out. This loss is unusually large and indicates a highly hydrated glass. When compared with the rhyolitic rocks of the Yellowstone Park region, which is 50 miles to the southeast, the volcanic dust of the

Gallatin Valley is found to be much richer in K_2O and poorer in Na_2O, and to contain more MgO and a little more CaO and iron oxide. Analysis III, of a rhyolite from the North Madison Plateau, Yellowstone Park, is placed by the side of that of the volcanic dust for comparison. It is a fair representative of the composition of most of the rhyolite of the region. The relatively high percentage of MgO and CaO, and the presence of fragments of hornblende and pyroxene and feldspar, suggests that the volcanic dust may be the glassy portion of a lava having the composition of a dacite, in which potash was concentrated in the groundmass by the crystallization of the soda in lime-soda feldspars. Since this is purely speculative and the actual history of this particular deposit of dust is unknown, it will be better to refer it to the rhyolites on the basis of its high content of silica, remembering that its chemical composition is not normal when compared with the great bodies of rhyolite that were erupted in the region to the southeast, and noting the fact that it may be related to the explosive eruptions of andesite which also took place in earlier Neocene times in the same region.

For accounts of the transportation of volcanic dust, sometimes to distances of 500 and 700 miles, the student is referred to the text-books of Dana, Geikie, and others.

NO. 59. RHYOLITIC PUMICE.

(FROM MONO LAKE, MONO COUNTY, CALIFORNIA. DESCRIBED BY WALDEMAR LINDGREN.)

At most volcanic eruptions the effused or ejected masses are partly of a porous or scoriaceous structure, due to the expansion of gases and vapors contained in the magma. The extreme result of such a dilation of the magma by expanding gases is a light, spongy, froth-like substance, usually more or less drawn out in threads and sometimes, indeed, forming fibrous masses with silky luster. It is called pumice.

Pumice may be formed during the eruption of any magma, and we may thus speak of rhyolitic pumice, of andesitic pumice, etc. No doubt, on account of the more viscous character of the magma the kind first mentioned is most common, and such is the rock here described.

The late Tertiary or Pleistocene volcanoes south of Mono Lake, at the eastern base of the Sierra Nevada, when active poured out heavy masses of rhyolitic glass or obsidian.

Violent explosions accompanied the eruptions, and fine volcanic dust, together with "volcanic bombs" of pumice, were scattered all over the surrounding country for miles beyond the craters.

The pumice is light gray, usually somewhat fibrous or silky on account of the long drawn-out pores which it contains. As a rule the pieces will float on water. Under the microscope it is found to consist of a colorless glass, perfectly isotropic, containing a few large porphyritic crystals or phenocrysts of plagioclase with narrow striations; one or two larger greenish pyroxene grains were also noted. More abundant are foils of a brown biotite, sometimes 1^{mm} long. The glass is much purer than that of the obsidian from the same locality. It contains no or very few trichites, and only a moderate quantity of microlites. Among these, biotite foils, sometimes hexagonal and occasionally bent and twisted, together with minute feldspar microlites, are the most abundant. Local accumulation of opacite grains and obscure microlites are frequent. Very characteristic is the stringy or drawn-out structure of the glass, caused by long, winding, thread-like gas inclusions.

The macroscopic pores of the pumice of course appear prominently in the sections. They are usually drawn out in an elongated shape parallel to the thin, microscopic gas inclusions in the glass, and are sometimes so abundant that only a slender network of glass remains.

The appended analysis by W. H. Melville shows by the high percentage of alkali and small amount of lime that the rock belongs in the group characterized by the prevalence of alkali feldspars, albite, and orthoclase, though probably a little oligoclase is also present. The silica is rather low for a rhyolitic pumice, and in this respect the rock approaches the trachytes.

Analysis of rhyolitic pumice from Mono Lake, California.

	Per cent.
Loss	2.06
SiO_2	67.39
Al_2O_3	15.99
Fe_2O_3	0.56
FeO	1.99
CaO	1.63
MgO	0.77
K_2O	4.80
Na_2O	4.74
Total	99.93

NO. 60. RHYOLITIC OBSIDIAN.

(FROM MONO LAKE, MONO COUNTY, CALIFORNIA. DESCRIBED BY WALDEMAR LINDGREN.)

Just south of Mono Lake, in the Great Basin, and a few miles east of the great fault scarp of the Sierra Nevada, there rises a long row of volcanic cones with a maximum height of 2,700 feet above the level of the lake. Probably in Pliocene, and certainly in Pleistocene times, these craters were in full activity, pouring out acid viscous lavas, which consolidated as rhyolite and obsidian, and scattering volcanic bombs, lapilli, and ashes all over the surrounding country. The volcanoes are no longer active, but their cones are still excellently preserved.

The lava flows are principally composed of a rhyolitic obsidian, which is a rapidly cooled and consequently glassy lava. The obsidian, which was collected at the foot of one of these ridges, is of deep-black color, has a glassy luster, and beautiful conchoidal fracture; in thin fragments it is translucent with a grayish or smoky color.

Under the microscope the principal constituent is a colorless, isotropic glass, filled with a great variety of minute inclusions and crystals, very frequently arranged so as to give the rock a banded or fluidal appearance. Once an inclusion of a glassy andesitic rock with feldspar and augite microlites was noted, showing that on its way up the magma broke through more basic eruptives. Although there are no large phenocrysts, the glass abounds with minute crystals and inclusions, to a degree not to be suspected by the appearance of the rock.

While the mineralogical character of some of these may be distinctly recognized, others are so small and obscure that we can only infer from their form that they possess the physical characteristics of crystals. These are designated microlitic forms.

Among the crystals which may be identified we note biotite, a few distinct augite prisms, small magnetite grains, pretty generally distributed, and minute colorless prisms, with feeble refraction, which almost certainly are feldspars.

The most abundant mineral is brown biotite in long-drawn foils with a maximum length of 0.066^{mm}, although generally much smaller. Sometimes these biotite foils are bent or broken. Further we note a few yellowish-green, strongly refracting grains of augite, and some colorless rounded masses (maximum diameter 0.1^{mm}) of a strongly refracting doubtful substance. Between crossed nicols these latter show undulous extinction and gray colors of interference. Besides these the glass swarms with microlites, which are usually of slender prismatic forms and act on the polarized light, but which can not be positively identified.

Most prominent, however, are other microlitic forms which are designated as trichites. They are defined as capillary crystals of exceedingly small thickness compared with their length. They are nearly always bent, broken, or curved in complicated forms. The trichites have a great tendency to combine in groups, radiating spider-like from a common center, usually a small grain of magnetite. On account of their minute thickness, rounded form, and the total reflection caused thereby, they usually appear opaque, but occasionally larger ones may be found which transmit the light with a dark-brown color. Sometimes the trichites appear isolated, as curved or straight hairs with a maximum length of 0.15^{mm}, and it seems, indeed, as if there were a transition between the recognizable narrow biotite foils and the trichites, although such a connection has not been conclusively proved. At any rate, the trichites seem to be composed of some silicate rich in iron.

Besides these microlitic forms the glass contains a great many gas inclusions, generally more or less drawn out in one direction.

The structure and microscopic appearance of the obsidian containing all these minute forms are by no means constant and similar throughout the mass. The principal cause of this is the microfluidal structure prevailing in the rock and showing that the magma has been in motion after the separation of the crystals and the microlitic forms. Most slides have a more or less distinct banded appearance. In some bands biotite crystals abound, in parallel arrangment; in others, trichites predominate; in still other streaks, minute feldspar crystals may prevail. The bands are often curved in a complex way.

Sometimes the glass may be comparatively free from microlitic forms, while in other places they accumulate in dense masses.

A faint double refraction of the glass is often noticed; in most cases, however, this is due to extremely small microlites, discernible with difficulty even with strong objectives, but in a few places it really appears as if the glass itself were faintly double refracting.

The appended analysis by W. H. Melville shows that the rock has the composition of a typical rhyolite, indicated by the high percentage of silica, small amount of lime, and relatively large quantities of soda and potassa.

Analysis of rhyolitic obsidian from Mono Lake, California.

	Per cent.
Loss	0.41
SiO_2	75.78
Al_2O_3	12.39
Fe_2O_3	0.22
FeO	1.25
CaO	0.81
MgO	0.31
K_2O	4.64
Na_2O	4.00
Total	99.81

No. 61. RHYOLITIC PERLITE.

(FROM YELLOWSTONE NATIONAL PARK. DESCRIBED BY J. P. IDDINGS.)

A dark-gray rhyolite glass forms a cliff on the east side of the Firehole River, opposite Excelsior geyser and the Midway geyser basin. It is part of the great body of rhyolite which, as a surficial flow of lava, constitutes the plateau of the Yellowstone Park.

The rock varies in character in bands, which are alternately glassy and lithoidal. The glassy portions are distinctly perlitic, and also finely porous and vesicular, the cavities containing minute white pellets of tridymite. In places the centers of perlitic shells are black glass, the surrounding thin shells being light gray. This is a common feature of perlites in many localities in the Yellowstone Park. The less glassy or lithoidal layers lack the vitreous luster, and are dull gray; they are also porous, the vesicles or cavities in the rock being unequally distributed in different layers. The banding produced by the variously constituted layers of the rock, which express what is called the flow-structure, becomes more apparent in large masses of rock. The whole is filled with small phenocrysts of quartz and feldspar. In some parts of the rock there are small spherulites.

In thin sections the microscopic character of the rock is quite varied. The groundmass consists, in places, of colorless glass, with numerous trichites and microlites with marked fluidal arrangement. Such places exhibit perlitic cracks. Through this glass are scattered spherulites that appear brown in transmitted light and show the optical characteristics of those in the lithoidite from Obsidian Cliff. They are close together in the lithoidal portion of the rock and have attained various degrees of crystallization. Occasionally they have formed around the phenocrysts as a spherulitic border. Their microstructure, as well as that of the clusters of tridymite, is the same as in the lithoidite of Obsidian Cliff, and needs no special description. The phenocrysts are quartz, sanidine, plagioclase, and augite, with smaller crystals of magnetite. Quartz occurs in idiomorphic crystals, whose sections are those of double hexagonal pyramids; some are rounded. They frequently carry a number of brown glass inclusions in negative crystal cavities, and less frequently bays of groundmass.

Sanidine forms idiomorphic crystals, which sometimes have rounded corners. These crystals often carry numerous inclusions of groundmass, and also of colorless glass. Sanidine in some instances surrounds plagioclase more or less completely, the two feldspars having parallel orientation.

The plagioclase exhibits polysynthetic twinning, in thin lamellæ with low extinction angles in symmetrical sections. It is probably oligoclase. Frequently it is crowded with inclusions of groundmass and glass, so as to be fairly honeycombed. Augite occurs in comparatively large phenocrysts, but in small amount. It is light green and frequently incloses magnetite and glass. Magnetite forms crystals and grains of considerable size, 0.4^{mm} in diameter. With it are generally associated colorless crystals of zircon and some of apatite. On the edges or walls of cavities and in places where tridymite and sanidine have crystallized in microscopic crystals there is a small amount of brown biotite in six-sided plates.[1]

The chemical composition is shown by the following analysis, made by H. N. Stokes in the chemical laboratory of the United States Geological Survey.

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[1] For fuller description of the rhyolites of the Yellowstone National Park see the forthcoming monograph on that region: Mon. U. S. Geol. Survey, Vol. XXXII.

Analysis of rhyolitic perlite from Yellowstone National Park.

	Per cent.
SiO_2	73.84
Al_2O_3	12.47
Fe_2O_3	.32
FeO	.90
MnO	trace
CaO	1.08
MgO	.25
K_2O	5.38
Na_2O	2.88
Ignition	2.76
Total	99.88

No. 62. LITHOIDITE.

(FROM OBSIDIAN CLIFF, YELLOWSTONE NATIONAL PARK. DESCRIBED BY J. P. IDDINGS.)

The lithoidite in this series of rocks was collected from the northern end of Obsidian Cliff in the Yellowstone National Park. It represents the laminated and more or less crystalline portion of a great flow of rhyolitic glass which forms the picturesque cliff of obsidian, well known to the tourist by its glossy black columns that rise high above the road. The jet-black obsidian is filled with spherulites and lithophysæ, which are scattered through it in layers. In places the spherulites are minute and crowded together, so as to form light-gray layers having a stony or lithoidal appearance. As these lithoidal bands become more numerous the rock is composed of alternating layers of black glass and gray lithoidal ones. At the northern end of the cliff the lower portion of the whole mass is lithoidal, as in the specimen.

The composition and structure of the spherulites and lithophysæ and the character and probable origin of the lamination of the lithoidite have been described in detail by the writer in an article on Obsidian Cliff,[1] from which the following extracts are taken:

> This lithoidite [loc. cit., p. 264] is a light purplish-gray rock which shows, on cross-fractures, delicate bands of light and dark colored layers. The former are crystalline, with small cavities scattered along them, which form planes of weakness and permit the rock to split into thin plates, often one-sixteenth of an inch in thickness. The dark layers are microspherulitic and dense [and are sometimes glassy]. . . . . The lithoidal rock is as full of spherulitic forms as the obsidian, but it appears more porous and contains a multitude of hollow spherules of the utmost delicacy and beauty. An idea of their great abundance is given by Pl. XIII, fig. 2 [Pl. XXV of this bulletin, p. 154], which was drawn from a slab of lithoidite and is the natural size. Most of them are hemispherical and consist of a group of concentric shells which curve one over another like the petals of a rose. The shal-

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[1] J. P. Iddings, Obsidian Cliff, Yellowstone National Park: Seventh Ann. Rept. U. S. Geol. Survey, 1888. A part of this paper was previously published under the title, The nature and origin of lithophysæ and the lamination of acid lavas: Am. Jour. Sci., Jan., 1887, 3d series, Vol. XXXIII, pp. 36-45.

lower ones present small, rose-like centers surrounded by thin, circular shells. The disks are sometimes oval and sometimes composed of several sets of shells which have started from centers near together and developed in sectors, giving a scalloped form to the curves. Others are eccentric or send out long, curving arms, cross-walled like a chambered ammonite.

The partition walls are generally very thin and often close together, in one instance 50 occurring within a radius of 2 inches. They are very fragile and crumble under the touch, being made up of small and slightly adhering crystals with brilliant, glistening faces.

The minerals occurring in the lithophysæ and hollow spherulites and other cavities in the lithoidite are quartz, tridymite, sanidine, fayalite, and magnetite, the detailed descriptions of which will be found in the the paper referred to and in a more recent one in which the quartz is especially described.[1]

The microscopical character of this lithoidal rhyolite is extremely varied, and exemplifies the structure or phases of crystallization common to many rhyolitic lavas in most parts of the world. It has been made the subject of a special paper on spherulitic crystallization[2] from which the following description has been taken:

In thin sections the rock is irregularly banded or mottled according as the sections have been ground across or parallel to the layers of lamination. The most crystalline parts are colorless, the dark-gray portions are mottled with minute spots, and with a low magnifying power these dark portions are seen to be minutely spherulitic, exhibiting characteristic black crosses. The transparent parts are quite crystalline aggregations of tridymite or quartz and feldspar, often with numerous irregular cavities between the crystals. Occasionally these places contain irregular grains of fayalite, and still more rarely brown mica, besides scattered spherulites, which also border these more crystalline portions.

The thin sections show a few of the larger spherulites which are porous, and in some places branching, arborescent or feather-like growths of feldspar—in fact, all of the modifications of spherulitic crystallization described in the paper on Obsidian Cliff.

Studied with higher magnifying power, it is seen that the finely spherulitic portions are crowded with trichites, which are more perfect as the spherulitic structure is more minute, but which lose their form and uniformly fluidal arrangement when the spherulites are more developed, sometimes being crowded out toward the margin of the spherulites and aggregated in opaque lines between the spherulite individuals. The finely spherulitic parts of the rock section also exhibit an extremely minute granulation by transmitted light and appear brown; but by incident light this granulated portion is white, evidently in consequence of the reflection of the light from innumerable small surfaces or cracks. In the small spherulites that lie isolated in and also bordering on the more crystalline portions of the rock the centers of the spherulites are granulated and brown while the margins are often colorless and transparent. In some cases the centers of the spherulites are colorless, and the brown color is confined to an outer zone. In such spherulites the fibers of the outer zone are more delicate than those of the central portion, showing a lower degree of crystallization.

These small spherulites when investigated with the quartz plate prove to be optically negative—that is, the axis of greatest elasticity, $\mathfrak{a}$, lies approximately parallel to the direction of the radial fibers. This is also true of the most minute colorless

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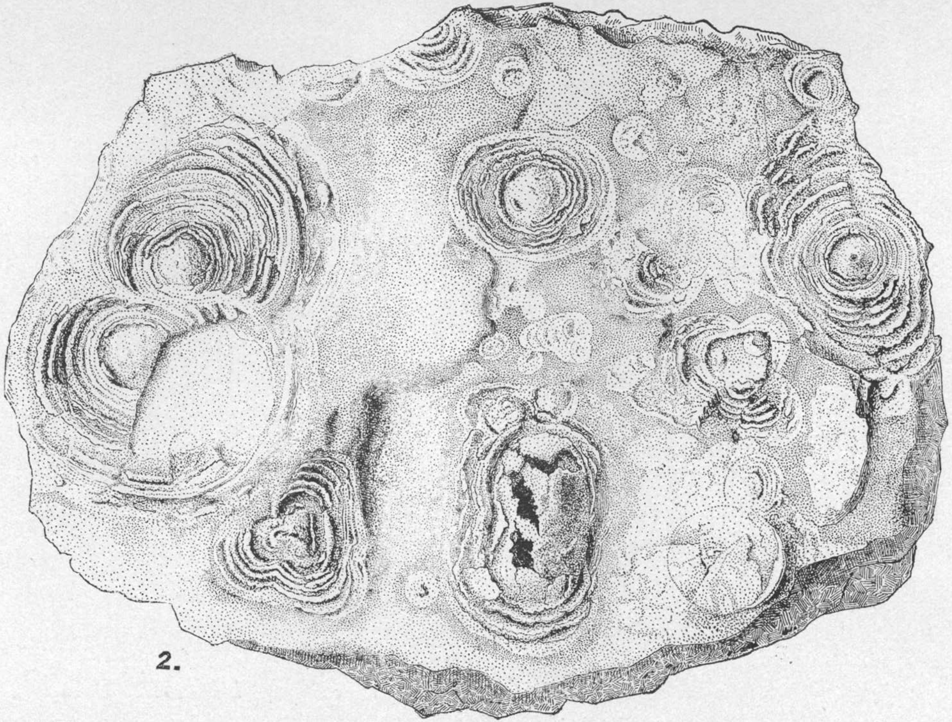
[1] J. P. Iddings and S. L. Penfield, The minerals in hollow spherulites of rhyolite from Glade Creek, Wyoming: Am. Jour. Sci., July, 1891, 3d series, Vol. XLII, pp. 39-46.

[2] J. P. Iddings, Spherulitic crystallization: Bull. Philos. Soc. Washington, Vol. XI, 1891, pp. 445-464, pls. 7, 8.



2.

LITHOPHYSÆ IN LITHOIDITE OF OBSIDIAN CLIFF, YELLOWSTONE NATIONAL PARK.

Natural size.

spherulites which occur in the glass of the obsidian, and are represented by fig. 1, Pl. VII [fig. 1, Pl. XXVI of this bulletin, p. 156]. In the lithoidite the spherulites have formed in juxtaposition, so that they adjoin one another with more or less polygonal boundaries. Occasionally there is a small space between several spherulites where the magma has crystallized differently. These spaces may attain a considerable size, relatively, or may constitute layers of the rock. The spherulites bordering such spaces frequently continue their crystallization a short distance into them, and exhibit distinct prismatic rays that project beyond the apparent periphery of the spherule, and resemble the teeth of a cogwheel. Sometimes the projecting rays assume a comparatively great size. These forms are illustrated by figs. 3 and 5, Pl. VII [Pl. XXVI of this bulletin, p. 156]. In such cases the mineral character of the rays is clearly determinable. The projecting rays are prisms with parallel sides and crystallographic terminations. They extend with uniform optical orientation toward the center of the spherulite. They exhibit in a few instances distinct cleavage parallel to the sides of the prism. The angle of extinction ranges from 0° to 10° or 12°, being usually low. The prisms are invariably optically negative, and are therefore orthoclase crystals elongated in the direction of the clino axis. The high limit of the extinction angles, as well as the chemical composition of the rock and the spherulites, since there is no evidence of the presence of more than one species of feldspar, indicates that the orthoclase is rich in soda, the molecular ratio of the potash to soda in the rock being 1 to 1.

There is a difference between the end of the projecting prisms of feldspar and the part of the ray within the spherulite. The former is transparent and clear, without inclusions; the part within the spherulite proper is clouded and granulated, as already stated. In some instances the granulation assumes a more definite character and has a radiating feather-like structure, which at once suggests the granophyric arrangement of quartz in feldspar. This is unquestionably its true character, although the quartz does not appear to affect the optical behavior of the feldspar rays.

An examination of the microscopic granophyre groups of feldspar and quartz which occur in the same thin sections, and which have been described in the article on Obsidian Cliff (p. 274), shows the same optical characters and feather-like structure. Such an intergrowth is represented in fig. 2, Pl. VII [Pl. XXVI of this bulletin.] It is made up of feldspar crystals, which cross one another at a common point, or which radiate from a common center. These feldspars invariably have the axis of greatest elasticity, $\mathfrak{a}$, approximately parallel to the direction of radiation. They have the same crystallographic orientation as the feldspar rays of the spherulites. The intergrown quartz does not alter perceptibly the optical orientation; therefore it must be either so oriented as to have its axis of greatest elasticity more or less coincident with that of the feldspar, or it is not present in sufficient amount to influence the interference phenomena appreciably. The latter is most probably the case, for in a large granophyric group with the same structure, which was studied for comparison, it was observed that the quartz, though appearing to be present in considerable amount, was not sufficient to change the character of the double refraction of the feldspar, which was the predominant mineral. It modified it, however, to a variable extent; and in places where quartz was more abundant its optical character was predominant.

The small spherulites of this rock are unquestionably composed of orthoclase prisms or needles elongated in the direction of the clinoaxis, which radiate from a center and are intergrown with quartz, after the manner of granophyre or micropegmatite; and it is this microscopic intergrowth which gives them the granulated or feather-like structure.

In the case of the spherulites with projecting rays of pure feldspar, it is evident that the free silica ceased to crystallize as quartz in intimate connection with the orthoclase and allowed the latter to continue alone and project into a highly siliceous residual paste, which finally crystallized as tridymite in most instances.

EXPLANATION OF PLATE XXVI.

SECTIONS OF SPHERULITES.

FIG. 1. Colorless microscopic spherulite, showing irregular dark cross between crossed nicols, enlarged 153 diameters.

FIG. 2. Simple form of granophyre group of quartz and feldspar between crossed nicols, enlarged 235 diameters.

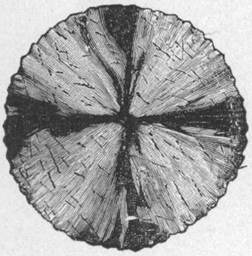
FIG. 3. Microscopic spherulite with projecting rays of orthoclase, enlarged 120 diameters.

FIG. 4. Like fig. 3, with crescent-shaped area of pure feldspar substance, enlarged 130 diameters.

FIG. 5. The same as fig. 3, enlarged 120 diameters.

FIG. 6. Portion of large spherulite, showing different forms of feldspar needles.

FIG. 7. Branching group of orthoclase needles occurring in the outer portion of the spherulite of fig. 6.



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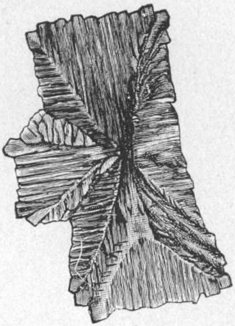

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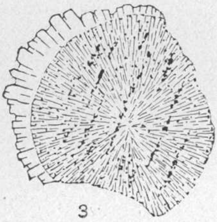

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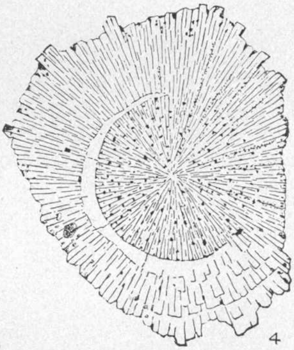

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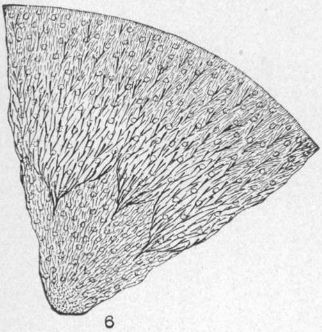

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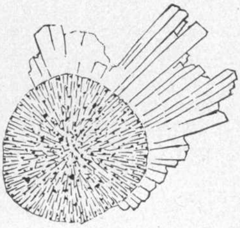


5

SECTIONS OF SPHERULITES FROM YELLOWSTONE NATIONAL PARK.

In certain cases the zone of clear feldspar does not occur on the margin of the spherulite, but forms a crescent-shaped transparent belt within it, as shown in fig. 4, Pl. VII [Pl. XXVI of this bulletin]. In ordinary light this belt appears to be a gaping, circular crack, though its definition is lost at one end. Between crossed nicols it is found to consist of pure feldspar, oriented in accord with the radiating prisms, and producing no disturbance of the dark cross which passes regularly through it. At the lower end, fig. 4, it is seen to be part of the same crystallization as the purer feldspar rays of that part of the spherulite; and in the upper part it differs from the rest of the spherulite simply by being free from the granulated or micropegmatitic structure. There can be no doubt that it is a part of the original crystallization of the spherulite, and that from some cause the free silica ceased to crystallize for a short space and then continued as in other portions of the spherulite. This is in harmony with the observation that the micropegmatitic structure and the other phases of crystallization in this part of the rock are irregularly scattered in patches, so that adjoining parts of adjacent spherulites are micropegmatitic, while other portions of them are free from this structure. Such crescent-shaped spaces in the spherulites of this rock have undoubtedly been produced at the time of the crystallization of the feldspar rays, by conditions which affected the quantity or distribution of the free silica or of the mineralizing agencies engaged in its crystallization.

In parts of the rock the small feathery spherulites bordering an area of tridymite do not terminate in well-defined feldspar prisms, but pass out into irregularly shaped feldspars and send out acicular rays of extreme delicacy. These transparent needles also lie in various directions in the tridymite area. They have apparently the same double refraction as orthoclase, and have the axis of greatest elasticity, $\mathfrak{a}$, parallel to their length. A transverse parting is slightly developed. Their mineralogical character can not be made out with any degree of satisfaction from the smallest needles, but they can be traced to stouter ones which are undoubtedly orthoclase; so that there would seem to be no question that the delicate acicular rays of these spherulites are needles of orthoclase elongated parallel to the clinoaxis. They are then the same as the stouter prismatic rays, but have probably developed an acicular form because of some slight difference in the conditions under which they crystallized.

The spaces between the spherulites already mentioned are in most instances occupied by tridymite in comparatively large crystals, often twinned and carrying numerous gas cavities. These patches may be completely filled with tridymite or may be but partially filled, there being open spaces between the crystals which cross one another in all directions, and in extreme cases the tridymite may simply coat the walls of a hollow cavity. In most instances the area is completely occupied, when the free silica is sometimes in the form of quartz. There are always other minerals present in variable amounts, including orthoclase and magnetite, with less regularly tourmaline, mica, and fayalite. The fayalite occurs in relatively large irregular individuals, with an opaque border, which at times entirely replaces the original mineral.

The tourmaline and mica occur in minute crystals about 0.025 ^{mm} long and 0.01 ^{mm} thick. They are abundant in places and lie scattered through the tridymite or quartz, and also in the margin of the bordering spherulites. They occur sometimes together, but usually one is present to the exclusion of the other. The tourmaline is recognized by its decided pleochroism, the strong absorption being across the prisms, $O > E$. Its color is brownish-green; colorless parallel to E. The double refraction is strong and negative. Transverse sections exhibit a uniaxial cross, and are bounded by six sides, alternately three short and three long. It also occurs in the tridymite coating the walls of the hollow cavities in some cases.

The mica is green and also yellowish brown to reddish. It forms stout tablets with six sides, and exhibits strong absorption, from colorless to almost opaque, which is of course in the opposite direction from that of the tourmaline, the axes of elasticity also in the long and narrow sections being reversed in the two minerals. The dark-green mica may be easily mistaken for the tourmaline.

The tourmaline and mica are idiomorphic and must have crystallized just before the outer portion of the small spherulites and the tridymite and quartz in which they lie. They are confined to the region of these interspherulitic spaces, and are not found scattered indiscriminately through the compactly spherulitic portion of the rock. Their period of crystallization is therefore later than that in which the small spherulites began to crystallize and earlier than the final crystallization of the residual magma or paste. Their separation from the magma was preceded by that of quartz and orthoclase, and was also followed by the same. Their crystallization in such a siliceous lava is abnormal, for they are locally abundant in very small spaces within the body of the rock, and not along a contact face of it. The crystallization of the tourmaline at least involves the presence of a small amount of boron and fluorine within the magma before its final solidification; but they were probably present in extremely small amounts and only locally.

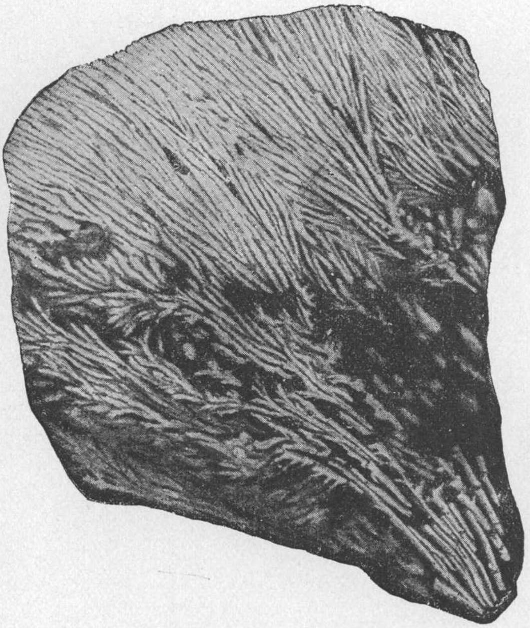
While the occurrence of the tourmaline, like that of the fayalite, may be referred to the category of "fumarole action," still this is only correct when the term is so defined as to include any mineralizing influence which heated vapors may have upon crystallization. It would thus include their primary action within fused magmas, as well as their secondary action on solidified ones. The effect of heated vapors which permeate the rocks in many places in the Yellowstone National Park is distinctly a destructive or metamorphosing process; and all such fumarole action is plainly secondary in the sense that it effects changes in the crystalline character of rocks already solidified. It would seem advisable, therefore, in order to avoid confusion, to use some other terms for the primary mineralizing influence of absorbed vapors upon the crystallization of molten magmas.

The second kind of spherulites occurring in this rock, which were described in the paper on Obsidian Cliff under the head of *porous spherulites* (p. 278), are distinguished by being composed of more or less distinct rays of feldspar, which are generally branched, and a cementing material of tridymite, with numerous hollow spaces or gas cavities. The branching feldspars may also lie in an isotropic base, which appears to be glass. The arborescent feldspar growth may form a complete sphere or only a plume-shaped growth, or it may even resemble the stem and branches of a shrub. The optical investigation of these feldspar rays shows them in some cases to consist of many small stout prisms of feldspar grown together with their longer axes parallel and forming long crooked rods in the direction of this axis.

In thin section these rods or rays are partly positive and partly negative—that is, the axis of elasticity, which is approximately parallel to their length, is sometimes less and sometimes greater than that at right angles to this direction. The prisms have a small extinction angle of variable size, and it is observed that the negative rays exhibit less double refraction than the positive ones and have a lower extinction angle. From these characters it is evident that the rays are prisms of orthoclase elongated parallel to the vertical axis *c*, and that the plane of the optic axes is normal to the plane of symmetry. In spherulites of this sort the positive and negative rays are generally uniformly mixed throughout the whole. Such a spherulite sometimes has an outer zone or border of compact, finely fibrous structure, which is negative and is the same growth as the small granophyric spherulites. Tridymite is scattered through these spherulites, besides small grains of magnetite, and sometimes a few grains of fayalite and a little mica.

In other cases the branching rays are all positive. This indicates that the feldspar prisms have the same development—that is, parallel to the axis *c*—but that the plane of the optic axes is in the plane of symmetry, which is frequently observed to be the case in prisms of orthoclase which have crystallized independently in the tridymite in other parts of the rock.

The distinctly arborescent growths of feldspar in which the long slender rays branch off from a stouter stalk is shown in the figure on Pl. VIII [Pl. XXVII of this bulletin]. The prisms become thinner and more crowded together as they grow



BRANCHING CRYSTALS OF ORTHOCLASE, MANEBACHER TWINS, FROM YELLOWSTONE NATIONAL PARK, × 43.

outward, and terminate in broad fronds like leaves. The stems are usually twinned throughout their length, as are also the fronds, which are sometimes found as isolated growths. These are twinned in the same manner, the composition plane dividing the crystal in two in the direction of its length. These twinned prisms of orthoclase are always negative, and the inclination to the twinning plane of the axis of greatest elasticity is about 7° or 8°. These characteristics could only be found in orthoclase prisms elongated parallel to the clinoaxis *a*, and twinned according to the Manebach law, which is the orientation already given for this form of feldspar in the article on Obsidian Cliff (p. 278).

In the large porous spherulites several forms of feldspar growths occur together. In one instance the center consists of an aggregation of partial spherulites of small size and positive character. This is surrounded by a narrow zone of cloudy material, but slightly doubly refracting, and with a positive character. Outside of this zone the porous portion of the spherulite begins. It is made up of nearly straight radiating fibers of feldspar, with weak double refraction, which are all positive. From points at various distances from the center of the whole spherulite, within these positive fibers, there start stouter fibers of feldspar with stronger double refraction and negative character. These branch out into radiating bunches, which unite to form the outer zone of the spherulite, where the fibers are partly negative and partly positive. In this outer zone it is observed, on closer inspection, that the negative feldspars form stems from which thinner positive feldspar fibers branch like the needles of a pine twig. These needles curve to a position parallel to the stem and to the radii of the sphere. All of the porous portion of the spherulite is thickly spotted with pellets of tridymite. The structure is very crudely represented by figs. 6 and 7 of Pl. VII [Pl. XXVI of this bulletin], the actual structure being extremely complex, formed as it is by innumerable delicate crystals. The first porous zone of weakly refracting rays of feldspar, all of which are positive, must be composed of prisms elongated in the direction of the vertical axis, *c*, with the plane of the optic axes in the plane of symmetry. The branching groups of strongly refracting feldspars, which are all negative, must be prisms parallel to the clinoaxis *a*; they are twinned according to the Manebach law. In the outer zone these latter prisms send out thinner ones in the direction of the vertical axis, *c*, which are positive. These thinner needles branch forward from both sides of the twinned stem; consequently the crystallization of the twinned prism must have advanced out from the angle 2 β made by the *c* axes of the twinned halves of the crystal.

The synchronous growth of crystals of the same mineral with two distinct habits is a natural consequence of crystallographic branching as distinguished from that due to the splitting or cracking of microlites.[1] Its occurrence in this rock indicates how slight may be the difference in the conditions under which either form of crystal is induced. This accords with the fact that we find no fixed order in which positive and negative spherulitic growths have been developed. In the rock of Obsidian Cliff they alternate with each other, sometimes one having started first and sometimes the other.

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[1] O. Lehman, Molekular Physik, Leipzig, 1888, p. 378.

The chemical composition of the lithoidite at Obsidian Cliff is shown by the following analysis, made by J. E. Whitfield:

Analysis of lithoidite from Obsidian Cliff, Yellowstone National Park.

	Per cent.
SiO_2	75.50
TiO_2	none
Al_2O_3	13.25
Fe_2O_3	1.02
FeO	.91
MnO	none
CaO	.90
MgO	.07
Li_2O	.06
Na_2O	4.76
K_2O	2.85
P_2O_5	none
SO_3	.32
H_2O	.41
Total	100.05

No. 63. LIPARITE.

(FROM PINTO PEAK, EUREKA COUNTY, NEVADA. DESCRIBED BY J. P. IDDINGS.)

The rhyolite of Pinto Peak is part of a large body of rhyolitic lava that has been poured out over a limestone country, and that is accompanied by breccia, tuff, and pumice of the same magma. It is mostly white, or light gray, and lithoidal, with abundant minute cavities, producing a rough fracture, and sometimes an earthy appearance. The rock is filled with phenocrysts of dark-colored quartz and colorless and white feldspars, besides minute crystals of biotite. In some cases minute red garnets may be seen with a pocket lens. The most conspicuous constituent is quartz, whose dark-colored substance is strongly contrasted with the white groundmass. The quartzes are cracked, and seldom exhibit crystallographic forms. Feldspar, though equally abundant, is less noticeable because of its color. It is brilliant and glassy, and is partly sanidine and partly plagioclase. Biotite occurs in distinct six-sided crystals.

In thin section the rock consists of a holocrystalline groundmass and porphyritic crystals and angular fragments. The groundmass exhibits flow-structure, which is expressed by streaks of semiopaque, faintly yellow material with no definite characteristics. The arrangement of the crystal particles presents no special connection with the flow-structure, except in some instances. The form of the grains in the groundmass is indefinite and allotriomorphic; their size varies from microscopic to submicroscopic proportions, so that their existence is inferred from their action on polarized light. The structure is then known as microcryptocrystalline.

A study of favorable spots shows the groundmass to consist of microscopic interpenetrating grains of quartz and feldspar, through which are scattered larger grains, about 0.06 ^{mm} in diameter, for the most part quartz; a portion is orthoclase and plagioclase. There are also minute crystals of biotite in some cases, and a small amount of light red garnet in irregularly shaped grains. The latter is quite uniformly distributed through the mass of the rock.

The phenocrysts of quartz occur in well-developed dihexahedrons, and in angular fragments; rarely as rounded grains. They are irregularly cracked and free from impurities, but sometimes contain bays of groundmass and a few colorless glass inclusions. Around the inclusion may sometimes be seen double-refraction phenomena, which have been produced by internal strain. This in some cases has caused small cracks that pass through the center of the dihexahedral glass inclusion and extend short distances into the quartz crystal along three planes corresponding to three planes of symmetry in the crystal. Occasionally there are fluid inclusions with moving bubbles.

The feldspar phenocrysts are sanidine, and also plagioclase in variable proportions. The substance of the feldspars is fresh and very free from impurities. Their forms are sometimes crystallographic, often angular and fragmental. The twinning of the feldspars is characteristic. Many of the sanidines are Carlsbad twins; the plagioclase exhibits polysynthetic twinning according to the albite law, and sometimes according to the pericline law. Zonal structure is rarely observed. Cleavage is frequently perfect, though often wanting; conchoidal fractures occur, and the resemblance to quartz is so strong that optical tests are necessary to distinguish them. The sanidine often exhibits a very small angle between the optic axes, and the plane of the optic axes is sometimes normal to the plane of symmetry and sometimes parallel to it.

The plagioclase feldspar is probably oligoclase, its substance is like that of sanidine, and the polysynthetic twins are also twinned according to the Carlsbad law. Gas cavities sometimes occur, but none of glass. Biotite occurs in small crystals, dark brown, with small optical angle. Zircon occurs sparingly. Magnetite is almost entirely absent; occasionally a minute crystal of it may be seen.[1]

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[1] For further description see Monograph XX, U. S. Geological Survey, Geology of the Eureka District, by Arnold Hague, pp. 237, 264, 374.

The chemical composition is given in the following analysis by Dr. Edward Hart:

Analysis of liparite from Pinto Peak, Nevada.

	Per cent.
SiO_2	73.91
TiO_2	....
Al_2O_3	15.29
Fe_2O_3	....
FeO	0.89
MnO	....
MgO	....
CaO	0.77
Na_2O	3.62
K_2O	4.79
P_2O_5	0.07
Ignition	1.19
Total	100.53

NO. 64. NEVADITE.

(FROM CHALK MOUNTAIN, EAGLE COUNTY, COLORADO. DESCRIBED BY WHITMAN CROSS.)

Geologic occurrence.—The nevadite of which No. 64 is a specimen forms a low mountain mass between the headwaters of the Arkansas, Eagle, and Tenmile rivers. The mountain lies on the continental divide, and has steep slopes with a cliff at the top on the south, east, and north, while cut into by stream branches on the west. The nearly level summit lies at an elevation of a little less than 12,000 feet on the eastern side of the mass. The mountain derives its name from the white color of the cliffs.

All about the mass, which is 2 miles in longest diameter, Carboniferous sandstones and conglomerates of the Weber formation are exposed, but the contacts with the nevadite are so much obscured by talus slopes that the relation of the sedimentary to the igneous rock can not be fully made out. From the structure of the nevadite it is inferred that the mass seen must have consolidated very near the surface. The body is interpreted as an irregular intrusive sheet cutting obliquely across the Carboniferous strata, and it is assumed that parts of the magma may have reached the surface and formed lava streams.

Definition.—The term nevadite is here applied, as defined by Hague and Iddings,[1] to a rhyolite "characterized by an abundance of porphyritic crystals embedded in a relatively small amount of groundmass."

General description.—This rock has many phenocrysts of sanidine, oligoclase, smoky quartz, and a few of biotite, embedded in a light-gray groundmass which a hand lens shows to be evenly granular and specked by numerous small biotite leaves and a dust of magnetite.

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[1] Am. Jour. Sci, 3d series, Vol. XXVII, 1884, p. 461.

Two somewhat different modifications are represented in the collection. One has large sanidine crystals, reaching a maximum length of 3^{cm}, which usually show a delicate satiny luster parallel to a steep orthodome, apparently $\frac{15}{2} P \bar{\infty}$, $(\overline{15}.0.2)$. In the other form of the rock the sanidines are smaller and clearer with faint luster, if any. Both varieties have numerous smoky quartz crystals, generally much fractured, and showing prismatic and pyramidal faces. Oligoclase is present in many small phenocrysts, and these are often included in the larger sanidine crystals. The mica is a very subordinate element of the rock.

The phenocrysts.—The especially noteworthy mineral of the rock is sanidine. Its crystals are fresh and glassy, usually developed as thick tablets parallel to the clinopinacoid, with prism and two or three orthodomes as the terminal planes. Carlsbad twinning is common. The delicate satiny luster referred to is very beautifully developed in many crystals. The luster is due to films of air between the thin plates of a very perfect parting which is not exactly like a cleavage. When actual separation of these plates has not occurred there is sometimes an exquisite blue color to be seen parallel to the steep orthodome. This color is most brilliant in the small sanidines of certain rhyolites, where no cleavage parallel to the dome in question can be detected.

The numerous small crystals of oligoclase in this nevadite are quantitatively much less than the sanidines. They are frequently included in the latter.

Quartz occurs very abundantly in more or less rounded or resorbed crystals. The material is very pure, free from inclusions of other minerals or of glass, and from penetrating arms of the groundmass. Gas pores of very minute size are numerous, and also fluid intrusions with relatively little fluid in them.

Biotite is sparingly developed in rudely hexagonal leaves, containing many included grains of magnetite.

The groundmass.—Quartz and feldspar in very even-grained mixture, with flakes of biotite, constitute the groundmass. Quartz is very often developed in double pyramids, leaving the feldspar to occur in irregular grains. But little triclinic feldspar can be detected. There are sometimes small gas pores between groundmass grains, and in some sections there appears to be a very small amount of clear amorphous substance in angular spaces between the quartz and feldspar particles of the groundmass. This is never sufficiently developed to form a basis, and while it seems to be residual glass its nature is not clearly determinable. It is identical in appearance and development with what has been determined as glass in the rhyolite of the Hohenburg, near Berkum on the Rhine.

Occasionally there are drusy cavities in this nevadite which contain many thin sanidine tablets and, rarely, a few stout crystals of quartz and topaz. This occurrence of topaz was the first to be described as primary in igneous rocks. Topaz is now known in lithophysal cavities of many rhyolites, and the development of these drusy cavities in the Chalk Mountain nevadite, with the occurrence of topaz in them, is one of the principal indications that the rock consolidated near the earth's surface.

Chemical composition.—A specimen of the finer-grained rock of Chalk Mountain was subjected to quantitative analysis by W. F. Hillebrand with the following result, under I. The clear sanidine phenocrysts have the composition given under II.

Analyses of nevadite and sanidine from Chalk Mountain, Colorado.

	I.	II.
	Per cent.	*Per cent.*
SiO_2	74.45	65.04
Al_2O_3	14.72	20.40
Fe_2O_3	none	
FeO	0.56	
MnO_2	0.28	
CaO	0.83	0.79
MgO	0.37	
K_2O	4.53	9.74
Na_2O	3.97	4.11
Li_2O	trace	
H_2O	0.66	.29
P_2O_5	0.01	
Total	100.38	100.37

Specific gravity of rock, 2.61 at 32° C

There probably should have been a very small amount of Fe_2O_3 found, but the rock analyzed was nearly free from magnetite, and contained little biotite. MnO_2 is present as a stain of pyrolusite in patches through the rock. It is clear that the rock has a large excess of silica as quartz and that much of the soda is present in the sanidine.

The following publications by the writer refer to the nevadite of Chalk Mountain:

Bull. U. S. Geol. Survey, No. 20, Contributions to the Mineralogy of the Rocky Mountains, pp. 75-80. On the luster exhibited by sanidine in certain rhyolites.

Ibid., pp. 81-82. An unusual occurrence of topaz.

Mon. U. S. Geol. Survey, Vol. XII, Geology and Mining Industry of Leadville, Colorado, by S. F. Emmons. In Appendix I, Petrography, pp. 345-349.

No. 65. METARHYOLITE.

(FROM UTLEY, GREEN LAKE COUNTY, WISCONSIN. DESCRIBED BY S. WEIDMAN.[1])

The Utley metarhyolite (quartz-keratophyre) is of pre-Cambrian age, probably Keweenawan, and occurs as a single knob in unconformable

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[1] Adapted from an article on the Utley metarhyolite: Bull. No. 3, Geol. and Nat. Hist. Survey of Wisconsin.

contact with lower Ordovician sandstone and limestone. It is intruded by a few small dikes of diabase of pre-Cambrian age.

The normal rock of this area has a dark—almost black—groundmass, in which are embedded numerous phenocrysts of feldspar and quartz. The rock is very compact and brittle, and breaks easily, with a conchoidal fracture.

The phenocrysts of feldspar, which are more numerous than those of quartz, are grayish white in the fresh specimens, but are somewhat reddish on the weathered surface, owing to alteration. They vary in size from 1^{mm} to 5^{mm} in diameter, and sometimes in certain coarse spots they attain a thickness of 8^{mm} and even 10^{mm}. These feldspar crystals are triclinic, as is indicated by their well-developed cleavage, the angle between the two most important cleavage faces being about 93° 32′′.

The quartz crystals, as seen in the hand specimen, have the characteristic limpid appearance, and usually possess good crystal forms, but are sometimes rounded. They vary in size and are approximately equidimensional with the feldspar phenocrysts with which they are associated.

The dark-colored groundmass is megascopically very dense and aphanitic and always breaks along curved planes. Thick masses of nodules or spheroids, produced by spheroidal parting, which phenomenon is brought out clearly on the weathered surface, form an interesting feature of this rhyolite outcrop. The spheroids vary in size from ½ inch to 1½ inches in diameter, and do not differ in composition or texture from the normal rock in which they occur. They have separated out as nodules by weathering or altering along the spheroidal partings. These partings are produced by contraction during the original cooling of the magma.

Under the crossed nicols of the microscope and with low power the feldspar crystals of thin sections of the rock always have a mottled appearance. With a higher power, this mottled appearance is seen to be due to a close intergrowth of two varieties of feldspar, producing what is termed a microperthitic feldspar or microperthite.[1] Besides this microperthite there are a few phenocrysts of polysynthetically twinned plagioclase, probably near the albite end of the series. There is a definite relation between this twinned plagioclase and the microperthite which will be referred to again.

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[1] The term *microperthite*, which is usually meant to include an intergrowth of orthoclase with albite or other acid plagioclase, is here extended and meant to include intergrowths within the plagioclase series as well.

The chemical composition of this feldspar, as determined by C. F. Tolman, is as follows:

Analysis of feldspar of the Utley metarhyolite.

	Per cent.
SiO_2	62.57
Al_2O_3	18.12
FeO	1.32
CaO	5.52
K_2O	5.11
Na_2O	7.20
Total	99.84

The microperthite is distinctly triclinic, as shown by its cleavage system. Its chemical composition and optical properties are such as to place it entirely within the plagioclase series, the intergrown plagioclase species ranging from albite to andesine.

The microperthite phenocrysts are usually composed of intergrowths of two varieties or species of feldspar. One species that is always present is albite, having an extinction angle of + 19° on the brachypinacoid (∞ P∞̆). Another species that is usually if not always present is a variety of oligoclase-andesine, having an extinction angle of from + 5° to 7° on the same face (∞ P ∞̆). In one case the microperthite proved to be albite and andesine, the latter having an extinction angle of − 3° on ∞ P∞̆.

The nature of the microperthite is that of a lamellar intergrowth of albite with a more basic plagioclase, each species tending to have a definite crystal form with vertical axes in a common direction. It has a regular and invariable arrangement of its component feldspars, unless, as in a few cases, it has been interfered with by excessive pressure. The appearance of the microperthite in a section cut parallel to the brachypinacoid (∞ P ∞̆) is shown in Fig. *B* of Pl. XXVIII.

The microperthite is wholly secondary—that is, its development by processes of metamorphism has been long subsequent to the original crystallization and solidification of the magma. This process of change in the upbuilding of the microperthite may be said to have been accomplished by three somewhat different, yet related, methods.

First, by outgrowths on older feldspar. Growth of this kind is shown in Fig. *A*, Pl. XXVIII, photographed in polarized light. The outer shell of microperthite is seen to inclose a twinned plagioclase of perfect crystal form. The outer boundary of the enlargement is somewhat irregular. The inner crystal contains fractures which do not extend into the microperthite. The outer zone of microperthite is fresh, while the inner core shows much decomposition. The relation of the microperthite to the twinned plagioclase, as seen in this photograph, shows that the latter was fractured and considerably altered before the formation of the rim of microperthite.

Second, by regeneration of older plagioclase. In this process the perthitic intergrowths of albite and oligoclase-andesine are products of the recrystallization of the older twinned plagioclase. This process begins along the outer boundaries and fractures of the older crystal and very probably takes place along the easy solution planes of the latter. The *c* axes of the perthitic growths are, except in a few cases, parallel to the *c* axes of the original crystal. This relation is shown in Fig. *B*, Pl. XXVIII. This process, to a small extent, has gone on in the crystal shown in the photograph Fig. *A*, Pl. XXVIII. In the lower left-hand part of the inner crystal core, above the dark line separating the original from the secondary feldspar, is a small area of perthite forming out of the older crystal. Numerous other cases could be cited[1] where the alteration of the twinned plagioclase to microperthite has been brought about. The unperthitized feldspar is always in an advanced stage of alteration, while the microperthite is always fresh.

Third, by new growth from the groundmass. This process has developed small irregular crystals. These irregular crystals of microperthite have a medial suture from which extend normally radiating fibers of microperthite.

These processes of change have very probably been aided by pressure. In some cases cross twinning after the pericline law has been induced in the original crystal by pressure. In such cases the later growth of perthite seems to follow along the composition faces of the pericline twins. When the latter phenomenon occurs, the laths of perthite have their longer direction almost normal to the *c* axis of the older crystal.

The quartz phenocrysts have a fairly perfect crystal form, but are sometimes rounded. They are often corroded and have embayments, and, like some of the feldspar crystals, show the effect of a moving magma by being cracked and broken, the dismembered parts being separated by films of groundmass. They often contain rounded and rhombic-shaped areas of included groundmass. Rhombic cleavage is developed in some of the crystals.

Biotite, although not apparent in the hand specimen, is seen to be rather abundant in the thin section. It occurs as minute, short, tabular crystals, to some extent scattered throughout the groundmass, but also seems to be congregated in little patches and in zones about the feldspar crystals, and in the fractures as vein material. It is probably wholly secondary.

Hornblende was once present in this rock, but has been completely altered. The fact that it was once present is indicated by angular areas having the typical outlines of basal sections of this mineral. The hornblende is replaced by other minerals, such as magnetite, calcite, epidote, biotite, sphene, apatite, garnet, and quartz. These minerals also occur scattered throughout the groundmass. Minute flakes of brown hornblende, of secondary origin, occur to some extent in the rock.

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[1] A more comprehensive discussion of the origin and nature of the microperthite is given in the paper cited on page 165.

EXPLANATION OF PLATE XXVIII.

SECTIONS OF METARHYOLITE.

Fig. *A*. Metarhyolite, Utley, Wisconsin; slide 4379, University of Wisconsin Collection: Secondary growth of microperthite about plagioclase. In polarized light, × 30. Twinned plagioclase core with crystal form, fractured and containing many secondary inclusions of biotite in the fractures, and what is probably sericite distributed through the plagioclase. The fractures and decomposition products are confined to the core. The outer rim is made up of short laths and wedges of feldspar lying in a parallel direction, giving a distinct difference in appearance to the ordinary twinned feldspar of the core. The secondary enlargement has been interfered with in its development by the small phenocryst above and to the right. In the lower left-hand corner of the older plagioclase crystal, above the boundary line of core and rim, is a patch of microperthite, which is similar to that of the rim. The inner patch is a product of the regeneration of the twinned plagioclase; the surrounding rim is a development from the groundmass. The position of the fractures and decomposition products within the plagioclase core establishes the earlier origin and advanced metamorphism of the plagioclase previous to the development of the microperthite.

Fig. *B*. Metarhyolite, Utley, Wisconsin; slide 3846, University of Wisconsin Collection: Phenocryst of the microperthite in polarized light, × 30. Section cut parallel to $\infty P \breve{\infty}$ on the *M* face, showing basal cleavage. A bisectrix nearly normal. The angle of extinction of dark part is from $+3^\circ$ to $+6^\circ$; of the light part about $+19^\circ$. The large amount of lime in the feldspar coupled with the lower angle of extinction of the dark part indicates that the latter is oligoclase with a composition of Ab_3An_1. The light part is albite. The microperthite is secondary, and the two varieties of feldspar are developed with their *c* axes parallel to the *c* axis of the original feldspar.

A

B

SECTIONS OF METARHYOLITE FROM UTLEY, WISCONSIN.

A. Secondary growth of microperthite about plagioclase; in polarized light, × 30.
B. Phenocryst of microperthite; in polarized light, ×30.

The groundmass is composed of microscopic grains of interlocked quartz and feldspar, intermingled with which are minute opaque specks and grains of iron oxide. To this iron oxide and other dark-colored microscopic minerals is due the blackish color of the groundmass as seen in the hand specimen. These small dark-colored minerals are arranged in sinuous lines and curve about the porphyritic crystals, producing the common fluxion texture characteristic of lava flows. There is also developed in some specimens a radial spherulitic texture of the groundmass, and in other specimens the mottled pœcilitic texture. The groundmass was once partly and probably wholly glassy, and is now devitrified. This devitrification has been accomplished, in great part at least, by secondary processes since the original solidification of the magma.

In the thin sections of the rock from the nodular or spheroidal beds occur abundant examples of perlitic parting in the groundmass. The perlitic parting assumes the shape of curved fractures sometimes approaching circles, but more often only parts of circles or of other curvilinear forms. From these minute curved cracks there extend, with their longer axes perpendicular to the parting, small crystals of feldspar or of feldspar and quartz, giving the appearance of a radial or spherulitic crystallization along the fracture. In the circular and curvilinear forms of perlitic parting, the radii of feldspar appear as zones surrounding an inner cryptocrystalline groundmass which is like that outside of the zone. This phenomenon is in close similarity to the larger structure of the spheroids of the hand specimens and indicates a common origin of the two structures. Throughout the area, as shown in both the hand specimen and thin sections, are numerous fractures that are filled with secondary quartz and feldspar. The vein material in the fracture of the feldspar is very often feldspar, while that in the groundmass and in the quartz crystals is usually quartz.

The chemical composition of the rock is as follows:

Analysis of metarhyolite from Utley, Wisconsin.

	Per cent.
SiO_2	73.09
Al_2O_3	13.43
Fe_2O_3 FeO	2.57
MnO	trace
CaO	2.29
MgO	1.03
Na_2O	3.85
K_2O	1.58
H_2O	.76
Total	98.60

Besides the constituents enumerated in the analysis, there are also present in the rock very small amounts of CO_2, ZrO_2, TiO_2, and P_2O_5, as indicated by the microscopic examination. The relatively large amount of lime and soda present explains the plagioclase composition of the microperthite. The proportionately large amount of soda would class this rock as a soda-quartz-porphyry or quartz-keratophyre. Applying the nomenclature of the more recent volcanic rocks to those of pre-Cambrian age, the Utley rock is in composition and texture a typical rhyolite, and in consideration of its altered condition may be called a metarhyolite.

No. 66. Granite.

(From Rocklin, Placer County, California. Described by Waldemar Lindgren.)

The granitic area of Rocklin forms an irregular rounded mass about 30 miles long and 20 miles wide, inclosed towards the north, east, and south by the auriferous slates of the Sierra Nevada. Westward it is bordered by the alluvial plains of the Sacramento Valley.

As a rule, the rock in this area contains only black mica and hornblende, sometimes, indeed, only hornblende together with quartz and feldspar, and is more closely allied to a diorite than to a granite. At Rocklin, which is a railroad station on the line of the Central Pacific, with an elevation of about 200 feet, the rock assumes a more granitic character and contains both black and white mica. It is somewhat finer grained than in other parts of the area and makes an excellent building stone. The extensive quarries at Rocklin supply a large proportion of the granite used for building purposes in San Francisco.

The rock is of light-gray color and of medium fine grain. Grayish quartz grains, white feldspars sometimes with striation on the cleavage planes, black or dark-brown biotite, and silvery muscovite in small scales may readily be distinguished by the naked eye.

Under the microscope the following primary constituents may be discerned: Magnetite, apatite, and zircon are the oldest minerals occurring as minute inclusions in the later consolidated grains; then come, in order of succession, biotite, muscovite, plagioclase, orthoclase, and quartz.

The quartz, being the last consolidated mineral, forms irregular grains, the outlines of which are determined by the older constituents, although there are indications that the consolidation of orthoclase and quartz in part went on simultaneously. It is clear and fresh, being, of course, much less subject to decomposition than the other constituents. It often shows notable undulous extinction. Fluid inclusions with moving bubbles are common, as usual, in the quartz of the granites. Small needles and foils of biotite and muscovite occasionally abound; while there is a little apatite in more or less slender prisms and small colorless crystals of zircon, recognizable by their strong double refraction.

The orthoclase occurs, as a rule, in clear, irregular grains, together with the quartz, between the more or less idiomorphic plagioclase crystals. More rarely it shows rough crystallographic outlines. Its period of consolidation is nearly identical with that of the quartz, and grains showing a micropegmatitic intergrowth of the two minerals are not uncommon.

Many orthoclase grains are filled with minute quartz grains, all extinguishing together. Undulous and zonal extinctions occur frequently. Fluid inclusions are not common. The orthoclase is less subject to decomposition than the plagoclase, to be described presently, but the alteration to white, fine, micaceous aggregates may often be observed, proceeding along the cleavage lines. As infiltrations from neighboring minerals chloritic aggregates and calcite may be noted.

The plagioclase is found to be more abundant than in a perfectly normal granite. In many cases there is considerably more plagioclase than orthoclase. The plagioclase is a very acid soda-lime feldspar, belonging to the series of the oligoclases; in only one instance was a grain of microcline noticed. No albite appears to be present. Twin striation narrow, not infrequently absent, or shown by very few polysynthetic lamellæ. Double refraction somewhat stronger than the orthoclase. Zonal structure exceedingly common. The plagioclase is, in contrast to the orthoclase, more or less idiomorphic, showing short prismatic or lathlike forms, without well defined terminal faces. Decomposition has, on the whole, made greater headway than in the orthoclase, and proceeds along the cleavage line and also sometimes concentrically in crystals with zonal structure. As it begins the crystals grow cloudy and milky, by reason of minute, irregular air, more seldom fluid, inclusions. Small scales of hematite and other indeterminable microlites are noted in the clouded mass. The final products of decomposition are fine aggregates of white mica, calcite, and, where a migration of magnesian solutions from adjoining minerals has taken place, single foils, and aggregates of chlorite and epidote.

The muscovite occurs in large and small straight foils, showing the usual characteristics of the mineral—strong double refraction, white color with notable absorption, etc. Idiomorphic foils of biotite may sometimes be noticed embedded in a larger foil of muscovite. The muscovite does not decompose readily.

The biotite is rather more abundant than the muscovite; it is from yellowish to greenish brown, has very strong absorption, and occurs as irregularly bordered straight foils. Inclusions are not abundant; apatite, magetite, and zircon are occasionally noted.

The biotite is decomposed to a considerable extent, the resulting minerals being a green chlorite and a yellowish-green pleochroic epidote. In a brown biotite foil green chloritic lamellæ are sometimes intercalated, showing the way in which a complete pseudomorph of chlorite after biotite may take place.

The chlorite is deep green, pleochroic, and shows the usual deep blue or purple colors of interference.

The structure of the rock is characterized as hypidiomorphic granular, in contrast to the structure designated as allotriomorphic granular. In the latter all of the constituents are irregular grains, while in the former one or more of them show crystallographic outlines. In this case the more or less lathlike oligoclase crystals, together with the micas, lie embedded in the clear, irregular grains of the orthoclase and quartz.

The chemical composition is shown by the appended analysis, made by W. H. Melville in the chemical laboratory of the United States Geological Survey:

Analysis of granite from Rocklin, Placer County, California.

	Per cent.
SiO_2	73
Al_2O_3	16.38
Fe_2O_3	none
FeO	.99
CaO	2.42
MgO	.48
K_2O	1.87
Na_2O	4.53
Ignition	.52
Total	100.19

From this and from a study of the thin section it is apparent that the rock has the composition of a normal granite, except that sodium is present in unusually large quantity and that a considerable part of the orthoclase is replaced by oligoclase.

NO. 67. BIOTITE-GRANITE.

(FROM PLATTE CANYON, JEFFERSON COUNTY, COLORADO. DESCRIBED BY E. B. MATHEWS.)

The granites from the Platte Canyon are but a portion of the large granitic area which extends along the whole length of the Colorado or Front Range. In the area described in the Pikes Peak folio of the United States Geologic Atlas a large portion of the district is occupied by a granitic complex which has been found to consist of several varieties of granites that can be grouped under four heads,[1] of which the Pikes Peak type is the most prominent. To this type belong the rocks of this series. The fresh unaltered granites are coarse grained aggre-

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[1] The granites of Pikes Peak, Colorado, by Edward B. Mathews: Bull. Geol. Soc. America, Vol. VI, 1894-95, pp. 471-473.

gates of quartz, perthitic feldspar, and biotite with an occasional fluorite megascopically developed. The microscope also reveals apatite, zircon, magnetite, rutile (?), hematite, limonite, and epidote.

The rocks are generally of a pinkish tone, which becomes more accentuated during incipient alteration and fades away when the rocks have undergone considerable metamorphism. The grain of the granite varies widely from a case in which the feldspar phenocrysts are 6 inches in length to the more normal grain in which the length of the feldspar individuals is not more than one-fourth of an inch. In the specimens belonging to this series the usual dimensions are one-half an inch for the feldspar and one-fourth to one-eighth of an inch for the quartz. The biotite areas are generally smaller than the quartz individuals, although sometimes they may be one-half an inch in width. The texture of the Pikes Peak type varies from an aggregate of minerals in which the feldspar is only slightly larger than the quartz to one in which the feldspar stands out in large imperfectly formed porphyritic crystals. The mass of the rock is composed of three or four mineral species, of which microcline is by far the most important.[1]

The quartz is present in large, irregularly rounded grains, which are distinctly outlined against the feldspathic and micaceous constituents. Toward the feldspars the quartz appears normally younger, although its contact with the larger porphyritic microcline sometimes indicates that the quartz had already consolidated before the formation of the phenocrysts. In thin sections the quartz is seen to occur either as primary individual grains, or in pegmatitic intergrowths with the feldspar, or as secondary grains filling the interstices and cracks which were formed subsequent to the consolidation of the rock. The largest fragments of the quartz may be one-fourth of an inch in diameter or the individual grains may scarcely be distinguished with the highest power of the microscope. Within the quartz are included numerous fluid and individualized interpositions. They are arranged in long bands or are disseminated irregularly throughout the host. Sometimes there are long hair-like inclusions whose mineral characteristics can not be specifically determined. These are the well-known "quartz needles," which have been considered by various authors as rutile, apatite, tourmaline, hornblende, or sillimanite. In a few instances their nature has been determined, but in the granites of this series the filaments are too fine to permit such specific determination.

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[1] A mechanical separation of 20 grams of the powered rock shows the constituents to be present in the following proportion by weight:

	Per cent.
Microcline	53.33
Quartz	33.41
Biotite	10.71
Oligoclase	2.55

Under the term "quartz" are included those fine filaments of albite which were separated from the microcline in the crushing, while in "biotite" are included all of those minerals which were not floated in a Thoulet solution when at its maximum density of 3.1.

Microcline constitutes more than one-half of the rock mass, and in all instances shows the characteristic microcline twinning. The color of this mineral is the principal source of the pink tone noticed in the rock specimens, and is usually due to the presence of minute hematite flakes evenly disseminated through the feldspar, or to iron staining along the cracks. The size of the feldspar individuals varies widely, but in the rocks of this collection it may be large or small, since the microcline usually occurs both in phenocrysts and as a constituent of the groundmass. The phenocrysts may occur in rudely automorphic crystals, showing poorly defined pinacoidal and prismatic faces, which give to the mineral a prismatic habit in which the elongation is parallel to the clino-axis. In the groundmass the feldspar individuals are small, somewhat larger than the quartz and without crystal form, occurring only as irregularly outlined grains or anhedrons.

The microcline of these rocks may show twinning in addition to that according to the albite law which produces the so-called microcline structure. Such twinning may be according to the Carlsbad law, in which the twinning plane is the orthopinaciod, or more commonly the twinning plane may be the basal pinacoid, according to the Manebach law. Throughout these potassium feldspars are numerous fine disks, lenses, or stringers of a plagioclastic feldspar, probably albite, in perthitic intergrowths with the host. These fine albite stringers occur in the basal pinacoid normal to the clinopinacoidal cleavage and on the clinopinacoid they show an inclination of about 73° in obtuse β; accordingly these albite lamellæ lie approximately parallel to a steep positive orthodome of the value of 8 $P\bar{\infty}$. In certain instances the albite occurs in small rounded disks, which oriented sections show are not cross sections of spindles, but of more or less spherical bodies.

Micropegmatitic intergrowths between the quartz and the feldspars are not common in these rocks, although they are sometimes present in minute branching or arborescent areas. A more extensive study of the rocks of the surrounding country shows that micropegmatite is not common in the granites of this class (Pikes Peak type), but when present is probably the result of alteration of the original constituents.

Oligoclase occurs in a few instances, but never constitutes any considerable portion of the rock mass. It is usually easily separated from the other constituents by the fine lamellæ twinned according to the albite law. The fineness of the lamellæ and the low extinction of one or two degrees clearly indicates the oligoclase nature. Within the microclines are also minute plagioclase disks which may or may not be twinned. These disks show the effect of marked alteration and are clouded by the alteration products. The altered disks are separated from the microcline host by a rim of clear feldspar which is in physical continuity with the inner core. At times the twinning of the inner core is continued in the rim either directly or alternately, as in the Roc Tourne twins described by Gustav Rose.[1]

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[1] Pogg. Ann., 1865.

The cause of the altered plagioclase with surrounding clear rims is not definitely known. The difference between the two parts may be the result of original differences of crystallization, the inclusion being more basic, more porous, or filled with interpositions; or the rim may be entirely secondary, a product of the alteration which the granites have undergone.

Biotite is the third in importance of the constituents of the granites, and is present either in fine shreds closely aggregated or in single, somewhat larger, individual flakes. This mica shows a deep-brown color, metallic luster, and a strong pleochroism. The absorption is very marked for the ray vibrating parallel to the basal cleavage where the plate becomes practically opaque; the ray vibrating at right angles to the cleavage is yellow—sometimes even straw-yellow. The plane of the optic axes apparently lies normal to the leading ray of the percussion figure, and is therefore of the first sort—anomite. This determination seems to be corroborated by the peculiar brown color, the small optic angle, and the brittleness of the perfectly fresh cleavage flakes.

Fluorite is present in many sections of this series where it occurs in small irregular grains, and rarely in well-defined crystals, which suggest either cubes or octahedrons. The mineral is specially characterized by a highly perfect octahedral cleavage, which is well developed in the larger areas, but is lacking in the minute crystals. The little anhedrons are clear, and may be colorless, purple, faintly pink, or green, and when the grains are colored the pigment is unevenly disseminated through them, and seems to be more intense about inclusions than in the clearer portions of the mineral. Between crossed nicols the areas show complete isotropism and no anomalous double refraction. The index of refraction of the fluorite in these rocks appears exceptionally high, even as high as that for garnets. The cause of the anomaly is not apparent, but that the mineral is fluorite, and is not a garnet, is shown by the fluorine content in the bulk analysis, where the fluorine sometimes reaches 1 per cent.

Zircon, apatite, and epidote are sometimes present in the sections. They are usually in minute, more or less prismatic crystals, colorless or faintly yellow, that may be distinguished by the low double refraction of the apatite, the high index, double refraction, and lack of cleavage of the zircon, and the irregularity of outline and cracked or shagreened upper surface of the epidote.

The order of crystallization of the minerals in the rocks seems to have been as follows: The magnetite when present formed first, and was immediately followed by the zircon and the apatite. Biotite formed somewhat later, including all of the minerals then existing in the magma. Probably the separation of the biotite was followed by the crystallization of a small amount of plagioclase and a much larger amount of microcline. The microcline of the groundmass is clearly older than the quartz, but in the larger phenocrysts of microcline the relative age of the quartz and feldspar is different, and it is very probable that the large phenocrysts of microcline succeeded the separation of the quartz and were the last of the original minerals to crystallize from the magma. The age relationships of the epidote and fluorite are unknown. The facts indicate that the epidote is a product of moderate alteration of the feldspar, while the fluorite is closely associated with the biotite or irregularly disseminated throughout the rock mass. When the former is associated with the biotite, the mica is clear and unaltered, and appears younger than the fluorite, and does not suggest that the fluorite is in anywise formed at the expense of a fluorine-bearing mica. On the other hand, the fluorite is not clearly a miarolitic filling, but appears instead to be one of the older constituents of the rock, perhaps of the same age as the apatite and zircon.

The granites from the Platte Canyon very often show evidences of alteration as the result of dynamic metamorphism. The extinction of the quartz becomes undulatory or mottled, and very frequently the quartz has been crushed into a mosaic in which individual fragments are drawn out in a common direction, producing the well-known "striefenquarz."

The feldspars have been deformed by a rounding of their angles and a drawing out or stretching of their material into long bands or flat ellipsoids. This deformation of the feldspars changes the well-formed phenocrysts into large lenses or eyes, so that the granite passes from a massive rock into a schistose augen-gneiss. Few, if any, new minerals are formed by the deformation of the original constituents which differ in specific character from the original minerals. The rocks when crushed show secondary quartz, microcline, and biotite, with rarely any other additional minerals, unless occasionally muscovite, which is formed through the bleaching of the biotite and the decomposition of the feldspars.

The granite under discussion is one relatively rich in silica, sodium, and fluorine, and poor in calcium, iron, and magnesium. The following analysis, by W. F. Hillebrand, is that of a granite from the upper slope of Pikes Peak, closely related to the granite of the Platte Canyon in structure, and in mineralogical and chemical composition.

Analysis of biotite-granite from Pikes Peak, Colorado.

	Per cent.
SiO_2	77.03
TiO_2	.13
Al_2O_3	12.00
Fe_2O_3	.76
FeO	.86
MnO	trace
CaO	.80
BaO	trace
MgO	.04
K_2O	4.92
Na_2O	3.21
Li_2O	str. trace
H_2O below 110° C	.14
H_2O above 110° C	.30
P_2O_5	trace
F	.36
CO_2	....
Total	100.55
Less O for F	.15
Total	100.40

The practical absence of phosphoric acid indicates that only a small proportion of the fluorine is needed for the apatite seen in the rocks, even though the apatite is a pure fluor-apatite. The remaining fluorine is sufficient to combine with most of the calcium and still be present in the biotite. The calcium occurring as a calcium-fluoride leaves little which may enter into the composition of the feldspar, and consequently the oligoclase must be very near the albite limit. The strong pleochroism and the deep color of the mica suggest that almost all of the iron is used up in the relatively slight development of biotite. The percentage of alumina indicates that much of this is in the feldspar, and that only a small amount is in combination in the mica. After all of the elements are satisfied the silica is considerably in excess, as is evident from the abundance of quartz.

From the texture and from the mineralogical and chemical composition it is evident that the granite from the Platte Canyon is a somewhat porphyritic example of granitite (Rosenbusch), biotite-granite (Zirkel), and true granite (Michel Lévy).

NO. 68. HORNBLENDE-BEARING BIOTITE-GRANITE.

(FROM FOX ISLAND, MAINE. DESCRIBED BY J. P. IDDINGS.)

This rock occurs on Vinal Haven Island, one of the Fox Islands, in Penobscot Bay, Maine, where, according to George O. Smith,[1] it occupies a roughly circular area nearly 5 miles in diameter.

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[1] See Geological Map of the Fox Islands, Pl. II of the Geology of the Fox Islands, Maine, by George Otis Smith, 1896.

It is medium grained and light colored, and consists of pinkish-gray feldspars and about an equal amount of brownish quartz, besides a smaller quantity of black ferromagnesian minerals, mostly biotite, but partly hornblende. These dark-colored constituents are in much smaller crystals than the feldspars, which are partly idiomorphic.

In thin section the rock is hypidiomorphic-granular in texture, each of the constituent minerals possessing some degree of idiomorphism.

The large feldspars are for the most part microcline, with very delicate double polysynthetic twinning—that is, lamellar twinning—according to the albite and the pericline laws. There is also pronounced microperthitic intergrowth of lime-soda feldspar, whose index of refraction relative to that of microcline, and whose low angles of extinction indicate that it is oligoclase. Some of the large feldspars are orthoclase, and exhibit no polysynthetic twinning, while oligoclase also occurs in small partially idomorphic crystals.

In some microclines the twinned lamellæ are curved and crowded in certain spots, and since the quartz crystals exhibit a strain phenomenon of an analogous kind, it is probable that the microcline twinning is, in part at least, due to mechanical strains undergone by the rock.

In places the feldspar is clouded with minute dots which have a lower index of refraction than the feldspar and are white by incident light. Their exact nature can not be determined, but they are probably in part cavities, in part kaolin. In some cases very small flakes of colorless mica or muscovite are present. The same form of alteration occurs in the orthoclase. In the perthitic microcline the intergrown lime-soda-feldspar is more altered than the microcline. A zonal structure is present in some of the microclines, but is more noticeable in the oligoclase.

Quartz exhibits the characters commonly found in the quartz in granite. It is allotriomorphic, and was probably the last mineral crystallized, though its crystallization undoubtedly began while the feldspars were being formed, and its growth was contemporaneous with that of the latter part of the feldspar. Some crystals exhibit irregular double refraction when examined between crossed nicols, showing that different parts of one crystal have different optical orientation. In some cases the portions are very minute, and appear like indistinct lamination in two directions, as in microcline.

Fluid inclusions are abundant and very small. They sometimes occur in planes which occasionally traverse several quartz crystals in one direction, proving that they are of secondary origin—that is, they were formed subsequent to the crystallization of the quartz and consequently of the rock as a whole.

Biotite occurs in irregularly shaped plates. Its color is brown, with strong absorption for rays vibrating at right angles to $\mathfrak{a}$—that is, for rays vibrating nearly in the plane of cleavage. It is light brown for rays vibrating parallel to $\mathfrak{a}$ or at right angles to the plane of cleavage.

It incloses numerous crystals of colorless apatite and fewer of zircon and of magnetite. Hornblende is in smaller amount than biotite, and occurs in irregular anhedrons. Its color is brownish green, with the usual pleochroism from greenish brown for rays vibrating parallel to $\mathfrak{a}$, the direction of vibration of the fastest traveling ray, to dark green parallel to $\mathfrak{b}$, and $\mathfrak{c}$, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. Biotite and hornblende are sometimes grown together. They are both quite fresh and unaltered.

Sphene occurs in yellowish anhedrons, associated with the hornblende. Zircon is comparatively abundant in small, short prisms, but apatite is much more abundant in small, stout crystals, which are colorless. These are readily distinguished from one another by their optical properties. Sphene, having very high index of refraction and comparatively low double refraction, stands out prominently in the section, has a roughened or shadowed surface, and is not brilliant between crossed nicols. Zircon, having both high refraction and high double refraction, but being in very small crystals, exhibits strongly marked outlines, has a strong relief, and is brilliant between crossed nicols; while apatite, with strong index of refraction and very low double refraction, exhibits strong relief, and very low color between crossed nicols.

Iron oxide is sparingly present, presumably as magnetite. There are also small microscopic crystals, which are brown to opaque, whose character is indeterminable.

No. 69. Biotite-bearing Hornblende-granite.

(From Cape Ann, Massachusetts. Described by J. P. Iddings.)

This rock occurs along the coast of Massachusetts north of Boston, where, in the vicinity of Gloucester, it forms the greater portion of Cape Ann, and is extensively quarried for building purposes. Its texture is medium grained and its color light greenish gray. It is composed of greenish-gray feldspar, with somewhat pearly cleavage surfaces, about an equal amount of brownish quartz, and a much smaller amount of black mineral, which is mostly hornblende. In thin section the texture is hypidiomorphic granular, the quartzes and feldspars having very irregular outlines and an arrangement suggestive of that in gneisses. The anhedrons of quartz have jagged outlines and interlock with one another, a number of quartzes being clustered together in places. They exhibit irregular double refraction, and are often separated into patches having slightly different optical orientation (feldererscheinungen), which is the result of mechanical strain. There are numerous minute fluid inclusions, and, rarely, inclosed crystals of zircon.

The feldspars are microcline and lime-soda feldspar, which is mostly oligoclase. These are intimately intergrown, as in perthite. The microcline appears to form disconnected pieces, while oligoclase constitutes a continuous intersecting web between the pieces of microcline. The microcline looks as though a large crystal had been cracked and had been pulled apart, the interstices being filled with oligoclase; but all parts of the microcline have one orientation. The microcline is clouded with minute particles, indicating partial alteration, while the substance of the oligoclase is perfectly fresh and pure. These large complex feldspars are usually twinned after the Carlsbad law.

In some cases there appears to be an intergrowth of two large feldspars in much the same manner as in the graphic intergrowth of quartz and orthoclase—that is, the crystals cross one another at oblique angles.

Between the large crystals of feldspar is a border of smaller feldspars which are mostly lime-soda-feldspar, and probably oligoclase. With these small crystals are also small crystals of hornblende and biotite. These minerals occur in the same manner adjacent to large anhedrons of quartz.

The hornblende is brownish green with the usual pleochroism. The shape of its anhedrons is very irregular against both feldspar and quartz. Its outline is quite jagged, with minute projections of hornblende and of biotite, which have grown in the margin of the anhedron. It carries inclusions of biotite, magnetite, and zircon; besides larger ones of monoclinic pyroxene, probably malacolite. These have irregular outlines and various orientations. Hornblende also occurs in clusters of minute anhedrons, together with similar anhedrons of biotite, inclosed in feldspar and quartz.

The biotite is brown with the usual absorption and other optical properties. Its shape is quite irregular. Its anhedrons are not so large as those of the hornblende. It appears to have crystallized at the same time as the last part of the hornblende, being inclosed in the margins of crystals of the latter mineral.

Monoclinic pyroxene is quite subordinate in amount, and occurs with irregular outlines, both as inclosures in feldspar and in hornblende. Its color in thin section is pale green, and its double refraction is fairly high. It is probably malacolite.

Zircon occurs in comparatively numerous, minute, short crystals. Apatite is not abundant. It is in small stout prisms, and also in needle-like forms. It sometimes contains rounded isotropic inclusions resembling glass. Iron oxide, which is apparently magnetite, occurs sparingly, and is generally associated in clusters or in juxtaposition with crystals of the ferromagnesian minerals.

Allanite is present in occasional anhedrons, irregularly shaped. Its color is chestnut-brown with strong pleochroism.

The microstructure of the rock is that of a metamorphic granite or of a metamorphosed granite rather than that of a purely igneous or of an unaltered eruptive granite.

The quarries at Cape Ann are said to be next to the largest in the United States, and have furnished stone for many of the buildings in the cities of the Atlantic coast. For further information on the geology of that region see paper by N. S. Shaler on The Geology of Cape Ann, Massachusetts, in the Ninth Annual Report of the United States Geological Survey, pp. 535 to 611.

SYENITE TRACHYTE FAMILY.

No. 70. TRACHYTE.

(FROM GAME RIDGE, NEAR ROSITA, CUSTER COUNTY, COLORADO. DESCRIBED BY WHITMAN CROSS.)

Occurrence.—This trachyte forms a surface mass resting on andesitic tuff and breccia. The rock was the last one in the sequence of seven distinct eruptions from the Rosita volcano, the others having been andesites of various types, dacite, and rhyolite. Game Ridge is a small mass of trachyte preserved from erosion by faulting, and none of the rock now remaining exhibits the outer structural features of lava streams. Dikes of the same rock seen near by show the channels through which the magma came to the surface.

Description.—The rock is light-gray, porphyritic, its most conspicuous constituent being sanidine in characteristic glassy crystals, much fissured and occurring both in tabular and stout prismatic forms, with a diameter rarely exceeding 1 centimeter. These crystals are not very abundant, the greater part of this feldspar being in the gray groundmass. There are many small phenocrysts of oligoclase, but they are not prominent, as a rule; while the less numerous leaves of biotite, the only dark silicate of the rock, are naturally distinct.

Microscopical study shows the predominant gray groundmass to consist chiefly of orthoclase feldspar in short prisms, which, by their more or less distinct parallel arrangement and the curving of the bands about the phenocrysts, cause a fluidal structure. This case illustrates very well that groundmass structure commonly called "trachytic," which is due to the predominance of feldspar and its tendency to crystalize in these microlitic prisms.

The groundmass contains a small amount of quartz, usually found in little, elongated clusters of clear grains, or as matrix for the orthoclase staves. This latter association is rarely so developed as to become truly a poikilitic structure. The amount of quartz is not enough to invalidate the reference of the rock to the trachytes. Oligoclase appears in a very few minute crystals in the groundmass, and a scanty magnetite dust is found in the fresh rock. Ordinarily, there is much limonite in flakes all through the rock, often giving it a pinkish tinge.

Apatite and zircon are very sparingly present, in characteristic form.

The sanidine crystals are very free from included mineral grains except in the outer zone, where they contain groundmass particles, this zone being an added growth of the groundmass period. The plagioclase of the rock is oligoclase, as shown by the extinction very near to the albitic twinning line in all sections normal to the twinning plane.

Biotite is developed only in thin brown leaves which seldom have regular outline and are often very ragged, with magnetite grains included in the border zone or lying adjacent to the leaf, as though resulting from recrystallization after partial resorption of the mica.

Chemical composition.—The freshest available specimen of this trachyte has the composition shown in the following analysis, by L. G. Eakins:

Analysis of trachyte from Rosita, Colorado.

	Per cent.
SiO_2	66.03
Al_2O_3	18.49
Fe_2O_3	2.18
FeO	.22
MnO	trace
CaO	.96
MgO	.39
K_2O	5.86
Na_2O	5.22
H_2O	.85
P_2O_5	.01
CO_2	trace
Total	100.24
Sp. gr. at 29° C	2.59

This composition confirms the deductions from mineral constitution that the rock is nearly a typical trachyte. Silica is higher than is normal, but not sufficient to place the rock with the rhyolites. The high percentage of alkalies and the low amount of lime makes it clear that alkali feldspar must make up the great bulk of the rock and that the oligoclase can not play a prominent rôle in the groundmass. The percentages of the iron oxides and of magnesia correspond to the small amount of biotite and the change of magnetite into limonite.

Relationship of the rock.—The Game Ridge trachyte is to be compared especially with the well-known occurrences of the Siebengebirge, on the Rhine, near Bonn. Many of the rocks of this classic locality are very similar to that of Game Ridge in structure, in relative importance of the oligoclase, and in general chemical composition. The similarity with the trachyte of the Drachenfels, as represented in specimens accessible to the writer, is particularly striking, especially in regard to amount and development of quartz and biotite and the structure of the groundmass.

Literature.—On some Eruptive Rocks from Custer County, Colorado, by Whitman Cross, Proceedings Colorado Scientific Society, Vol. III, pp. 233–237; Geology of Silver Cliff and the Rosita Hills, Colorado, by Whitman Cross, Seventeenth Annual Report, United States Geological Survey, Part II, 1896, pp. 263–403.

No. 71. SYENITE.

(FROM CUSTER COUNTY, COLORADO, TWO AND ONE-THIRD MILES A LITTLE EAST OF NORTH FROM SILVER CLIFF, AND ONE-HALF MILE SOUTHEAST OF THE BULL DOMINGO MINE. DESCRIBED BY WHITMAN CROSS.)

Geological occurrence and distribution.—This syenite occurs in narrow dikes cutting gneiss or granite in a considerable area of mountainous country lying south of the lower portion of the Grand Canyon of the Arkansas River. The dikes have been specially observed in the vicinity of Silver Cliff, but they occur all through the area drained by Grape Creek, which enters the Arkansas near the mouth of the Royal Gorge, and they probably have a still wider distribution in the Wet Mountain Range, to which the district mentioned is adjacent.

These dikes, standing in nearly vertical position, cut in all directions across the strike of the steeply upturned gneisses and schists. They are therefore younger than the folding of those gneisses, but are older than the great erosion which took place probably in very early Tertiary times and produced surface features not far different from those of the present day. The dikes are certainly pre-Tertiary, but their age can not be more closely fixed from known evidence. Associated with the syenite dikes through this area are numerous narrow dikes of normal diabase.

The dikes of syenite vary in width from an observed maximum of about 20 feet down to 1 foot or less. They are continuous for distances of more than a mile, in several instances, and their courses are often nearly straight. The dike from which the specimens of this series came was traced for more than a mile, and varies in width from 2 to 12 feet. At the point where the specimens were obtained it was about 6 feet wide and had been penetrated by a prospect shaft, furnishing the material for collection.

Description.—The field habit of this syenite is very characteristic. The rock has commonly a strong brick-red color, sometimes with a yellowish shade. This causes outcrops of dikes to be distinguishable often at considerable distances as red lines, contrasting with the darker shades of the ordinary gneiss.

The predominant mineral of the rock is red feldspar, developed in thin tablets, and by the prevailing arrangement of these tablets approximately parallel to the dike walls a schistose structure is produced. There is commonly a dense contact zone of three or four inches in width which grades off rapidly into the average coarser rock of the dike. These contact bands are usually of darker color, and have a dense porphyritic structure.

On macroscopical examination this rock is seen to be chiefly made up of red feldspar tablets, with a subordinate amount of dark material in fine particles, among which hornblende, mica, and epidote can here and there be recognized. The feldspar tablets are like rounded disks, seldom more than 2^{mm} across. The schistose structure arising from their rudely parallel arrangement is clearly illustrated by most of the specimens collected, for the rock fractures easily in the direction of this lamination and with difficulty across it. Occasionally larger crystals of orthoclase are developed, and, more rarely, long thin prisms of hornblende.

A microscopical study shows the primary constituents of this syenite to be orthoclase, plagioclase, amphibole, biotite, and apatite, while epidote, chlorite, calcite, and a ferritic pigment are secondary products.

The coloring pigment of the rock occurs in extremely small particles, which are doubtless limonite, and which impregnate nearly all of the feldspar crystals as a dense cloud. A large number of the feldspar tablets are plagioclase, as the common polysynthetic twin structure clearly demonstrates, but the pigment often so obscures the optical action that the angles of extinction can not be closely measured. In the zone normal to the twinning plane the extinction angle is always small, however, and it is probable that oligoclase is the only member of the soda-line series here developed. Orthoclase certainly predominates over plagioclase.

The feldspar tablets are never perfectly idiomorphic. The crystallization of the oligoclase individuals was finished before that of orthoclase, and the predominant pinacoidal plane was then sharply defined, while the prismatic and terminal planes seem to have been irregular. The orthoclase tablets are throughout of irregular outline, owing to their mutual interference in the last stages of growth.

The schistose structure referred to was doubtless produced by a movement of the magma during crystallization. By this means the feldspar tablets, which were already large, were forced into a position approximately parallel to the dike walls. Many angular spaces were naturally left, into which the free amphibole prisms and biotite leaves were crowded. The biotite, however, seems to have continued its growth after this movement, for it often fills the irregular spaces completely, and has the usual hexagonal form only when included by some feldspar individual. Some of the angular spaces between clouded feldspars are filled by a colorless mineral, and in polarized light this matter almost invariably resolves into segments having the optical orientations of the adjoining feldspar individuals. The material seems in all cases to be orthoclase, and the ferritic pigment never penetrates into substance of this origin. Epidote and calcite also occur as fillings of these angular spaces, without their proper crystal form. Epidote occasionally appears as a direct decomposition product of biotite, but does not replace feldspar substance except in the more decomposed rocks.

From the facts above given it seems probable that upon final solidification of the syenitic magma there remained some angular spaces between crystals, which were unoccupied by any mineral substance, and that epidote and calcite were deposited from solutions in these cavities at a later period. Whether the clear feldspar substance also belongs to this later period, or to the final stage of crystallization of the magma, is not fully evident. Porous structure originating in this way is known as the miarolitic structure.

The amphibole of this syenite is unlike any of the common varieties of the group. The prisms are seldom of perfect form in the coarser-grained parts of dikes, and are usually made up in part of a brown and in part of a dark-blue amphibole, the brown forming the inner portion and being surrounded in very irregular manner by the blue variety. The relations of the two are such as to indicate that the blue is merely the later part of the crystal, and grounds for considering it as a paramorphic product from the brown have not been observed. In other dikes of this syenite the brown and the blue varieties have been found in separate crystals. The blue amphibole has the following pleochroism: $\mathfrak{a}$ = strong yellowish-brown, $\mathfrak{b}$ = dark blue; $\mathfrak{c}$ = dark greenish-blue; $c \wedge \mathfrak{c}$ = about 10°, absorption strong, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. The brown amphibole has dark chestnut-brown color parallel to $\mathfrak{b}$ and $\mathfrak{c}$, and a lighter shade parallel to $\mathfrak{a}$. Extinction 12° or more, not closely determinable. The brown variety also has a strong absorption parallel to $\mathfrak{b}$ and $\mathfrak{c}$. Both varieties seem to have the optical orientation of normal hornblende, and the blue is, therefore, unlike glaucophane on the one hand, and arfvedsonite or riebeckite on the other, while the brown is apparently related to barkevicite.

The biotite is almost uniaxial, and has $\mathfrak{b} + \mathfrak{c}$ = dark green, and $\mathfrak{a}$ = yellow-brown. Absorption is very strong.

Allanite was observed in a few small characteristic prisms in the contact zone of one of the narrower syenite dikes.

Chemical composition.—The freshest specimen of the average rock that could be obtained was analyzed by L. G. Eakins, with the following result:

Analysis of syenite from near Silver Cliff, Colorado.

	Per cent.
SiO_2	59.78
Al_2O_3	16.86
Fe_2O_3	3.08
FeO	3.72
MnO	.14
CaO	2.96
MgO	.69
K_2O	5.01
Na_2O	5.39
H_2O	1.58
CO_2	.75
Total	99.96
Sp. gr. at 30° C., 2.689.	

The rock analyzed contains calcite and epidote as secondary minerals, developed chiefly as fillings of the miarolitic cavities. The feldspar is not visibly decomposed, and it seems more likely that the lime of the epidote and calcite was brought in by solutions than that it was derived from the adjacent feldspars. The character of the feldspar contents of the rock analyzed must in any case be calculated after deducting lime for calcite, epidote, and amphibole. Nearly one-third of the lime is required for the carbonic acid to form calcite, and at least another third may be deducted for the other two minerals. This leaves one-third as belonging to an oligoclase.

If one-third of the lime belongs to oligoclase of the composition Ab_5An_1, and the remainder of the soda is referred with the potash to a pure alkali feldspar, the amount of the oligoclase in the rock will be nearly 30 per cent and of the alkali feldspar nearly 50 per cent. The percentage of oligoclase will rise rapidly with an increased amount of lime introduced into the calculation, but it is quite probable that the oligoclase molecule is richer in lime than has been assumed, and this would reduce the percentage of possible oligoclase in the rock.

Literature.—This syenite was first described in an article entitled, On some Eruptive Rocks from Custer County, Colorado, by Whitman Cross, published in Proceedings Colorado Scientific Society, Vol. III, 1887, pp. 237–240. It is further discussed, with details of geological relations, in a report on the Geology of Silver Cliff and the Rosita Hills, Colorado, by Whitman Cross, in Seventeenth Annual Report United States Geological Survey, Part II, 1896, pp. 263–403.

NEPHELITE-LEUCITE ROCKS.

No. 72. ORENDITE.

(FROM LEUCITE HILLS, SWEETWATER COUNTY, WYOMING. DESCRIBED BY WHITMAN CROSS.)

Introductory.—When the project of gathering the rocks of this collection was first considered, the only leucite-bearing rock known in the United States was that occurring in the Leucite Hills, discovered by S. F. Emmons, and described by Prof. F. Zirkel.[1] It was decided to collect that rock for the Educational Series. When the material was brought in and subjected to microscopical study, it was found that the greater part was not like that described by Zirkel, but contained both sanidine and leucite. The rock collected has, however, been described under the name of orendite,[2] being made the type of the kind of volcanic rock rich in leucite and sanidine with diopside and magnesian mica as other essentials. The rock is still representative of the types especially characterized by leucite.

Megascopical description.—The orendite of this collection has a dull reddish-brown color and is quite vesicular, the pores being small and

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[1] Reports of the Fortieth Parallel Survey, Vol. VII, Microscopical Petrography, 1876, p. 259.

[2] Igneous rocks of the Leucite Hills and Pilot Butte, Wyoming, by Whitman Cross: Am. Jour. Sci., 4th series, Vol. IV, 1897, pp. 123–126.

irregular in shape, with divergent smooth-walled arms. The vesicles are usually much less than 1^{cm} in size, but vary considerably in different specimens. On examination with a hand lens the walls of these cavities may, in most specimens, be seen to be coated with a network of very pale yellowish needles of a peculiar amphibole, which will be described below. Hyaline opal, in clear globular droplike forms, is not uncommon in the pores. A dull white indistinctly crystalline substance of undetermined character is also often present.

The only distinct megascopic constituent of the rock mass is a reddish-brown mica, found by chemical analysis to be phlogopite, occurring in hexagonal leaves only 3 or 4^{mm} broad at most, and sinking to microscopic dimensions. The general color tone of the rock is due to this mica.

In some specimens are occasional dull grains of orthoclase, which are corroded and belong to foreign rocks found in larger inclusions in many places throughout the mass.

Microscopical description.—Microscopical study shows the rock under discussion to consist of leucite and sanidine in slightly predominant amount as compared with the ferromagnesian silicates, phlogopite, amphibole, and diopside. Apatite is unusually abundant and a few much-resorbed flakes of brown biotite may commonly be found in each section. Needles of a yellow mineral, rutile (?), are present in minute quantities, but magnetite, ilmenite, or pyrite have not been found.

In quantitative development leucite and sanidine vary considerably; now the one, now the other, seeming to predominate. Of the darker silicates phlogopite is the most important, while diopside varies with leucite, and amphibole with sanidine.

Leucite occurs in this rock in a multitude of minute rounded grains, between 0.01^{mm} and 0.05^{mm} in diameter. Some of them have the common icositetrahedral form, with a zone of minute inclusions, but more of the grains are anhedral. All are perfectly isotropic. In every way these leucite crystals and grains are identical in habit with those of the sanidine-free rock.

The sanidine of orendite occurs in stout, square prisms, of rough outline and seldom exceeding 1^{mm} in length. The prismatic axis is a, as shown by the optical orientation. It is always the axis $\mathfrak{a}$ of elasticity which lies near the prismatic axis, and the maximum observed angle of extinction is 10°. Rude dome and prism faces terminate the crystals as a rule. Twinning after the Carlsbad law is not uncommon.

The reddish-brown mica appears in thin sections to have a very weak pleochroism, varying only from a pale salmon-pink to pale yellow. Sections normal to the cleavage often reveal a polysynthetic basal twinning, which is made evident through the perceptible angle between the axis, $\mathfrak{a}$, of elasticity and the crystallographic axis, c. This reaches 3° or 4°. Thin basal sections, not twinned, when examined in convergent, polarized light show a negative bisectrix and an unusually large optic angle. The leaves are usually of hexagonal form, and they are fresh and free from inclusions except rare ones of glass and still rarer yellowish needles, most probably of rutile.

The mica of this rock was isolated and analyzed by W. F. Hillebrand with the result given below, which shows it to have the composition of phlogopite, a species of mica not before identified as an original constituent of igneous rocks. The observed physical properties agree with this determination.

Analysis of phlogopite of orendite from Wyoming.

	Per cent.
SiO_2	42.56
TiO_2	2.09
Al_2O_3	12.18
Cr_2O_3	.73
Fe_2O_3	2.73
FeO	.90
CaO	.20
BaO	1.00
MgO	22.40
K_2O	10.70
Na_2O	.44
H_2O	2.35
P_2O_5	.06
F	2.46
Total	100.80
Less O for F	1.03
Total	99.77

Diopside occurs in small prisms, pale green or colorless, which sink to microlitic needles not easily determinable. In some of the other rocks of the region this mineral is developed in somewhat larger prisms, and W. F. Hillebrand has isolated and analyzed it, showing it to be an entirely normal diopside.

Analysis of diopside of orendite from Wyoming.

	Per cent.
SiO_2	50.86
TiO_2 P_2O_5	3.03
Al_2O_3	none
Fe_2O_3	1.19
FeO	1.82
MnO	.03
CaO	23.32
MgO	17.42
K_2O	.42
Na_2O	.76
H_2O	.31
Total	99.16
Sp. gr. at 20° C. 3.29.	

The amphibole of this rock is a very unusual one in its optical characters, and its determination as a member of this group depends largely on the strongly marked cleavage parallel to a prism whose angles measure about 124° and 56°, together with the general habit of the mineral. It occurs in rudely prismatic individuals, between the sanidine and leucite grains, producing structures soon to be described. Occasionally it has nearly regular crystal form with prism and pinacoid as in amphibole, and a termination apparently made up of pyramid and dome faces. Refraction and double refraction are of about the strength of actinolitic amphibole. Extinction is parallel to c, as far as has been ascertained. $\mathfrak{a} = a$ is pale yellow, $\mathfrak{b} = b$ is red, $\mathfrak{c} = c$ is bright yellow. The reddish tone is similar to that of hypersthene, and all colors increase rapidly in intensity with increasing thickness of the sections. Absorption, $\mathfrak{b} > \mathfrak{c} > \mathfrak{a}$.

The association of minerals in orendite leads to several interesting microstructures. Phlogopite appears to have formed first, and it is almost free from inclusions. Leucite and sanidine are as a rule developed in separate patches or areas, the former in swarms of minute round grains, the latter in aggregates of a few irregular prisms seldom exceeding 1^{mm} in length. Diopside is developed mainly in minute needles and microlites, a large share of which are included quite irregularly in the sanidines, producing a certain micropœcilitic structure. The remainder of the diopside occurs between other larger mineral grains.

The amphibole seems one of the latest crystallizations of the rock, and varies in development. In the angular spaces between the sanidines the yellowish amphibole occurs exactly as does augite in ophitic diabase, acting as an oriented cement for several sanidine crystals. In the leucitic areas the same amphibole appears in stout prisms inclosing numerous leucites, just as ægirine holds the nephelines in many phonolites. In this manner another form of the micropœcilitic structure is produced. It also occurs in very minute needles in many of the vesicles.

In occasional spots and adjacent to the pores of the rock the minerals are less intimately intergrown. Leucite is sometimes found inclosed in sanidine, but frequently the separation as described is very sharp. There are thus in this orendite two kinds of micropœcilitic structures, a curious separation of the analogous silicates, leucite and sanidine, ophitic structure, and through the prominence of phlogopite leaves a porphyritic structure.

Chemical composition.—Two analyses of orendite have been made by W. F. Hillebrand, which are given below. Analysis I is of the rock from Fifteen Mile Spring, on the eastern edge of the Leucite Hills, the locality from which all the specimens of the educational collection were obtained. Analysis II is of a very similar rock from North Table Butte, in the northern part of the Leucite Hills.

Analyses of orendite from Leucite Hills, Wyoming.

	I.	II.
	Per cent.	*Per cent.*
SiO_2	54.08	54.17
TiO_2	2.08	2.67
ZrO_2	....	.22
Al_2O_3	9.49	10.16
Cr_2O_3	.07	.05
Fe_2O_3	3.19	3.34
FeO	1.03	.65
MnO	.05	.06
CaO	3.55	4.19
SrO	.20	.18
BaO	.67	.59
MgO	6.74	6.62
K_2O	11.76	11.91
Na_2O	1.39	1.21
Li_2O	trace	trace
H_2O below 110° C	.79	.52
H_2O above 110° C	2.71	1.01
P_2O_5	1.35	1.59
SO_3	.29	.16
Cl	.04	.06
F	.49	.36
CO_2	....	.49
Total	99.97	100.21
Less O for F	.21	.17
Total	99.76	100.04

The rocks are remarkable for the large number of rare elements contained in them in determinable quantities. ZrO_2 was not tested for in the first analysis. It does not belong in the mineral zircon, as that can not be identified in thin sections, and it seems most probable that the peculiar amphibole is allied to certain silicates which may be classed with the pyroxenes, in having TiO_2 and ZrO_2 replace a part of the SiO_2. Cr_2O_3 and most of the F belong in phlogopite, together with a large part of the BaO. SO_3 represents some mineral easily soluble in weak acids, probably noselite, which may be indistinguishable from leucite in thin sections. Both the mica and the pyroxene contain TiO_2, but the rare yellow needles occasionally seen may be rutile.

As regards the commoner rock constituents, the predominance of potash in orendite causes characteristic minerals contrasting with those of the corresponding soda-rich rock, phonolite. Leucite is developed in place of nepheline. A potash-bearing mica appears instead of ægirine and arfvedsonite, which are common in phonolite. The pyroxene of orendite is almost a pure lime-magnesia mineral, and soda is prevented from entering into plagioclase.

Occurrence and relationships.—The rock now under discussion occurs in lava flows of Tertiary age. In the same flows a part of the magma has crystallized free from sanidine, but with leucite, diopside, and phlogopite of the same development observed in orendite. This rock, the one originally described by Zirkel, has the same bulk chemical composition as orendite. Since leucite contains less silica than sanidine, there is of necessity an excess of this acid radical in the pure leucite rock, apparently in the form of an obscure glassy base. This rock has been called "wyomingite" in the cited paper on the rocks of the Leucite Hills.

At Pilot Butte, west of the Leucite Hills, occurs a rock rich in diopside, phlogopite, and perofskite, with a glassy base which the analysis of the rock shows must have nearly the composition of leucite. The name "madupite" has been proposed for this type.

Orendite belongs in the group called leucite-trachyte by Zirkel, and leucite-phonolite by Rosenbusch. A special name has been proposed in the belief that both the compound terms above mentioned are objectionable, and that it is appropriate and desirable to have a distinctive name for the leucite-sanidine rocks corresponding to phonolite.

No. 73. PHONOLITE.

(FROM BLACK HILLS, SOUTH DAKOTA. DESCRIBED BY WHITMAN CROSS.)

Megascopical description.—This rock has a dense aphanitic texture except for a few small sanidine tablets. Its general color is a dull brownish green, mottled by numerous dark bluish-green spots of indistinct sheaf-like form. These dark spots are due to the bundles of ægirine needles. A peculiar greasy or semivitreous luster is produced by the reflections from the multitude of minute faces of nepheline or sanidine grains forming the mass of the rock.

Microscopical description.—The principal constituents of this phonolite are nepheline, sanidine, and ægirine, with a characteristic accompaniment of noselite and sodalite. Nepheline is very distinctly developed in short prisms causing the hexagonal or nearly square outlines seen in thin sections. The average diameter of these nepheline crystals is about 0.1^{mm} and their length less than 0.2^{mm}. In this development the nephelines lie in a fine-grained mass consisting chiefly of sanidine scales and tablets, which overlap so much that very thin sections and high powers of the microscope are necessary clearly to resolve the mass into its elements.

To a subordinate degree in the sections examined the sanidine is developed in more elongated staves and needles, and these are commonly arranged in nearly parallel position, producing an apparent fluidal structure. It is noticeable that in these portions of the rock nepheline is developed in much smaller crystals than elsewhere.

Ægirine is the mineral causing the dark spots of the rock. It occurs in bundles or sheaves of minute needles which in the central zone seem more or less of a common orientation or are united practically into one crystal which feathers out at each end. Owing to the great numbers of included nepheline or sanidine grains, even in the most massive part of these bundles, the thin sections rarely show the actual existing continuity of the ægirine substance. Where the latter is most massive the abundant inclusions of other minerals produce a typical micropœcilitic structure. The optical characters of this ægirine are entirely normal. Its pleochroism is strong, as follows: $\mathfrak{a}$ = pure green; $\mathfrak{b}$ = olive green; $\mathfrak{c}$ = yellowish green. $\mathfrak{a}$ lies very near the prismatic axis. No considerable angle of extinction was observed, so that ægirine-augite is not developed in this rock.

Scattered through the rock in amount greatly subordinate to nepheline, but still an important constituent, is a mineral of the regular system characterized by a cloud of dark, dusty interpositions. While this substance is apt to be decomposed, it has the characters often found in noselite as occurring in phonolites. Its rudely irregular crystals are somewhat larger than the nephelines and may reach 1^{mm} in diameter. From the chemical analysis, which shows both sulphuric acid and chlorine in the rock, it is to be inferred that sodalite is a companion of noselite here as in many other phonolites, but no means of distinguishing the two have been found in this case.

In almost every section of this phonolite may be found small areas of clear, colorless, isotropic substance in angular spaces between well-defined crystals of other minerals. It is thought probable that this isotropic substance is analcite, through analogy with the occurrence of that mineral in the very similar phonolites of the Cripple Creek region in Colorado.

Other minerals occur in this rock only in minute traces. There are occasional specks of magnetite and possibly of pyrite. The titanic and zirconic acids shown by analysis are most probably contained in a mineral occurring sporadically in a manner much like the ægirine; that is, in irregular particles in residual spaces or inclosing minute grains of nepheline or feldspar. This mineral is almost colorless, of high single and double refraction, with no or very slight pleochroism and apparent parallel extinction. It resembles a mineral observed, but not positively identified, in the Cripple Creek phonolites, though there the association with låvenite led to the supposition that it was to be referred to that species or to some allied complex silico-titanate with zirconic acid also present.

Chemical composition.—In the subjoined table of analyses, Column I represents the composition of this phonolite as analyzed by W. F. Hillebrand; II, an analysis by Pirsson of phonolite from the Devils Tower, near the Black Hills;[1] III, analysis by Hillebrand of a phonolite from Miter Peak near Cripple Creek, Colorado;[2] IV, analysis by vom Rath of a typical German phonolite from Zittau, Saxony.[3]

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[1] Phonolitic rocks from the Black Hills: Am. Jour. Sci. 3d series, Vol. XLVII, 1894, p. 341.

[2] General geology of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey, Part II, p. 39.

[3] Quoted by Zirkel, Lehrbuch der Petrographie, 2d ed., p. 446.

Analyses of phonolite from various localities.

	I.	II.	III.	IV.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
SiO_2	57.86	58.98	61.08	59.17
ZrO_2	.15	.20	....	....
TiO_2	.22	.24	.18	....
Al_2O_3	20.26	20.54	18.71	19.74
Fe_2O_3	2.35	1.65	1.91	3.39
FeO	.39	.48	.63	....
MnO	.21	.26	trace	....
CaO	.89	.67	1.58	.92
SrO	.04	none	....	....
BaO	.09	none	.05	....
MgO	.04	.11	.08	.15
K_2O	5.19	5.31	4.63	6.45
Na_2O	9.47	9.95	8.68	8.88
Li_2O	trace	trace	....	....
$H_2O - 110° C$	.21	.19	*a* 2.21	*a* 1.18
$H_2O + 110° C$	2.40	.97	....	....
P_2O_5	.03	.04	....	....
SO_3	.06	.20	trace	....
Cl	.08	.28	.12	....
F	(?)	....	....	....
CO_2	none	none	....	....
S	.03	....	....	....
Total	99.97	100.07	99.86	99.88

a, total water.

The analysis shows the phonolite of this collection to be quite typical, and very closely related to the rock so abundant in the Cripple Creek district of Colorado. It was ascertained that the Cripple Creek phonolites contained from 35 to 40 per cent of nepheline, and it is evident that there must be about the same amount in this rock. Sanidine probably constitutes at least 40 per cent of the rock, leaving about 20 per cent for ægirine, noselite, sodalite, and the accessory minerals.

The presence of zirconic acid in determinable amount without discernible zircon crystals, and the similar amount of titanic acid, seem to indicate the presence of some one or more of the rare minerals containing these acid radicals, such as låvenite, which have been noted of recent years in eleolite-syenite or phonolite.

Literature.—The first phonolite to be discovered in the United States was found at Black Butte in the Black Hills, and was described by J. H. Caswell.[1] In 1894, L. V. Pirsson described the rock of Devils Tower, near the Black Hills, as a phonolite and gave an analysis of the same which has been reproduced in the above table. It is known that there are many other occurrences of phonolite in and near

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[1] Report on the Geology and Resources of the Black Hills of Dakota, by Henry Newton and Walter P. Jenney, 1880, p. 492.

the Black Hills, but no systematic examination of their occurrence and relationships has been made.

NO. 74. PULASKITE (ELEOLITE-HORNBLENDE-SYENITE).

(FROM LITTLE ROCK, ARKANSAS. DESCRIBED BY J. P. IDDINGS.)

This rock is the so-called "blue granite" of Arkansas, which has been studied and fully described by J. F. Williams,[1] from whose report the following has been extracted.

The rock is an intrusive body occurring in a wide, dike-like mass, whose eruption took place about the close of the Cretaceous period, and which forms the main ridges of the Fourche Mountain region. It is a bluish-gray, crystalline rock, in some parts dark in others light colored. It has a peculiar semi-porphyritic appearance when viewed megascopically. The feldspar phenocrysts are conspicuous on account of their size and their highly perfect cleavage-planes and the light reflected from them. They appear to be crudely tabular parallel to the clinopinacoid (010), and give a trachytoidal texture to the rock. The crystals are not sharply defined, since they interlock with the smaller crystals of the groundmass. The groundmass is subordinate to the feldspar phenocrysts, is phanerocrystalline, but dubiodiagnostic, consisting of whitish, gray, and dark-colored grains. Occasionally small plates of mica and crystals of dark amphibole or pyroxene are recognizable. The greater portion, however, is feldspathic.

The texture of the rock varies throughout the body from granitic porphyritic to hypidiomorphic granular. The following minerals are usually found in every specimen of the rock, but are present in variable quantities. Especially among the dark-colored minerals is this noticeable, since in many cases one of them predominates to the almost complete exclusion of the others. The minerals are orthoclase (cryptoperthite), hornblende (arfvedsonite), augite (diopside), biotite, eleolite, sodalite (rare), titanite, apatite.

Orthoclase is by far the most important mineral in the rock. It appears usually in two forms as the result of two distinct periods of crystallization. The crystals belonging to the first are the phenocrysts, from 10 to 30^{mm} in length. They often show an idiomorphic form, although this is frequently impaired by the juxtaposition and mutual penetration of the smaller crystals of the second period of crystallization. Where crystal faces have been recognized they are $0P$ (001), $\infty P \breve{\infty}$ (010), and ∞P (110). Some crystals are twinned according to the Manebach law, others according to the Carlsbad. In one instance both kinds of twinning were observed in one crystal. The feldspar phenocrysts are impellucid as a result of more or less advanced kaolinization.

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[1] J. F. Williams, The igneous rocks of Arkansas: Ann. Rept. Geol. Survey Arkansas, Vol. II, 1890, pp. 39–71; Little Rock, 1891.

The angle between the two cleavage planes is nearly 90°. Some crystals exhibit delicate microcline twinning which, taken in connection with the chemical composition, indicate soda-microcline. In some crystals there is a microscopic intergrowth with another feldspar showing albite twinning and extinction angles of oligoclase. The feldspar corresponds to Brögger's kryptoperthite. Some of the feldspars exhibit no polysynthetic twinning. Some contain minute cavities elongated so as to appear like needles. These are generally in parallel groups, either perpendicular to the cleavage planes or parallel to them. A few larger cavities appear to contain fluid with a gas bubble. There are also inclusions of the ferromagnesian minerals with apatite and magnetite, besides more numerous grains of eleolite, irregularly shaped, and sometimes with hexagonal outline. Less frequently there are colorless isotropic inclusions with lower refraction than feldspar, which are probably sodalite.

The chemical analysis of the feldspar is as follows:

Analysis of feldspar of pulaskite from Little Rock, Arkansas.

	Per cent.
SiO_2	66.95
Al_2O_3	17.87
Fe_2O_3	0.90
CaO	0.52
MgO	0.24
K_2O	7.82
Na_2O	5.20
Ignition	0.30
Total	99.80

There is an excess of silica not accounted for. No quartz has been observed in the rock, and no individual crystals of lime-soda feldspar. The small feldspars constituting the groundmass have the same characters as the large ones. The greater part of the rock is orthoclastic feldspar. The ferromagnesian minerals are generally very small, and are monoclinic pyroxene, amphibole, and biotite. The monoclinic pyroxene is pale green in thin section, without pleochroism. Its form is irregular, and it is generally surrounded more or less completely by greenish-brown hornblende. In some parts of the rock the margin has a decided green color, probably ægirite, the principal portion of the pyroxene being diopside or malacolite. The green margin shows an increase in the amount of sodium taken up from the magma toward the end of the crystallization of the pyroxene. The cleavage is that common in pyroxene; and the ordinary twinning parallel to the orthopinacoid (100) is present in some crystals. Among the inclusions noted are apatite, magnetite, titanite, biotite, and irregularly distributed gas-pores.

The amphibole when seen in thin section is rich chestnut brown in some cases and greenish brown or dark green in others. When idiomorphic it is bounded by the faces $\infty P\,(110)$, $\infty P\bar{\infty}\,(100)$, $\infty P\breve{\infty}\,(010)$, and OP (001) and some orthodome $(m0\bar{1})$ has also been observed. Amphibole cleavage is well developed.

The pleochroism in some cases is as follows:

$\mathfrak{b}$ = reddish brown; $\mathfrak{a}$ = light yellowish brown; $\mathfrak{c}$ = dark reddish brown; the absorption being $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. In other cases the pleochroism is: $\mathfrak{b}$ = deep bluish green; $\mathfrak{a}$ = brownish yellow; $\mathfrak{c}$ = yellowish green; the absorption being $\mathfrak{b} > \mathfrak{c} > \mathfrak{a}$. A dark green edge, or border, surrounds many of the brown crystals. Some of the brown crystals are completely free from such a border, but it almost always appears about the greenish ones.

It is probable that these amphiboles belong to the arfvedsonite group, but no chemical tests have been attempted in proof of this supposition. Inclusions are similar to those contained in the pyroxene.

The biotite is reddish-brown in thin section, with fairly strong pleochroism from yellow to reddish brown. It forms plates parallel to the basal plane, which are idiomorphic in some cases and irregularly outlined in others. It carries inclusions of magnetite, sphene, apatite, and zircon. It often surrounds comparatively large crystals of magnetite, sphene, and apatite. Sometimes it is on the outside of the pyroxene and amphibole, and sometimes it is inclosed by hornblende and pyroxene. Its crystallization appears to have begun before that of hornblende. But in general the pyroxene appears to be older than the hornblende, and the biotite continued its growth to the end of the series of ferromagnesian minerals.[1]

Eleolite or nephelite occurs in variable quantities. In some parts of the rock it is quite insignificant, while in other parts it is an important constituent. It occurs in allotriomorphic anhedrons, often occupying spaces between large feldspars or forming irregularly shaped inclusions within them. It is colorless, with a higher refraction than the feldspar, and is sometimes more or less altered to analcite. Eleolite is nearly free from inclusions, but contains a few needles of apatite and occasionally slender crystals of ægirite.

Sodalite is found in some parts of the rock. It is generally filled with dust-like inclusions, but more often is altered to indeterminable decomposition products. The sodalite crystals are about half a millimeter in diameter.

Sphene is the most important of the subordinate minerals. It forms light to dark yellow idiomorphic crystals, some of which are 1.5^{mm} in length. In thin section the crystals exhibit sharp outlines and a rough-looking surface, and the mineral appears to have been the earliest to crystallize.

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[1] This is not the order stated by Professor Williams, but appears to be that shown by the sections of specimens collected for the Educational Series. J. P. I.

Apatite is quite abundant in crystals, sometimes 2^{mm} long. The larger crystals are comparatively short and stout, the smaller ones being slender prisms, occasionally very thin and hair-like. In most cases colorless, some of the crystals are dusted and contain rod-like inclusions. Magnetite occurs sparingly in small anhedrons. Fluorite has been observed in some varieties of the rock; also minute crystals of ægirite, which appear to be of secondary origin.

According to Williams there is no zircon present. But certain minute crystals with high refraction and double refraction occur in the thin sections from specimens in the educational series, which appear to be zircon. They may be easily confused with sphene.

Williams points out the resemblance between pulaskite and the laurvikite of Norway, described by Brögger. The two rocks resemble one another mineralogically and chemically, but differ somewhat in texture. Laurvikite is coarser grained.

NO. 75. THERALITE.

(FROM GORDONS BUTTE, CRAZY MOUNTAINS, MEAGHER COUNTY, MONTANA. DESCRIBED BY J. E. WOLFF.)

The Crazy Mountains, from the borders of which specimens 75 and 76 were collected, constitute an outlying range situated a few miles east of the main mass of the Rocky Mountains in Montana and near the boundary between the great eastern plains and the mountains. The Yellowstone River flows around the southern end of the range and the Musselshell, a branch of the Missouri, bounds it on the north.

The mountains are composed of strata of Cretaceo-Tertiary age, lying for the most part nearly flat or at low angles, through which many kinds of eruptive rocks have been intruded as stocks, laccoliths, sheets, or dikes. Among these eruptive rocks certain peculiar dark basaltic rocks are found which occur generally near the periphery of the range, the center of which is formed of masses of dioritic rocks.

These basaltic rocks are coarsely crystalline when they occur in thick sheets or laccoliths, but fine grained and porphyritic when occurring in thin sheets or dikes, where the conditions of quicker cooling have been effective. They are characterized chemically by a low per cent of silica and high per cents of the alkalies and of lime, magnesia, and iron, together with exceptional amounts of barium and strontium, as will be seen in the accompanying analyses. Mineralogically they are peculiar in the combination of augite, nephelite, a mineral of the sodalite group, and a feldspar which is chemically a potassium feldspar with barium and some sodium, calcium, and strontium. In the original descriptions of the rocks this feldspar was determined as in part ordinary sanidine, in part a soda-lime feldspar, and the rocks were therefore made the types of a plutonic rock characterized by the mineral combination nephelite, soda-lime feldspar, and named theralite by Professor Rosenbusch. The feldspar appears to be, strictly speaking, neither ordinary sanidine nor soda-lime feldspar, and hence for classificatory purposes the weight should be put on the chemical composition and the presence of nephelite and feldspar.

Specimen 75 is from Gordons Butte, an outstanding hill on the northwestern side of the range, which is oval in outline, with a diameter of 2½ miles. The base of the butte is formed by sandstones, shales, and limestones, which lie nearly flat but dip gently in toward the center. Above these and toward the base, frequently interlaminated with the sedimentary rocks, is a great intrusive sheet of theralite which is nearly 600 feet in total thickness. The original cover of shale has been worn off and only little patches of loose, baked shale can be found. The great laccolith of eruptive rock has very perfect vertical prismatic structure or jointing, the columns of which lean gently inward, corresponding to the position of the contacts which conform to the dip of the containing strata. A great line of cliffs, nearly circular in outline, forms the outside edge of the summit, which in the interior is a basin with gently sloping sides. The specimens were gathered from the northwest base of the cliffs and represent the coarsest variety of theralite found in the range. They come from the center of the mass, where the crystallization was coarsest.

Description of the specimen (*hand specimen*).—The prisms of augite are the most striking characteristic. They have a roughly parallel arrangement, caused by the motion of the rock as it flowed parallel to the bounding country rock. The light-green border of ægirite can be occasionally noticed. Large brown plates of biotite and occasional clear yellow grains of titanite are visible. The nephelite and feldspar make up the colorless part. The former is recognized by its yellowish-gray color and somewhat greasy luster, while the feldspar is white, with distinct glassy luster on the cleavage surfaces. In other places in this same laccolith the feldspar contains little crystals of haüynite and nephelite distributed through it, and this causes a luster mottling or pœcilitic structure on the cleavage surfaces. In the variety represented here this character is obscure.

In the thin section the augite is seen in stout prisms with both pinacoids developed and rarely terminal planes. It is pale green in color, passing into a deeper green toward the periphery, owing to mixture of the ægirite molecule, which often results in a border of deep-green ægirite in parallel orientation to the augite. The ægirite also occurs independently in radiating prisms. The augite incloses crystals of apatite and magnetite, and is often touched by plates of biotite, which may be oriented with the basal cleavage parallel to the augite prism.

The biotite plates contain apatite, magnetite, and rarely augite. Their rounded outline and occasional embayment by the later-formed minerals shows that they have been subjected to resorptive action. Small serpentinized grains of olivine inclosed in the biotite are uncommon in this occurrence, although found at other localities (see description of specimen No. 76).

The feldspar occurs in large, irregular areas, which can be recognized as such by their clear, transparent look and polarization tint, bluish white of the lower order. The two cleavages show distinctly only in very thin sections or near the edge, where the strain of grinding has developed it. It incloses little prisms of nephelite and rarely in this occurrence square or hexagonal sections of haüynite crystals, although this mineral is abundant in other parts of the same rock mass.

The nephelite appears also in large prismatic masses which have an imperfect crystal outline; the two cleavages, prismatic and basal, are well developed, giving generally two rectangular cleavages of which the prismatic is best developed. It polarizes with almost the same tint as the feldspar, extinguishes parallel to the cleavages when both show, and basal sections are isotropic and give an indistinct cross in converging light. The nephelite is in places fresh, but generally more or less filled with decomposition products; some of these with bright polarizing tints and slightly yellow color (which is distinct in the hand specimen) are probably cancrinite, the rest zeolites, which give an aggregate fibrous appearance.

The feldspar in this rock has generally the optical properties of sanidine, with the plane of the optic axes 5° from the base, small angle of the optic axes, and the axis of greatest elasticity an acute bisectrix. Its chemical composition has, however, already been mentioned; the specific gravity seems to vary from 2.63 to 2.57.

The order of crystallization is evidently first the apatite, magnetite, and olivine (since they are inclosed in the biotite and augite); then the augite and biotite; then the nephelite, and lastly the feldspar. The formation of the ægirite at the close of the augite period and its occurrence as the periphery of augite crystals, suggests a caustic action of the magma which impregnated the forming or already formed augite with the ægirite material. The chemical analysis of the theralite from Gordon's Butte is given with that of the specimen from Alabaugh Creek, on page 197.

NO. 76. PORPHYRITIC THERALITE.

(FROM MOUTH OF ALABAUGH CREEK, CRAZY MOUNTAINS, MEAGHER COUNTY, MONTANA. DESCRIBED BY J. E. WOLFF.)

Specimen 76 is from a sheet or bedded dike from Alabaugh Creek at the north end of the mountains. The structure and mineralogical composition are different from 75, although they represent the same rock.

Description of the specimen (*hand specimen*).—A grayish-black rock containing long slender prisms of augite with octagonal outline, hexagonal plates of biotite and grains of olivine, which have a yellow core and rusty red exterior. The groundmass is seen to glitter with little flakes of biotite, and small augite prisms can be detected in it. The augite crystals have a rough parallel arrangement due to the flowing of the rock.

In the thin section the augite phenocrysts have the same pale-green color and ægirite border as in 75, but the latter is much less marked. In addition to apatite and magnetite, they are honeycombed with inclusions of the residual magma, which is generally individualized to nephelite or feldspar. Sometimes the groundmass has pushed into the augite in little bays which may contain biotite. The biotite is in distinct hexagonal plates inclosing apatite, magnetite, and olivine; it has been corroded by the caustic action of the magma, which has produced the rounded forms sometimes seen. This biotite has a very marked obliquity of extinction to the cleavage. The olivine is in rounded grains touched or even surrounded by the biotite; between the two minerals there is a deep brown zone (iddingsite) which seems to grade into the biotite. The olivine incloses apatite, which occurs also independently in quite large crystals.

The groundmass contains augite, biotite, magnetite, apatite, olivine, a mineral of the sodalite group in deep blue crystals with square or hexagonal outline (due to the fact that they are sections of the rhombic dodecahedron), and isotropic character. The colorless part of the groundmass is threefold; there are long colorless laths of feldspar, sometimes in Carlsbad twins, which optically correspond to sanidine (in other occurrences of this rock they may be anorthoclase); between these is a fibrous substance, often in prismatic aggregates, which is the zeolitized nephelite; and lastly clear glassy areas, which are nearly or quite isotropic, show traces of cubic cleavage and are analcite.

It will be seen on careful study that there are two forms of feldspar in the groundmass, one occurring in slender crystals, the other in larger irregular grains which seem to have formed later; there is probably a chemical difference in these two forms corresponding to the different habit and period; whether one be sanidine and the other anorthoclase is not apparent.

The distinction between the phenocrysts (crystals of the first generation) and the same minerals in the groundmass is not very sharp, but the relations between the feldspar and nephelite are different from those in the other specimen, for here the nephelite is later than the prismatic feldspar, although perhaps contemporaneous with the other. We see that the olivine followed the apatite and magnetite and preceded the biotite.

The following two analyses represent the chemical composition of the coarse and porphyritic theralite. No. 1, coarse theralite from Gordon's Butte, was made by W. F. Hillebrand in the laboratory of the United States Geological Survey, at Washington, and Nos. 2 and 3 by E. A. Schneider, in the same laboratory. Analysis No. 2 is of specimen No. 75, and No. 3 of specimen No. 76.

Analyses of theralite from Crazy Mountains, Montana.

	1.	2.	3.
	Per cent.	*Per cent.*	*Per cent.*
SiO_2	44.65	44.31	47.67
TiO_2	.95	(*b*)	(*b*)
Al_2O_3	13.87	17.20	18.22
Fe_2O_3	6.06	4.64	3.65
FeO	2.94	3.73	3.85
MnO	.17	.10	.28
CaO	9.57	10.40	8.03
SrO [a]	.37	(*b*)	(*b*)
BaO	.76	(*b*)	(*b*)
MgO	5.15	6.57	6.35
K_2O	4.49	3.64	3.82
Na_2O	5.67	4.45	4.93
Li_2O	trace	(*b*)	(*b*)
H_2O (below 110° C.)	.95	.77	.38
H_2O (above 110° C.)	2.10	3.30	2.97
P_2O_5	1.50	(*b*)	(*b*)
CO_2	.11	(*b*)	(*b*)
Cl	trace	(*b*)	(*b*)
SO_3	.61	(*b*)	(*b*)
Total	99.92	99.11	100.15

[a] Contains some CaO. [b] Undetermined.

NO. 77. NEPHELITE-SYENITE (ELEOLITE-SYENITE).

(FROM LITCHFIELD, KENNEBEC COUNTY, MAINE. DESCRIBED BY W. S. BAYLEY.)

It is not certain that the rock represented by this specimen has been found in place. It is known to occur in five or six localities in the vicinity of Litchfield, Kennebec County, Maine, usually in the form of bowlders lying on the surface, but sometimes in low ledge-like exposures nearly covered by glacial sands. The specimens in the collection were obtained from a pile of loose material lying on both sides of the road running from South Litchfield post-office, in the town of Litchfield, in Kennebec County, Maine, to the city of Gardiner, on the Maine Central Railroad, about 6 miles south of Augusta. The distance of the locality from South Litchfield is about three-quarters of a mile, and from Gardiner about 8 miles.[1]

The rock is a moderately coarse-grained crystalline aggregate of three principal substances, none of which are porphyritically developed. Its texture is thus hypidiomorphically granular, or granitic. Occasionally a general parallel arrangement of the constituents may be detected, when the structure becomes schistose.

The most abundant of the components is a white mineral, with brilliant cleavage faces, often characterized by a pearly luster. This occurs both in large columnar grains from a quarter to a half inch in length,

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[1] For description of other localities see article by W. S. Bayley in Bull. Geol. Soc. America, Vol. III, pp. 231–252.

and in small irregular ones, so arranged in certain areas as to cause their aggregation to resemble a fine-grained marble. The larger grains, which are albite, have a density varying between 2.600 and 2.608 and a composition[1] as follows:

Analysis of albite of nephelite-syenite from Litchfield, Maine.

	Per cent.
SiO_2	66.39
Al_2O_3	19.69
K_2O	.99
Na_2O	10.17
H_2O	.52
Undetermined	2.24

Another of the prominent constituents that may be seen in the hand specimen is in irregularly shaped masses of a grayish color, and with an oily luster. It possesses a well-marked cleavage, which is emphasized by the interposition of long black needles between the cleavage plates. A fragment of this substance dissolves quite readily in hydrochloric acid, leaving a residue of gelatinous silica. Its composition, as determined by Dr. Clarke,[2] is that of nephelite (eleolite):

Analysis of nephelite of nephelite-syenite from Litchfield, Maine.

	Per cent.
SiO_2	43.74
Al_2O_3	34.48
CaO	trace
MgO	trace
K_2O	4.55
Na_2O	16.62
H_2O	.86
Total	100.25

The only dark-colored mineral present in the rock is a lustrous black lamellar one, which cleaves with such ease that large plates can be split from it. These plates are elastic, and they show a nearly uniaxial interference figure in converged light between crossed nicols. The mineral is a biotite of the variety known as lepidomelane, as shown by Dr. Clarke.[3]

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[1] F. W. Clarke, Am. Jour. Sci., 3d series, Vol. XXXI, p. 268.

[2] Ibid., p. 262.

[3] Ibid., Vol. XXXIV, p. 133.

Analysis of lepidomelane of nephelite-syenite from Litchfield, Maine.

	Per cent.
SiO_2	32.35
Al_2O_3	17.47
Fe_2O_3	24.22
FeO	13.11
MnO	1.02
CaO	.89
K_2O	.70
Na_2O	6.40
H_2O	4.67
Total	100.83

The three substances, albite, eleolite, and lepidomelane, occur in all specimens of the rock wherever found, and are thus to be termed essential constituents. The other components, though very common, are not found in all specimens, and hence are accessory. They comprise cancrinite, sodalite, and zircon, and are the minerals that have made the rock famous all over the world. The most common and at the same time the most striking of the accessory constituents is cancrinite, which is in very irregular lemon-yellow and orange grains, that are scattered indiscriminately among the other components, but appear to prefer the neighborhood of the nephelite. The orange-yellow variety yielded Dr. Clarke[1] the following analysis:

Analysis of cancrinite of nephelite-syenite from Kennebec County, Maine.

	Per cent.
SiO_2	36.29
Al_2O_3	30.12
Mn_2O_3	trace
Fe_2O_3	trace
CaO	4.27
Na_2O	19.56
K_2O	.18
H_2O	2.98
CO_2	6.96
Total	100.36

Upon comparing this analysis with that of the nephelite, Dr. Clarke reaches the conclusion that the former is an alteration product of the latter. The sodalite is much less common than the cancrinite. It is disseminated in small blue grains throughout the rock mass, and occurs

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[1] Am. Jour. Sci., 3d series, Vol. XXXI, p. 263.

as coatings on its joint cracks. The composition of the sodalite has also been determined by Dr. Clarke. It is as follows:

Analysis of sodalite of nephelite-syenite from Litchfield, Maine.

	Per cent.
SiO_2	37.33
Al_2O_3	31.87
Na_2O	24.56
K_2O	.10
Cl	6.83
H_2O	1.07
$O=Cl$	1.54
Total	100.22

The zircon, the only remaining mineral that can be recognized in the hand specimen, is the single component of the rock that possesses a crystal form. It is in hard, pinkish-brown grains, with an octahedral habit, that may be found here and there among the older constituents. Its crystals are bounded by the tetragonal prism and pyramid of the same order. An analysis by Gibbs[1] gave:

Analysis of zircon of nephelite-syenite from Litchfield, Maine.

	Per cent.
SiO_2	35.26
ZrO_2	63.33
Fe_2O_3	.79
Undetermined	.36
Total	99.74

The texture of the rock as seen under the microscope is thoroughly granitic, in that none of its essential components possess crystal outlines, although many of the nephelite grains and the larger albites have quite well defined rectangular cross sections. In ordinary light it appears to consist of plates of green mica embedded in a nearly homogenous, colorless, transparent groundmass, clouded here and there with opaque white and yellowish substances, that seem to be decomposition products of some constituent. Under crossed nicols, however, this groundmass is resolved into large and small grains of the minerals detected in the hand specimen, besides orthoclase and microcline. (See Pl. XXIX.)

The mica, which is the oldest mineral present, with the exception of the zircon, occurs not only in the large plates already mentioned, but also as inclusions in the other components, more particularly the eleolite. In basal sections it is so dark as to be almost opaque, except in extremely thin pieces, when it is of a clear, deep-green color. The optical figure when tested with the mica-plate is found to be negative,

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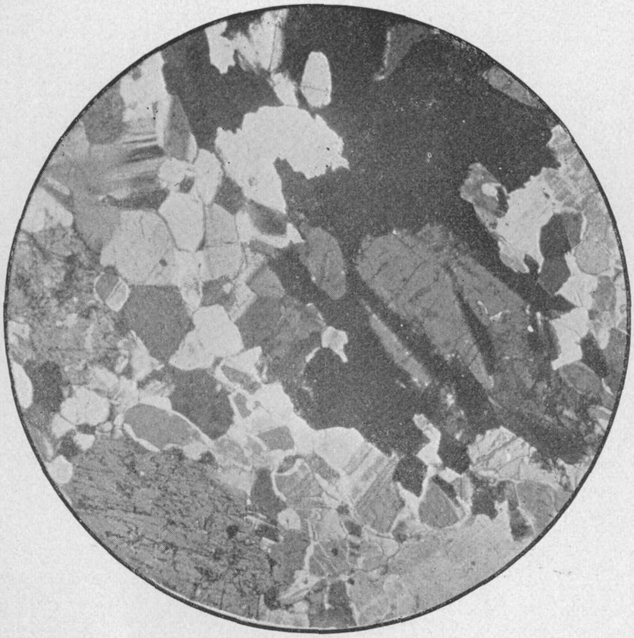
[1] Pogg. Ann., LXXI, p. 559.



THIN SECTION OF NEPHELITE-SYENITE AS SEEN UNDER A MICROSCOPE BETWEEN CROSSED NICOLS, × 33.

The black mineral in the upper right-hand quadrant is lepidomelane, whose arms include several grains of nephelite. In the lower left-hand quadrant are two other grains of the same mineral. In the extreme lower right-hand corner is part of an albite grain. The rest of the figure shows the fine-grained feldspathic mosaic. The twinning lamellæ are very plain in several of the grains, and in one, in the upper left-hand quadrant, the lamellæ disappear to the left of the grain. Several pieces of cancrinite are also discernible in this portion of the section, but in the photograph they can not be distinguished from the untwinned feldspar.

consequently the acute bisectrix, which, in the biotites, is nearly coincident with the crystallographic axis c, is the axis of greatest elasticity, $\mathfrak{a}$. In cross sections the pleochroism is very pronounced. The ray vibrating at right angles to the cleavage is a bright yellowish green, while that vibrating parallel to it is nearly all absorbed. The scheme for the absorption is therefore $\mathfrak{a} < \mathfrak{b} = \mathfrak{c}$. The extinction in these sections, as measured against the cleavage, varies from 0° to 1°. In its optical properties, as well as in its chemical nature, the mica corresponds to biotite.

The largest of the colorless components is that clouded with opaque substance. This is present with rudely rectangular cross-sections, in which a single cleavage may be detected, parallel to which is the extinction. The relief is slight, consequently the index of refraction of the substance is low. Its opacity in places is due to the crowding together of little glass and fluid inclusions, in some of the latter of which are tiny, movable bubbles, and of small flakes of a brilliantly polarizing micaceous mineral that are visible only between crossed nicols, and are probably secondary in origin. The only other inclusions noticed are narrow flakes of lepidomelane. These are arranged with their long axes in parallel directions, that are likewise parallel to the extinction plane of their host. A few of the rectangular sections when revolved between crossed nicols remain dark during the entire revolution. These in converged light show a uniaxial interference figure. All other sections polarize in gray or bluish-gray tints, and these tested by the mica plate are discovered to be negative. If the slide be uncovered and treated with hydrochloric acid, and then washed and dipped in a dilute solution of aniline purple, the areas occupied by this mineral will be found to be stained purple, indicating the presence of gelatinous silica. All these properties are those of nephelite.

The most abundant of the feldspars is the albite occurring in the columnar forms already mentioned. In the thin section it possesses long quadrangular outlines. Its grains are characterized by a series of remarkably fine twinning lamellæ that bend and curve, disappear suddenly at cleavage cracks, and reappear again in other parts of the grains—phenomena indicating that the mineral exhibiting them has at some time been subjected to great pressure. A close inspection of the grains will disclose the fact that some of them are made up of very fine lamellæ of different feldspars, in which the extinction is different. Others consist partly of lamellæ in which the gridiron structure of microcline is plainly apparent. The resemblance of such sections to the pictures of cryptoperthite and microcline-microperthite[1] is so strong as to suggest the probability of their being, like the latter, intergrowths of two feldspars. A feature well worthy of notice in connection with the singly striated grains is the fact that they are penetrated in all directions by jagged embayments of a pellucid plagioclase with broader twinning lamellæ than those of the rest of the grain. Small

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[1] W. C. Brögger, Zeitschr. für Krystallographie, Vol. XVI, Pl. XXII, fig. 3, and Pl. XXIII, fig. 4.

areas of this glassy feldspar occur all through the albites, so that the latter appear to be completely saturated with it. The clear feldspar polarizes in gray and blue tints and always has ragged outlines against the inclosing albite. From the fact that the saturating material is so much fresher than the material of the large grains, and because of its peculiar saturating character, it must be regarded as probably younger than the albite which it penetrates and as having been formed after the rock had consolidated.

By revolution of the slide between crossed nicols the transparent, colorless groundmass in which the mica and the cloudy albite and nephelite are embedded is found to break up into a mosaic of very brilliantly polarizing grains all of about the same size. This mosaic occupies all the space between the large grains and is so distributed as to appear to fill what were at some time fissures in the rock. (Cf. fig. *A*, Pl. XXVIII.[1]) The greater number of the grains in the mosaic are feldspar. Some are marked by a single set of twinning bars, others by two sets crossing each other at nearly right angles, and still others are untwinned. The large number of the latter noticed is an indication of the presence of orthoclase, though this can not be proved on account of the lack of cleavage lines, and of crystallographic contours in the grains. Those showing two sets of twinning lamellæ are probably microcline. The larger proportion of grains are of the first kind, but their lamellæ are so bent and bowed that their extinction angles can not be read with any degree of accuracy. The only method by which a knowledge of the nature of the various feldspars may be obtained is by their separation and analysis, and a comparison of the figures thus obtained with those indicating the composition of the rock as a whole. By use of the Thoulet solution, it will be found that two lots of feldspar fall when the density of the solution reaches 2.622 and 2.56, respectively. That which falls at 2.622 consists of grains usually striated in a single direction, and others in which no striations are visible. The latter extinguish at 19° from the cleavage, and show in converged light the bar of an axial figure. An analysis of some of this powder made by Mr. W. H. Melville gave:

Analysis of albite of nephelite-syenite.

	Per cent.
SiO_2	68.28
Al_2O_3	19.62
FeO	.23
CaO	.31
MgO	.09
K_2O	.39
Na_2O	10.81
H_2O	.09
Total	99.82

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[1] The structure produced by the embedding of the larger components of a rock in a finer grained aggregate, has been termed the "mortar" structure by Törnebohm. It is thought to be the result of pressure.

This is the composition of a very pure albite. In a separation made by the writer, the powder whose density was 2.56 comprised some untwinned grains, and many with the cross twinning of microcline. Its analysis gave the figures:

Analysis of microcline and orthoclase from nephelite-syenite.

	Per cent.
SiO_2	65.14
Al_2O_3	18.19
FeO	.25
CaO	.33
MgO	.16
K_2O	14.14
Na_2O	1.68
H_2O	.17
Total	99.82

This powder was thus a mixture of microcline with a little orthoclase. It is very evident that the feldspar grains of the mosaic are younger than the eleolite and the large grains of albite. Their smaller size, perfect transparency, lack of cleavage lines, and their method of occurrence, in narrow stringers and small areas between the undoubted primary constituents, point to a secondary origin for them. The cause of the production of this new feldspar in the rock, which had already consolidated and been fissured before the formation of the mosaic, was probably the pressure to which it was subjected at some time in its history, and of the action of which we have ample proof in the bending of the twinning lamellæ of the feldspars and in the "mortar" structure of the rock itself.[1]

In addition to the feldspars in the mosaic there is also present in it another brilliantly polarizing substance forming prismatic and lenticular grains. In natural light it is indistinguishable from the newer feldspar, except in very thick sections, where it has a slightly yellowish tinge. It is transparent and free from inclusions of all kinds, save little liquid ones, inclosing movable bubbles. Two cleavages cross nearly all its grains at right angles to each other, and the extinction is parallel to these. Sections that remain dark between crossed nicols show a uniaxial negative interference figure. The index of refraction is so low that grains have no relief. These properties sufficiently characterize the mineral as cancrinite. It is older than the other constituents of the mosaic, but is younger than the eleolite and the albite of the larger grains.

A few other grains in the mosaic and in the neighborhood of the nephelite remain completely dark in all positions between crossed

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[1] For a discussion of the origin of secondary minerals in dynamically metamorphosed rocks, see C. Callaway, Quart. Jour. Geol. Soc. London, Aug., 1889, p. 475, and G. H. Williams, Bull. U. S. Geol. Survey No. 62.

nicols, and when examined in converged light show no axial figures. These are sodalite. In ordinary light the mineral has a very pale-blue tint that can be recognized only by the contrast afforded by the colorless minerals in the field of view, which appear to be tinged with yellow.

The inclusions most abundant in it are grains of plagioclase, small plates of lepidomelane, cancrinite, and a few flakes of a brightly polarizing micaceous substance. Nephelite is often intergrown with it in such a way that a large number of apparently isolated areas of the former mineral polarize together. Since the sodalite includes all the minerals of the rock except nephelite, even those that are younger than this, and since it is intergrown with the latter, it must be an alteration product of it. It is the youngest of all the constituents. Not only is it present in irregular grains that include small particles of the other components, but it is found also as a cement binding together the grains of the mosaic.

The only remaining mineral to be spoken of is zircon, but this is so rarely seen in thin section that its discussion may be dismissed with a very few words. It occurs as small irregular grains, of a brownish-yellow color, with a very high index of refraction, and strong double refraction. No cleavage cracks cross them, nor are crystal contours sufficiently sharply marked to aid in the determination of the extinction. Occasionally a fragment remains dark during its revolution between crossed nicols. This may be made to show a uniaxial figure, which, when tested, is found to have a positive character.

The composition of the rock as a whole as determined by Mr. L. G. Eakins, is as follows:

Analysis of nephelite-syenite from Kennebec County Maine.

	Per cent.
SiO_2	60.39
Al_2O_3	22.51
Fe_2O_3	.42
FeO	2.26
MnO	.08
CaO	.32
MgO	.13
K_2O	4.77
Na_2O	8.44
H_2O	.57
CO_2	trace

The small quantity of K_2O as compared with the large amount of Na_2O present would indicate a scarcity of orthoclase and an abundance of albite among the feldspars. A calculation of the proportions of the different constituents based upon the analyses given leads to the figures: 7 per cent of lepidomelane, 2 per cent of cancrinite, 17 per cent of nephelite, 27 per cent of orthoclase and microcline, and 47 per cent of albite. No other feldspars are present than albite, orthoclase, and microcline.

The rock from Litchfield is thus a granitic aggregate of the essential constituents, lepidomelane, nephelite, and albite, and the accessories zircon, cancrinite, sodalite, albite, orthoclase, and microcline. It has been shattered and fissured as the result of the action upon it of great pressure, and the crevices thus formed have been filled with new feldspar and other minerals. As its original structure was granitic, and its original components are nephelite, biotite, and an acid feldspar, the rock must be classed with the nephelite-syenites. But as the acid feldspar is largely albite, whereas in normal nephelite-syenites it is principally orthoclase, the Maine rock represents a well-marked variety in the nephelite-syenite group, a variety that has been given the descriptive name litchfieldite.[1]

Most of the eleolite-syenites that have been described from North America are normal phases, containing large quantities of orthoclase, and, in addition, pyroxene, amphibole, and sphene. For descriptions of these the reader is referred to the original articles.[2]

NO. 78. NEPHELITE-SYENITE (ELEOLITE-SYENITE).

(FROM BEEMERVILLE, SUSSEX COUNTY, NEW JERSEY. DESCRIBED BY J. P. IDDINGS.)

The nephelite-syenite from Beemerville, New Jersey, is a medium- to coarse-grained, dark-gray rock, with a somewhat greasy luster. Its texture varies considerably from a fine-grained, evenly-granular mass to a coarse-grained one, with prominent feldspars, which present long, narrow sections on the surface of the rock. The rock forms a dike cutting Hudson River shales, and has been described in detail by Prof. B. K. Emerson.[3] In places the rock contains 90 per cent of nephelite. Under the microscope it is seen to consist of nephelite, orthoclase, aegirite, biotite, with melanite, sphene, apatite, and zircon in smaller amounts and in quite variable proportions. In fact the mineral composition differs considerably in different parts of the mass.

In general nephelite (eleolite) appears to have crystallized before the feldspar, when the nephelite is idiomorphic or is inclosed within the feldspar in irregularly-shaped crystals. Its substance is quite fresh, with little or no indication of decomposition. In some places there

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[1] Bull. Geol. Soc. America, Vol. III, p. 243.

[2] B. K. Emerson, On a great dike of foyaite or eleolite-syenite, cutting the Hudson River shales in northwestern New Jersey: Am. Jour. Sci., 3d series, Vol. XXIII, 1882, p. 302. Lacroix, Sur la syénite éléolithique de Montreal (Canada): Comptes Rendus, cx. 1890, p. 1152. J. F. Williams, The igneous rocks of Arkansas: Ann. Rept. Geol. Survey Arkansas, 1890, Vol. II, p. 129 et seq. W. S. Bayley, The eleolite-syenite of Litchfield, Maine, and Hawes' hornblende-syenite from Red Hill, New Hampshire: Bull. Geol. Soc. America, Vol. III, 1892, pp. 231-252.

[3] B. K. Emerson, On a great dike of foyaite or eleolite-syenite, cutting Hudson River shales in northwestern New Jersey: Am. Jour. Sci., 3d series, Vol. XXIII, 1882, pp. 302-308.

are minute irregular crystals of a transparent mineral, with strong double refraction and lower single refraction than nephelite; this is probably cancrinite, and may be secondary. The prismatic cleavage is somewhat developed, but not marked. Its index of refraction being higher than that of orthoclase, the nephelite stands out in distinct relief when in this mineral. The double refraction for both minerals ranges from zero to grayish white of the first order, and is not a means of distinction between them.

The feldspar appears to be wholly orthoclase, in some cases exhibiting microperthite intergrowth with plagioclase, presumably albite. The outline of the feldspar crystals is generally allotriomorphic. Twinning according to the Carlsbad law is common, that according to Baveno law also occurs, in simple twins, and also in crossed twins, furnishing cross sections with triangular quadrants, of which the opposite pairs have like orientation. The ordinary cleavage is often distinct. A slight decomposition has produced a cloudy indeterminable alteration product in some cases. In general the feldspars are less fresh than the nephelite. Both of these minerals are traversed by veins filled with an isotropic medium, probably sodalite. Ægirite occurs in crystals with irregular outlines, sometimes better defined in the prismatic zone. The color is dark green with pleochroism to brown. Cleavage is pronounced. The large crystals of ægirite inclose most all of the other rock constituents in small crystals or grains; that is, orthoclase and nephelite, and more often sphene, biotite, melanite, and magnetite. In some places all of these minerals are so intermingled as to appear to be contemporaneous in growth.

Biotite forms irregular crystals, with dark reddish-brown color and strong absorption. It may inclose sphene, ægirite, magnetite, apatite, and zircon. Melanite forms irregular grains, with a dark-brown color, high refraction, and isotropic character. It is not uniformly disseminated through the rock. It incloses ægirite, magnetite, and sphene, and appears intergrown with feldspar and nephelite to some extent.

Sphene is generally idiomorphic, and is abundant. It occurs in most all the other constituents in well-defined crystals, but is sometimes allotriomorphic with respect to ægirite and biotite, and occasionally incloses small crystals of ægirite. Twinning is frequently observed.

Apatite is abundant in more or less rounded, short, stout crystals, associated with the ferromagnesian minerals. It is sometimes in sharp crystals. Magnetite forms irregularly shaped grains intimately connected with the dark colored minerals. Zircon occurs in minute crystals, sometimes short and stout and rounded, sometimes long and narrow.

On account of the variability of this rock in texture and in mineral composition, it will be found that the specimens in the collection differ considerably in both these respects. The largest of the feldspars, according to Professor Emerson, are 30^{mm} in length. In some parts of the rock he estimated the percentage of nephelite present at 90.

The chemical composition of the average rock is given in the accompanying analysis, which was made by L. G. Eakins.

Analysis of nephelite-syenite.

	Per cent.
SiO_2	53.56
Al_2O_3	24.43
Fe_2O_3	2.19
FeO	1.22
MnO	.10
NiO	....
CaO	1.24
MgO	.31
K_2O	9.50
Na_2O	6.48
H_2O	.93
CO_2	....
Total	99.96

DIORITE-ANDESITE FAMILY.

No. 79. ANDESITIC TUFF.[1]

(FROM STILLWATER CREEK (NEAR RINEHART'S), EIGHT MILES NORTHEAST OF REDDING, CALIFORNIA. DESCRIBED BY J. S. DILLER.)

This gray, earthy rock in the hand specimen is not conspicuously fragmental, but if examined closely it will be found to contain lighter and darker colored pebbles embedded in a gray groundmass. In the cliff from which these specimens were collected it is readily seen that the white portions are fragments of pumice and the darker ones are andesitic lava, so that the material of which the rock is composed is evidently of volcanic origin.

On Stillwater Creek there is a small mass of this tuff now exposed, and it is many miles from the nearest volcanic center. Formerly it was connected both eastward and westward with larger masses of tuff, which have a wide distribution upon the borders of the Sacramento Valley. Upon the western side of the Sacramento Valley the material is very fine. Along the Stillwater it is intermediate in size, and on the eastern side of the valley, where the mass is very thick, it is coarse. Since sediments of volcanic origin are coarsest and their accumulation is thickest very close to the point of eruption, it is evident that the source of the tuff on Stillwater Creek is to be found to the eastward in the Lassen Peak district. Where best exposed the tuff is distinctly stratified, and was evidently deposited in a body of water which filled the Sacramento Valley.

In the hand specimen, besides the small fragments of andesite and pumice already mentioned, there are small, dark specks, which, when

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[1] Instead of *tuff* the word *tufa* is sometimes written. The former should be used for fragmental volcanic rocks only, and the latter for certain forms of carbonate of lime, as "calcareous tufa," deposited from solution in water.

removed from the specimen with the point of a knife blade, crushed and examined in polarized light, are found to have the cleavage, strong pleochroism, and inclined extension belonging to hornblende.

Grains of feldspar, too, are quite common in the hand specimen, but on account of the fragile nature of the matter in which they are embedded many of the crystals break out of the thin sections when the material is being ground. In the thin section the remaining feldspars are rarely idiomorphic. They are usually found to be very irregular, corroded or broken crystals, containing many glass and liquid inclusions. Their tabular form, zonal structure, and angle of extinction agree very closely with those of andesine from the andesites of the Lassen Peak region. Fragments of magnetite and of hornblende crystals are not common, and those of hypersthene are rare.

The gray groundmass, which constitutes at least 75 per cent of the tuff, is made up of minute fragments of volcanic glass. This is easily discovered when examined with a higher magnifying power. It is then seen to be composed of such curiously formed particles as are represented in fig. 15. *a* has the same tubulo-vesicular structure as the larger fragments, and in fact is a minute particle of pumice. Where thin, the glass is clear and transparent, but where thick it is slightly dark-colored. *b* represents the curved wall of a broken bubble. *c* is a small vesicle, still complete and surrounded by tubular glass, and *d* is interstitial glass between several bubbles and is not tubular. All are sharp, angular particles of glass, exactly analogous to volcanic dust. Although the macroscopic evidence indicating that the rock is tuffaceous is strong, the microscopic evidence is still stronger, and demonstrates completely its volcanic origin.

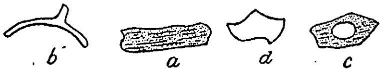

Fig. 15.—Fragments of volcanic glass in tuff as seen under the microscope, × 50.

The analysis given below shows its chemical composition, as determined by W. H. Melville:

Analysis of andesitic tuff from Stillwater Creek, California.

	Per cent.
Loss	3.63
SiO_2	69.51
Al_2O_3	15.61
Fe_2O_3	0.56
FeO	1.27
CaO	2.80
MgO	0.61
K_2O	2.81
Na_2O	3.43
Total	100.23

Tuff, in its widest sense, is applied to all fragmental rocks composed of volcanic material, but it is more frequently used to designate only those which are composed of fine volcanic detritus, such as lapilli, sand, or dust. Those made of coarse fragments, somewhat assorted according to size, are called volcanic conglomerates; while others, which are composed of large, angular blocks as well as fine material—all intermingled, as they frequently are in the immediate vicinity of the volcanic vent—are designated volcanic agglomerate.

Although much of the fragmental volcanic material about volcanic vents is more or less rounded, forming conglomerates, there are also many cases in which it is sharp and angular, forming breccias. These result not only from accumulations of angular ejected material, but also, and perhaps frequently, from the breaking up or complete brecciation of brittle viscous lava at the time of its eruption.

Uses.—The so-called pozzolana, of Italy, and trass, of the Eifel, in Germany, are tuffs, and are extensively used in the manufacture of hydraulic cement.

Near Paskenta, California, a tuff of the same stratum as that which occurs on the Stillwater is used for making water coolers. As it is porous it allows the water to evaporate rapidly through the sides of the vessel and thus cools the contents of the jar. Tuff, on account of its composition, is a poor conductor of heat, and does not readily crack when exposed to fire. On this account it is used quite extensively in volcanic regions for constructing chimneys. It is soft and easily cut into any desired shape, but, as it is easily crushed, it can not be used for large structures where it will be subjected to great pressure.

No. 80. DACITE.

(FROM BEAR CREEK FALLS, SHASTA COUNTY, CALIFORNIA. DESCRIBED BY J. S. DILLER.)

In the field this dacite is of comparatively small extent, covering only a few square miles. The forks of Bear Creek, in cutting their canyons, have severed the original mass into five smaller masses. They all rest upon andesitic tuff, which at the time the dacite was erupted was unconsolidated, so that the overflowing dacite picked up and included a multitude of small fragments of andesite. The flow has a maximum thickness of about 80 feet. Its upper portion is comparatively free from included fragments, but below it is full of them, and so closely resembles the tuff by which it is underlain that the line between the two rocks is generally indistinct. Some of the cliffs of this dacite along Bear Creek exhibit a remarkably well-developed columnar structure.

It is a rough, gray rock, containing short streaks of black glass, approximately parallel, giving to the rock a decided fluidal structure. This feature is usually much more conspicuous in the rhyolites than in the dacites. In the field this structure is parallel to the surface, and is plainly seen to have been produced by the flowing of the lava at the time of its eruption.

In the hand specimen it may be observed that the larger streaks of black glass are distinctly perlitic, and sprinkled with phenocrysts of feldspar. The gray portion is somewhat mottled, and envelops occasionally small fragments of andesite picked up at the time the lava was effused.

Under the microscope, as seen in Pl. XXX, the rock becomes plainly porphyritic, with angular fragments of feldspar, hypersthene, hornblende, and quartz embedded in a light-colored groundmass of glass, in which the fluidal structure is well displayed.

The feldspar occurs in irregular tabular crystals and fragments of crystals, which generally show the twinning lamellæ and angle of symmetric extinction belonging to andesine and labradorite. Polysynthetic twinning occurs according to both albite and pericline laws, but the former is much more frequent than the latter, and they are generally combined. The angle of extinction of cleavage plates on M and P ranges from zero to 20°, and lies chiefly about 13°, indicating labradorite.

There is a small amount of sanidine present, indicated in part by the absence of twinning lamellæ, but chiefly by the low specific gravity, 2.56, and the presence of considerable potassium, as shown by the chemical analysis of the rock. Only a portion of the potassium is to be relegated to sanidine, for the greater portion, as has been shown by chemical tests, is within the glassy groundmass.

The feldspar contains numerous liquid and glass inclusions, besides a smaller amount of magnetite, quartz, pyroxene, and hornblende, which crystallized at an earlier stage than the feldspar in the solidification of the rock. A striking feature of the feldspar is the rarity of perfect crystals. In form it is irregular and fragmental, affording evidence that the crystals were broken by the flowing viscous lava during its eruptions. Feldspar is more abundant than all the other minerals combined.

In ferromagnesian silicates this rock is especially poor, and of these hypersthene and hornblende are the only ones present. Hypersthene is most abundant, and, like the hornblende, it occurs in irregular phenocrysts and small grains.

Quartz is rare in angular fragments and round grains, containing dihexahedral glass inclusions.

The glassy groundmass constitutes nearly two-thirds of the rock, and has a marked fluidal structure due to irregular streaks of clear, colorless glass, alternating with others that are clouded. The clear streaks are frequently full of elongated glass cavities, as in pumice, and have perlitic structure, as shown in Pl. XXX. The clouded ones are composed chiefly of glass containing a multitude of amorphous, dust-like particles, and a few irregular grains of feldspar and other minerals. Occasionally they contain spherulitic portions.

THIN SECTION OF DACITE FROM BEAR CREEK, CALIFORNIA, AS SEEN UNDER A MICROSCOPE BETWEEN CROSSED NICOLS, × 35.

The chemical composition of the dacite, determined by R. B. Riggs, is as follows:

Analysis of dacite from Bear Creek Falls, Shasta County, California.

	Per cent.
SiO_2	68.10
TiO_2	0.15
Al_2O_3	15.50
Fe_2O_3	3.20
FeO	none
P_2O_5	0.03
MnO	trace
BaO	0.06
SrO	trace
CaO	3.02
MgO	0.10
Li_2O	none
Na_2O	4.20
K_2O	3.13
H_2O	2.72
Total	100.21
Dried at 105° C.	

The small amount of iron oxide and magnesia present is due to the small proportion of ferromagnesian silicates. The rather large amount of lime present is found in the labradorite, while the soda and potassa are found, as in the Lassen Peak dacite, chiefly in the groundmass.

NO. 81. DACITE.

(FROM SPRING VALLEY ROAD, EUREKA COUNTY, NEVADA. DESCRIBED BY J. P. IDDINGS.)

This rock occurs as part of a surficial body of andesitic perlite, which varies in mineral composition and character, the most siliceous modification being dacite.

The dacite is compact, with an earthy texture and rough fracture. It is buff, with lumps of pink, yellow, or white tuff, and is crowded with phenocrysts of black biotite, small amounts of hornblende and pyroxene, abundant feldspars, and numerous dark-colored quartzes. The quartzes resemble those in the rhyolite of Pinto Peak in this collection. The character of the rock differs somewhat in different specimens. In thin section the groundmass of the rock is seen to have been glass, which is more or less altered and devitrified. It exhibits characteristics of glasses that appear as welded fragments and bits of tuff, having a marked flow structure. It is seldom isotropic, but is faintly doubly refracting and in places consists of minute colorless globules. There is much semiopaque cloudy material of an indeterminable nature. Occasionally there is distinct spherulitic crystallization, and in places the groundmass is microcrystalline in irregular and ill-defined grains. The microstructure of the rock varies considerably in different parts of it.

The phenocrysts of feldspar are plagioclase; four-fifths of the individuals are striated, and the symmetrical extinction angles range from a few degrees to about 30°. They belong to the andesine-labradorite varieties. The double refraction corresponds to that of feldspars richer in lime. For the most part they are in angular fragments, but some exhibit the customary crystal outlines. Inclusions of colorless glass in rectangular shapes, and with an inclosed gas bubble, are common, and in some individuals are abundant. Clouds and streaks of dust-like particles prove to be made up of minute glass inclusions, 0.002^{mm} in diameter, together with grains of iron oxide, magnetite, and opaque rods. The streaks are often in parallel lines, whose orientation in the feldspar crystal is not determinable. They suggest the dust-like inclusions characteristic of the plagioclase of many gabbros. Minute crystals of apatite and zircon, and of the accompanying ferromagnesian minerals are also included. The substance of the feldspar is fresh and unaltered.

Quartz is much less abundant and occurs in rounded and irregular grains. Its substance is colorless in thin section. Glass inclusions in negative crystal cavities are common, and also those of groundmass. Other inclusions are seldom observed.

Hornblende is quite abundant in crystals and fragments. The crystals are well developed in the prismatic zone, with unit prism and clinopinacoid, less often the orthopinacoid. Terminal planes are rare. Its prismatic cleavage is characteristic. The color is brown, with a tinge of green; the absorption is strong, and, as usual, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. It is free from dark border, and has no characteristic inclusions, being in general quite free from them. Its substance is unaltered.

Of the pyroxenes, the orthorhombic form is more abundant than the monoclinic. Hypersthene in irregularly shaped crystals is more or less altered to a fibrous decomposition product. The unaltered hypersthene exhibits a slight pleochroism in thin sections, becoming more marked in thicker sections. It is green parallel to the axis $\mathfrak{c}$, light reddish brown parallel to $\mathfrak{a}$ and $\mathfrak{b}$. The substance is generally free from inclusions, but sometimes bears numerous magnetite grains and glass inclusions, besides apatite needles and grains of hornblende. When altered the hypersthene passes into a fibrous green mineral, whose fibers are about parallel to the crystallographic c axis. The alteration product has the optical properties of actinolite.[1] Augite occurs sparingly in pale-green grains and crystals, and is distinguished from the hypersthene by its lack of pleochroism, monoclinic characters, and by its generally unaltered condition when near hypersthene which is more or less decomposed.

Biotite is the most prominent ferromagnesian mineral in the more

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[1] See figs. 5 and 9, Pl. III, Monograph XX, Geol. of the Eureka District, Washington, 1892.

quartzose varieties of this rock. It forms six-sided plates, is dark brown in thin sections, with strong absorption. It possesses a small optic angle, behaving almost as a uniaxial mineral. It sometimes exhibits the common twinning. Inclusions are rare.

Magnetite, apatite, and zircon occur as subordinate minerals. The zircon crystals often have sharp outlines and well-developed forms, including the two unit prisms and pyramids, and the ditetragonal pyramid 3 P 3 (311). The more common forms are shown in figs. 15–20, Pl. III, Monograph XX, United States Geological Survey.

The chemical composition is probably similar to that of the dacite from northeast of South Hill in the same district, given on page 264, Monograph XX. (Consult Monograph XX, U. S. Geol. Surv., pp. 236 and 368 et seq.)

NO. 82. DACITE.

(FROM LASSEN PEAK, CALIFORNIA. DESCRIBED BY J. S. DILLER.)

Lava which is characterized by lime-soda feldspars and quartz is *dacite*. It is sometimes called quartz-andesite.

Lassen Peak, like Mount Shasta, Mount Hood, and many other prominent peaks of the Cascade range, was once an active volcano, and of its newer lavas dacite forms by far the greater portion. It is widely distributed about the base of the peak, and at one place, known as Chaos, it is of so recent eruption that it still remains in its original extremely rough, broken, rocky condition.

It is a porphyritic gray rock, which has a rough fracture and porous structure. At first sight it looks somewhat like granite,[1] from which, however, it differs essentially in containing a large amount of glassy base.

Among the phenocrysts embedded in the light-gray groundmass, hornblende and biotite are the most conspicuous. Plagioclase is most abundant. Quartz is common and pyroxene scarce. Idiomorphic phenocrysts are rare; the crystals are nearly all rounded or broken by the movements of the lava at the time of its eruption.

The hornblende is black where fresh, becoming brownish by alteration. It appears occasionally in well-defined crystals, but usually its form is broken or irregular. Pyroxene is occasionally found grown upon hornblende in parallel position. Grains of magnetite are frequently included in hornblende, but the black border so common about the hornblende and mica in many andesites is entirely absent here. Apatite, almost black, as seen in the hand specimen, by transmitted light appears deep brown and strongly pleochroic. It sometimes contains inclusions of both magnetite and apatite.

The feldspar phenocrysts, as shown by Hague and Iddings, are all plagioclase, and belong chiefly if not wholly to andesine. Well defined

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[1] Baron von Richthofen, The Natural System of Volcanic Rocks, p. 16. Hague and Iddings, Am. Jour. Sci., 3d series, Vol. XXVI, Sept., 1883, p. 231.

crystals are rare. The usual form is rounded or broken, and frequently contains numerous glass inclusions.

The quartz, when seen in thin sections, is found to be well rounded, and generally contains the characteristic dihexahedral glass inclusions.

The pyroxene is chiefly hypersthene, although augite is sometimes present. The crystals are usually so small that they belong rather to the groundmass than to the phenocrysts.

The gray groundmass is porous, sometimes fibrous and pumiceous, a feature which can be best observed in the hand specimen with a small lens. In the thin section it is seen to be composed chiefly of clear glass swarming with acicular colorless crystallites. It contains comparatively small crystals and grains of feldspar with a smaller proportion of hornblende, hypersthene, biotite, and magnetite, besides round or irregular dark gray felty spherulitic patches.

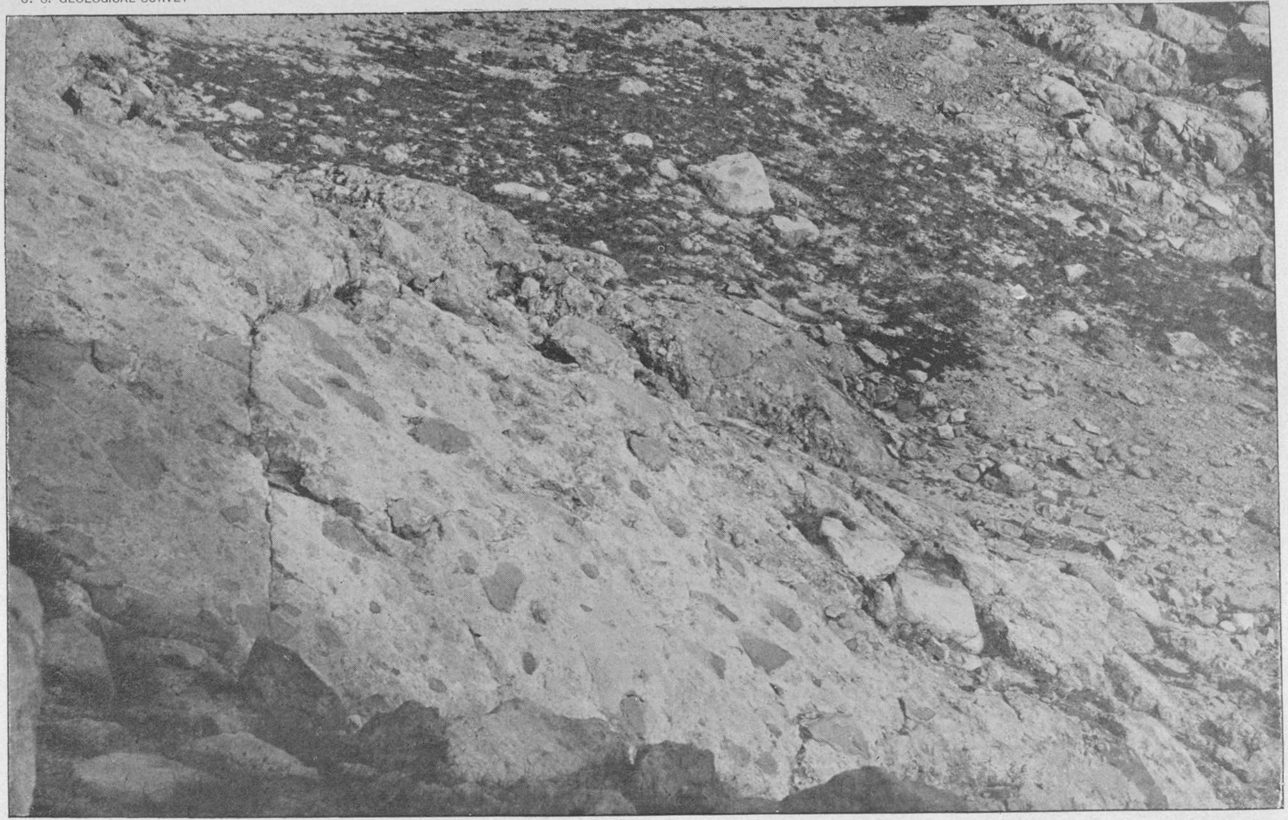
The chemical composition of the lava at Lassen Peak shows that it is a typical dacite. Analyses have been made of different flows and are given in the accompanying table.

Analyses of lava from Lassen Peak, California.

	1.	2.	3.	4.	5.	6.	7.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
SiO_2	69.51	68.20	68.72	68.32	55.14	65.77	76.75
TiO_2	....	....	0.31	0.31	0.52	....	....
Al_2O_3	15.75	16.98	15.15	15.26	19.10	21.51	12.32
Cr_2O_3	....	....	none	none	none	....	....
Fe_2O_3	3.34	3.95	1.16	1.66	6.16	....	....
FeO	....	....	1.76	1.26	0.54	trace	1.36
MnO	....	....	0.11	0.04	0.11	....	....
CaO	1.71	4.33	3.30	3.26	8.36	5.72	1.18
SrO	....	....	0.03	trace	0.07	....	....
BaO	....	....	0.07	0.07	trace	....	....
MgO	2.09	2.07	1.28	1.32	4.23	none	none
K_2O	3.34	1.52	2.78	2.81	1.04	0.83	3.98
Na_2O	3.89	2.98	4.26	4.27	3.71	5.92	3.55
Li_2O	....	....	trace	trace	trace	....	....
H_2O	0.56	0.44	0.74	1.37	0.91	0.34	0.54
P_2O_5	....	....	0.09	0.12	0.18	....	....
Total	100.19	100.27	99.76	100.07	100.07	100.09	99.68

No. 1. Gray dacite at southeast base of Lassen Peak. Analyst, T. M. Chatard.
No. 2. Reddish dacite at northeast base of Lassen Peak. Analyst, T. M. Chatard.
No. 3. Dacite of latest eruption at Chaos, north base of Lassen Peak. Analyst, W. F. Hillebrand.
No. 4. Gray dacite, west base of Lassen Peak, envelopes 5.
No. 5. Nodule contained in 4.
No. 6. Feldspar (Am. Jour. Sci., 3d series, Vol. XXVI, p. 232, Sept., 1883). Analyst, P. W. Shimer.
No. 7. Glass base (Am. Jour. Sci., 3d series, Vol. XXVI, p. 232, Sept., 1883). Analyst, P. W. Shimer.

In the first column is given an analysis of the material in this series. The composition of the feldspar, determined by Messrs. Hague and Iddings, is given in column 6, and that of the glass base in column 7, where it appears that the latter contains the chief portion of the potas-



NODULES IN DACITE, LASSEN PEAK, CALIFORNIA.

sium and that none of the feldspar is sanidine. It is evident also that the glass base contains a larger percentage of silica than the crystallized portion of the dacite. It is almost always true that in the process of crystallization the basic elements become mineralized with greater rapidity, relatively, than the silica, so that the amorphous residue in hypocrystalline eruptive rocks is generally richer in silica than the average of that portion which is crystallized.

Although the great mass of dacite at Lassen Peak contains a larger proportion of glass base and has attained a lower degree of crystallization than most of the other lavas in the same region, there are within the mass isolated nodules, as seen in Pl. XXXI, that are holocrystalline, or contain a relatively small amount of glass base. The complete crystallization of the mass at the time of its eruption was doubtless prevented by the condition of the magma taken in connection with its environment. The irregular holocrystalline nodules, on account of their higher degree of crystallization, may be regarded as the first portion of the mass to solidify.

In these nodules hornblende is much more abundant than in the dacite which envelops the nodules. It is frequently allotriomorphic against the feldspar, as the augite in diabase;[1] biotite and pyroxene are usually less abundant, and olivine is occasionally present, and some tridymite. The feldspar are generally lath-shaped. A chemical analysis of one of these nodules, with that of the enveloping dacite, is given in the table.

Similar nodules are found in many eruptive rocks, especially such as granite, diorite, etc., which have crystallized at a considerable depth beneath the earth's surface. They are generally more basic than the rock inclosing them, and are regarded by many petrographers, but not all, as the part of a once homogeneous magma, separated out in the process of differentiation and first to crystallize.

Dacites are sometimes holocrystalline, but frequently contain more or less amorphous matter. In a general way they are intermediate in the rock series between rhyolite and andesite. The structure and habit of many dacites appears most closely related to those of rhyolite, but in the field they are commonly found associated with andesites. In the Lassen Peak region the dacites and rhyolites are of approximately the same age, and both are younger than the andesites which they have overflowed.

No. 83. HORNBLENDE-MICA-ANDESITE.

(FROM HOOSAC MOUNTAIN, EUREKA COUNTY, NEVADA. DESCRIBED BY J. P. IDDINGS.)

This rock occurs in a small exposure on the road northeast of Hoosac Mountain, Eureka County, Nevada. It appears to be a lava flow or

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[1] See also Hague and Iddings, Am. Jour. Sci., Sept., 1883, 3d series, Vol. XXVI, p. 234, 235; and Rosenbusch, Mikroskopische Physiographie der massigen Gesteine, 2d edition, 1887, p. 675.

possibly an intrusive body, its contact with the limestone not having been discovered. It is a dense, compact rock having a reddish-purple to purplish-gray groundmass, rich in megascopic crystals of feldspar, hornblende, and biotite, the feldspar predominating. Pyroxene is wholly absent.

In thin sections the groundmass is seen to be holocrystalline, composed of microlites of plagioclase, largely oligoclase, in an aggregate of feldspar and quartz grains. These grains are nearly free from microlites at their centers. There are, besides, minute crystals of magnetite and opaque microlites which correspond to shreds of brown mica in some instances. The lath-shaped feldspars show fluidal arrangement. The feldspar phenocrysts are wholly triclinic. They are finely developed crystals, for the most part equidimensional, yielding sharply outlined sections having the usual forms. Zonal structure is pronounced and is well shown in fig. 1, Pl. V, Monograph XX, United States Geological Survey. They sometimes exhibit evidence of successive periods of growth and resorption. The customary cleavage is not well developed and is often wanting, there being, instead, irregular cracks, as in sanidine. The polysynthetic twinning after albite and pericline is very unevenly developed. (This is shown by figs. 3 and 4, Pl. V, and fig. 2, Pl. VI, Monograph XX.) The largest feldspars have quite irregular outlines and abundant narrow striæ; the medium-sized ones have sharp crystal outlines and fewer broader striæ. Most individuals are also twinned in two parts after the Carlsbad law (fig. 7, Pl, III, Monograph XX), and frequently several have grown together in parallel orientation (fig. 2, Pl. VI, Monograph XX). Most of the feldspar phenocrysts are labradorite or andesine; the microlites are probably oligoclase. The precise character of the grains in the groundmass is indeterminable; they may be in part orthoclase. The phenocrysts bear colorless glass inclusions and sometimes clouds and streaks of dust-like particles, besides occasional minute apatites and zircons.

The hornblende phenocrysts, which are recognized by their crystal form and characteristic six-sided cross section, are seen in thin section to be wholly decomposed. The opaque black border remains, but the interior of the crystal, when not lost during the process of grinding the section, is altered to a finely fibrous, yellowish-green mineral having the optical properties of amphibole (actinolite). Its fibers start from transverse fissures and run parallel to the *c* axis of the original crystal for a short distance. They form a network, the meshes of which are filled with a colorless substance, probably opal. There are sometimes opaque and also transparent globulites, besides ferrite and hematite. In some cases the decomposed hornblende is replaced by calcite, and in others by chlorite.

Biotite occurs in fewer and larger crystals, tabular and six-sided in form, and often quite thick. The crystals are frequently twinned parallel to ∞P (110), with O P (001) as the composition plane, the common law. Absorption strong; pleochroism marked, sections parallel to the base being brownish red, those inclined to it, orange, yellow, or green. Optic angle small. There are sometimes opaque, needle-like, possibly tabular inclusions arranged parallel to the six sides of the mica plates; also apatite and zircon inclosures. In some cases crystals of plagioclase are inclosed in the phenocrysts of biotite, and occasional intergrowths of these two minerals prove their crystallization to have been synchronous. It should be noted that the biotite is almost perfectly fresh, while the hornblende is completely altered.

Quartz occurs in sporadic phenocrysts, rounded and often greatly corroded and cracked. Its substance is very pure and free from inclusions. Microscopic quartz grains form a constituent of the groundmass. Magnetite occurs in grains among the phenocrysts and as a microscopic constituent of the groundmass. Apatite is well developed in small crystals, dusted red and orange, with noticeable absorption parallel to the *c* axis. It contains in some instances glass inclusions in negative crystal cavities (figs. 1, 4, 6, Pl. III, Monograph XX). Zircon is a constant ingredient in small quantities.

The chemical composition, determined by R. W. Mahon, is as follows:

Analysis of hornblende-mica-andesite from Hoosac Mountain, Nevada.

	Per cent.
SiO_2	67.83
TiO_2	1.04
Al_2O_3	15.02
Fe_2O_3	
FeO	5.16
MnO	
MgO	.29
CaO	3.07
Na_2O	2.40
K_2O	3.20
P_2O_5	.26
Ign	1.11
Total	99.38

For further details, see Monographs United States Geological Survey, Vol. XX, Geology of Eureka District, Nevada, pp. 233, 264, 364, et seq.

NO. 84. HORNBLENDE-ANDESITE.

(FROM BLACK BUTTE AT WESTERN BASE OF MOUNT SHASTA, CALIFORNIA. DESCRIBED BY J. S. DILLER.)

Andesites are lavas of intermediate chemical composition and are distinguished from the rhyolites and trachytes on the one hand and basalts on the other by the predominance of the soda-lime feldspar.

They are commonly divided into hornblende-andesites, mica-andesites, augite-andesites, and hypersthene-andesites, according to the predominating ferromagnesian silicate. Hornblende-andesite is one in which the characterizing ferromagnesian silicate is hornblende.

Mount Shasta,[1] California, during the latter part of the Tertiary period was an active volcano, and among the earlier lavas of its western slope hornblende-andesite plays an important rôle. The later lavas are hypersthene-andesites (specimen No. 87) and basalts. Where unaltered the hornblende-andesite is composed chiefly of a compact, light-gray groundmass, in which are sprinkled prominent crystals of black hornblende. Upon the surface the rock is usually altered and becomes reddish, owing to the liberation of oxide of iron in the process of alteration. It is a uniformly dense lava without any of the vesicular structure common to basaltic rocks of the same region.

Under the microscope it is seen that the gray groundmass contains small phenocrysts of feldspar which can not be readily detected in a hand specimen. They are all banded, and their angles of extinction indicate that they are anorthite and labradorite. In form they are commonly irregular but sometimes idiomorphic and nearly as broad as long. Their well-marked zonal structure affords an opportunity to observe the wide difference in angle of extinction between the outer and inner zones, a difference which is usually assumed to indicate that the central portion of the crystal is more basic than the outer zones. It may be sometimes observed, however, that the center and outer zones have the same angle of extinction, while the intermediate ones have a much larger angle.

The hornblende phenocrysts are larger than those of feldspar. They are usually deep brown, strongly dichroic, and surrounded by dark gray or black borders. Where the border can be resolved it is found to be composed chiefly of augite and magnetite, which originated in the caustic action of the magma upon the hornblende at the time of the eruption.

The groundmass is a mat of microlites. It is composed chiefly of lath-shaped crystals or irregular grains of feldspar, with a smaller proportion of hypersthene, magnetite, and amorphous substance. The feldspars, many of which are very minute, have the small angle of extinction which belongs to andesine. They are occasionally arranged in streams about the older crystals of feldspar and hornblende. The minute slender crystals of hypersthene in the fresh rock are inconspicuous. They are scarcely pleochroic, between yellowish and greenish. When the rock begins to alter they become yellowish red and impart color to the whole mass.

Hornblende-andesite from Black Butte, at the western base of Mount Shasta, contains among its phenocrysts neither mica nor pyroxene, and is a good type. Such forms, however, are rather exceptional, for the most common phase of hornblende-andesite, even in that region, con-

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[1] Mount Shasta a Typical Volcano, by J. S. Diller: Nat. Geog. Monograph No. 8. Published under the auspices of the National Geographic Society by the American Book Company.

tains phenocrystic hypersthene, but it is always less conspicuous than the hornblende. Augite, which is common in hornblende-andesites in many regions, is rarely if ever present in those of Mount Shasta. The same is true of mica. The groundmass, too, varies greatly; on the one hand it may be holocrystalline and on the other may contain an abundance of brown, glassy base, forming the principal constituent of the groundmass. Generally, however, there is only a trace of clear, vitreous base present. In general habit, as well as in chemical composition, the hornblende-andesite of Mount Shasta is related to the trachytes, and on this account[1] Rosenbusch classifies them as trachytoid hornblende-andesites.

The following chemical analysis of specimen No. 84 was made by W. H. Melville:

Analysis of hornblende-andesite from western base of Mount Shasta, California.

	Per cent.
Loss on ignition	0.06
SiO_2	64.48
Al_2O_3	19.28
Fe_2O_3	1.40
FeO	1.78
CaO	5.06
MgO	1.64
K_2O	1.12
Na_2O	4.41
Total	99.23

NO. 85. HORNBLENDE-PYROXENE-ANDESITE.

(FROM NEAR THE COMSTOCK LODE, VIRGINIA CITY, NEVADA. DESCRIBED BY J. P. IDDINGS.)

This rock, like the pyroxene-andesite from Virginia City, Nevada (specimen No. 88), forms massive volcanic lavas whose occurrence has been described by the authors mentioned in connection with the description of that rock (q. v.). It is dense and dark gray, with a rough fracture, an aphanitic groundmass carrying numerous small crystals of feldspar with brilliant cleavage planes. In thin sections it is seen to be partly altered, the ferromagnesian minerals, hornblende and pyroxene, being almost wholly changed.

It consists of a holocrystalline groundmass with abundant phenocrysts of plagioclase and few of altered ferromagnesian minerals. The plagioclase phenocrysts are fresh and unaltered, and exhibit zonal structure and polysynthetic twining according to the albite law, besides Carlsbad twinning. The symmetrical extinction angles are those of labradorite. The inclusions are minute rectangular glass ones, in some

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[1] Mikroskopische Physiographie, 3d edition, 1896, Vol. II, p. 888. See also paper by Hague and Iddings, Am. Jour. Sci., Sept., 1883, Vol. XXVI, pp. 222-235.

cases devitrified, and opaque grains and crystals, besides colorless apatite prisms. There is also included in some cases a highly doubly refracting mineral in flakes and films, which is possibly calcite. There are occasional rounded grains which are probably augite, and opaque magnetite grains.

Hornblende, which can be recognized by its forms in cross section, is altered to an aggregation of opaque grains (magnetite), and colorless mica (muscovite), and yellow, strongly refracting grains (epidote), green chlorite, and calcite. In some cases the hornblende is largely replaced by calcite. These pseudomorphous aggregations sometimes inclose small plagioclase feldspars and apatites, which were undoubtedly originally inclosed in the hornblende. Pyroxene, which is recognized by the shapes of its sections, is altered to chlorite with seams of calcite and some quartz and numerous grains of magnetite, which latter mineral may have been originally inclosed in the pyroxene. Epidote also occurs in these pseudomorphs. The chlorite is quite uniformly oriented and sometimes exhibits marked fibration and cleavage, like that of bastite. It is somewhat pleochroic, being green parallel to the fibers. and yellow for light vibrating at right angles to them. A few small phenocrysts of unaltered pale-green augite were found in the thin sections of this rock. One showed the customary twinning parallel to the orthopinacoid (100).

Microscopic phenocrysts of magnetite and apatite occur associated together in groups. The apatite is in the stout, colorless prisms usually found in andesites.

The groundmass is holocrystalline, both microcrystalline granular and microlitic. It consists of micropoikilitic quartz, feldspar microlites, and magnetite grains, besides chlorite and some other secondary minerals. The micropoikilitic quartz is primary, having formed as the last act of crystallization of the molten magma. The microscopic anhedrons of quartz inclose microlites of feldspar and other minerals. The larger microscopic feldspars are lath-shaped plagioclases. The magnetite grains and crystals are abundant. There are scattered through the groundmass small patches of calcite and aggregations of secondary quartz, in which the calcite occurs as minute rhombohedrons. Chlorite forms pseudomorphs after microscopic pyroxenes, and also occurs in spherical aggregates.[1]

NO. 86. HYPERSTHENE-ANDESITE.

(FROM NORTHEAST SHOULDER OF BUFFALO PEAK, PARK COUNTY, COLORADO. DESCRIBED BY WHITMAN CROSS.)

Occurrence.—Buffalo Peak (elevation, 13,541 feet) lies between South Park and the Arkansas River, a little southeast of the south end of the Mosquito Range.

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[1] Further information concerning this rock may be found in Mon. U. S. Geol. Survey, Vol. III, pp. 53-62, and Bull. U. S. Geol. Survey No. 17, pp. 22 and 23.

It is a double pointed mountain whose base consists of easterly dipping Carboniferous strata, while the upper part is made up of horizontal beds of andesitic tuff, capped by andesitic lava flows. The summit sheet is a hornblende-andesite containing some hypersthene, and the northeastern shoulder is made up chiefly of the dark hypersthene-andesite of this collection. The geology of the region has not been worked out in detail, but the mountain was visited in the summer of 1880 by members of the Rocky Mountain Division of the Survey, then engaged in the study of the adjacent Mosquito Range.

General description.—This hypersthene-andesite is a dark, almost black, rock, exhibiting to the eye many very small white feldspar crystals embedded in a black groundmass having a dull vitreous luster. On careful examination a number of dull-green grains and small prisms may be distinguished, which the microscope shows to be hypersthene or augite. Glistening particles of magnetite may also be detected.

The rock varies somewhat in texture, but the specimens collected show a large number of the white or clear glassy feldspar phenocrysts which the microscope proves to be labradorite. In other parts of the mass the groundmass is more prominent and more clearly vitreous.

The phenocrysts.—Microscopical examination reveals a lime-soda feldspar, hypersthene, augite, and magnetite as very distinct phenocrysts, in a groundmass which has a glassy base holding numerous augite and plagioclase microlites and magnetite particles. The phenocrysts equal or exceed the groundmass in quantity. All are very small, few surpassing 2^{mm} in diameter.

Plagioclase is probably developed in several varieties, but the chief one is certainly labradorite. The crystals vary much in size and form, in number and character of inclusions, and in twinning. The larger crystals are usually clouded by many original brown glass inclusions, now often devitrified, and obscured by an opaque ferritic dust. These inclusions are often connected and occupy more than half the space of the crystal. Zonal extinction is almost universal in the plagioclase, but does not always represent great difference in optical character. Various twinning laws have been noted, the common albitic law being accompanied by the Carlsbad, pericline, and other laws not determined.

A gradation in size occurs between the largest phenocrysts and the groundmass microlites, and these intermediate crystals usually carry few inclusions.

Both hypersthene and augite are present, as phenocrysts of very similar development, but hypersthene greatly predominates. The pyroxenes occur in prisms usually two or three times as long as they are thick, but of variable size. The largest are, however, only 3 or 4^{mm} in length.

The hypersthene of this rock has been determined chemically and optically, and it is typical of the hypersthene now known to be a very frequent constituent of basic andesites the world over. The pleochroism of the hypersthene, while not very strong, is sufficient to distinguish it from augite, and the parallel extinction of the orthorhombic prisms is also a very commonly applicable test. The augite is pale green in thin sections and not visibly pleochroic. The hypersthene gives $\mathfrak{a} = a$ reddish brown, $\mathfrak{b} = b$ reddish yellow, $\mathfrak{c} = c$ green, almost identical with that of the augite. In the thicker prisms the colors are quite strong. Cleavage is ordinarily not very markedly developed parallel to either pinacoid of the hypersthene. Sections parallel to the macropinacoid show that $\mathfrak{a}$ is the acute bisectrix, but the optic angle is not very small.

The hypersthene of the first specimen of this andesite collected at Buffalo Peak was isolated from the augite by Dr. Hillebrand through continued treatment of the rock powder with strong hydrofluoric acid, which attacks augite much easier than hypersthene. The purest material isolated was found on microscopical examination to be almost free from augite, and the analysis yielded Dr. Hillebrand the following result:

Analysis of hypersthene of hypersthene-andesite from Buffalo Peak, Colorado.

	Per cent.
SiO_2	51.70
Al_2O_3	1.72
Fe_2O_3	0.30
FeO	17.99
MnO	0.36
CaO	2.87
MgO	25.09
Total	100.03

This analysis, made in 1882, is very similar to many that have been made since that time of hypersthene from other rocks. It appears that andesitic hypersthene commonly contains magnesia and ferrous oxide in nearly equal amounts, but varieties richer in magnesia certainly occur in some cases.

The larger magnetite grains are to be considered as phenocrysts. They are frequently included in the pyroxenes, which are free from the more minute specks of iron ore characterizing the groundmass.

The groundmass consists of an almost colorless glass base, appearing brownish by low powers through globulitic specks, holding numerous short microlites of plagioclase and augite, and very minute magnetite grains. No hypersthene could be found among the minute prisms of the groundmass.

Chemical composition.—The following analysis of the fresh rock was made by W. F. Hillebrand:

Analysis of hypersthene-andesite from Buffalo Peak, Colorado.

	Per cent.
SiO_2	56.19
Al_2O_3	16.12
Fe_2O_3	4.92
FeO	4.43
MnO	trace
CaO	7.00
BaO	trace
SrO	trace
MgO	4.60
Na_2O	2.96
K_2O	2.37
H_2O	1.03
P_2O_5	.27
Cl	.02
Total	99.91
Sp. gr. at 16° C., 2.742.	

The percentages of lime and magnesia explain the development of hypersthene. The potash is so high as to indicate that if the rock had completely crystallized there must have been a considerable amount of orthoclase in the groundmass, as this alkali does not normally enter into any of the phenocrystic minerals.

Literature.—An outline of the geology of Buffalo Peaks and descriptions of the hypersthene-andesite were given in Bulletin No. 1, United States Geological Survey, On Hypersthene-andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a geological sketch of Buffalo Peaks, Colorado, by S. F. Emmons, 1883. The "triclinic" pyroxene referred to was augite, cut in sections nearly normal to the prism, and the erroneous determination was retracted in a note in the American Journal of Science, 3d ser., Vol. XXVI, 1883, p. 76.

NO. 87. HYPERSTHENE-ANDESITE.

(FROM WEST SLOPE OF MOUNT SHASTA, CALIFORNIA. DESCRIBED BY J. S. DILLER.)

The later lavas of Mount Shasta are chiefly hypersthene-andesite, and this specimen, No. 87, collected at Horse Camp, near the timber line, upon the western slope of Mount Shasta, represents one of the earlier of the late flows. The final flows upon the same slope are much darker colored and more basaltic in appearance.

The lava illustrated by specimen 87 is a compact, even-grained nonporphyritic rock, of a light-gray color, and contains only a few small crystals of pyroxene, which are visible to the naked eye.

In thin section, however, it becomes conspicuously porphyritic, as illustrated in Pl. XXXII, where the numerous square and brick-shaped crystals of feldspar and grains of hypersthene are seen distributed through a light-gray groundmass.

The feldspar is clear and colorless, showing polysynthetic twinning and zones of growth. It is all plagioclase, apparently, and the angle of extinction, as well as its composition, judging from the chemical analyses below, indicates that it is labradorite.

The chemical analyses were made by W. H. Melville. For the purpose of comparison, a chemical analysis of the later, dark-colored, more basaltic flow is given. In column I is an analysis of specimen 87, and in II is an analysis of a specimen taken from the latest flow.[1]

Analyses of hypersthene-andesite from Mount Shasta, California.

	I.	II.
Loss on ignition	0.20	0.44
SiO_2	64.52	63.03
Al_2O_3	18.31	17.72
Fe_2O_3	0.90	2.27
FeO	2.51	1.92
CaO	5.11	5.97
MgO	2.35	3.63
K_2O	1.25	1.06
Na_2O	4.64	3.92
Total	99.79	99.96

Hypersthene occurs in irregular grains and oblong crystals, like those in the hypersthene-andesite on Buffalo Peak, Colorado. As it is sometimes included in the feldspar, some of the hypersthene must have crystallized before the feldspar. Occasionally dark spots are found to be composed chiefly of magnetite and pyroxene, and suggest the former presence of hornblende.

The groundmass contains much glass, clouded by a multitude of feldspar microlites and minute grains of pyroxene and magnetite.

NO. 88. OLIVINE-BEARING PYROXENE-ANDESITE.

(FROM NEAR THE COMSTOCK LODE, VIRGINIA CITY, NEVADA. DESCRIBED BY J. P. IDDINGS.)

This rock forms a massive lava in the neighborhood of the Comstock Lode, Virginia City, Nevada. The rocks of this region have been described by Mr. George F. Becker,[2] Prof. F. Zirkel,[3] and Messrs. Hague and Iddings.[4] They form a great series of volcanic eruptions, the history of which has been variously given by the authors quoted. The pyroxene-andesite in this educational series is one of these volcanic lavas.

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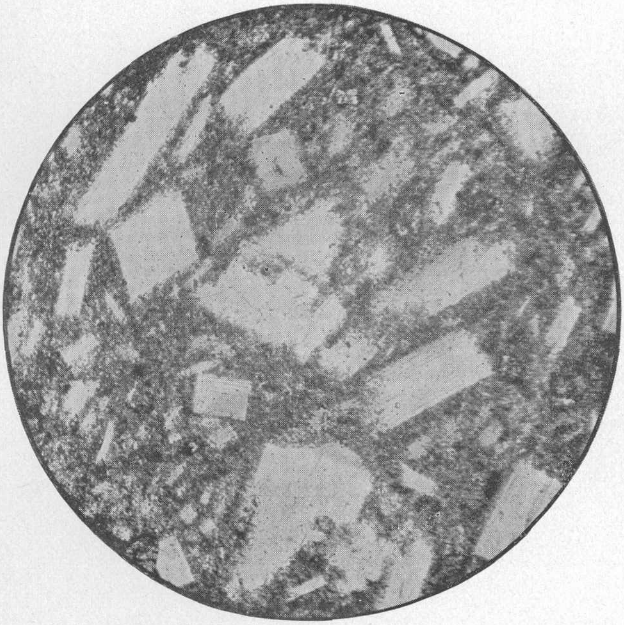
[1] See also Hague and Iddings paper in Am. Jour. Sci., 3d ser., Vol. XXVI, Sept., 1883, pp. 222–235.

[2] G. F. Becker, Geology of the Comstock Lode, etc.: Mon. U. S. Geol. Survey, Vol. III, 1882.

[3] F. Zirkel, Microscopical Petrography: U. S. Geol. Expl. Fortieth Parallel, Vol. VI, 1876.

[4] A. Hague and J. P. Iddings, The Development of Crystallization in the Igneous Rocks of Washoe, Nevada, etc.: Bull. U. S. Geol. Survey No. 17, 1885.



THIN SECTION OF HYPERSTHENE-ANDESITE FROM MOUNT SHASTA, CALIFORNIA, AS SEEN UNDER A MICROSCOPE, × 40.

The rock is dense and grayish black, with an uneven fracture. It sparkles with minute crystals that crowd a dark aphanitic groundmass. The megascopic crystals are feldspars with brilliant cleavage faces, and dark-colored minerals, more or less brilliant, which are pyroxenes. The mineral composition of the rock, however, can be discovered only in thin sections with the aid of the microscope. The rock is then seen to consist of a brown, glassy, and microlitic groundmass, bearing innumerable small phenocrysts of plagioclase feldspar, hypersthene, augite, altered olivine, and a few anhedrons of quartz.

The phenocrysts of feldspar exhibit marked zonal structure and polysynthetic twinning according to albite, pericline, and Carlsbad laws. Cross sections are rectangular, and also show evidences of prismatic and domal faces. The symmetrical extinction angles read from Carlsbad and albite twins, and, interpreted according to the method employed by Michel Lévy,[1] show that the feldspars are labradorite of about the composition Ab_2An_3. The feldspar is perfectly fresh, and carries fine glass inclusions, besides others of magnetite, rounded grains of pyroxene (both augite and hypersthene), apatite, and portions of the groundmass. There are also minute rectangular inclusions, with clear, colorless margins and dusted centers. They have one orientation in one feldspar, and are apparently parallel to the crystallographic axes. Some are comparatively large, others very minute. In some cases they appear isotropic, in others doubly refracting, and resemble feldspar.

In one feldspar crystal there was observed a large inclusion of brown globulitic glass, containing curved lines of opaque grains and rods that stand at right angles to the lines of opaque grains. In some cases these cross rods appear to be transparent prisms, probably pyroxene. These appear to be connected with hair-like needles of pyroxene, and larger needles of augite are present, studded with similar opaque rods and grains, and also with crystals of magnetite. The glass base immediately surrounding these black grains is colorless for a short distance, the brown coloring matter having been concentrated in the augite needles and opaque grains. Along the margin of the feldspar surrounding the brown glass inclusion are projecting crystals of feldspar, like the teeth of a saw. They have lower refraction than the main crystal of feldspar, and also lower angle of extinction, so that they are undoubtedly more alkaline, and may be of the same substance as the minute rectangular inclusions which have just been mentioned, which are sometimes doubly refracting.

The pyroxene is hypersthene and augite in nearly equal proportions, with possibly more augite than hypersthene. The two minerals appear almost identical in thin sections, and are easily confused with one another. The hypersthene has slight pleochroism between reddish and greenish, while the augite is not pleochroic and is pale green. The characteristic prismatic and pinacoidal cleavage is less well developed

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[1] A. Michel Lévy, Étude sur la détermination des feldspaths dans les plaques minces, Paris, 1896.

in the hypersthene than in the augite. General form, twinning, and inclusions are similar in both pyroxenes. The optical properties in one case are those of orthorhombic crystals, in the other those of monoclinic crystals.

The crystals are more or less idiomorphic, stout prisms, with the two pinacoids and unit prism in the prismatic zone, and terminal faces not readily recognizable. Cross sections show the characteristic 8-sided outline of pyroxene crystals. Twinning, in which the orthopinacoid or the macropinacoid is the twinning plane, is common in both pyroxenes.

Inclusions of magnetite are often observed, and also those of feldspar, apatite, and of glass in negative crystal cavities or in irregularly shaped cavities. They frequently carry a gas bubble. In some crystals they are numerous, and often they are very minute.

In certain spots in the rock are clusters of crystals of labradorite and pyroxene with magnetite and some interstitial brown, globulitic, and trichitic glass.

Serpentine derived from the alteration of olivine occurs in pseudomorphs having the shape of sections of olivine, usually 4 or 6 sided, with orthorhombic symmetry. The pseudomorph is surrounded by a narrow border of augite grains. The serpentine is green in some cases and brown in others. The amount of olivine originally present was not great, so that the rock may be classed with the andesites rather than with the basalts.

Magnetite occurs in comparatively large grains or anhedrons, somewhat irregularly shaped. In some cases the magnetite partly incloses pyroxene. It is frequently inclosed by the pyroxene.

There are relatively few crystals of apatite in stout prisms, which are comparatively large. They have the usual hexagonal forms, and are often dusted and slightly pleochroic, between brown and dark sepia, $E>O$. In some crystals there are minute opaque needles lying parallel to the prismatic axis *c*.

In one thin section studied, there is a rounded anhedron of quartz containing colorless glass inclusions with gas bubbles, and in one case what appears to be a colorless crystal with rhombic outline. The quartz is surrounded by brown glass and a shell of pyroxene crystals.

The groundmass is a fine example of glassy andesitic groundmasses. It consists of brown glass full of stout microlites of pyroxene, probably monoclinic for the most part, and those of lath-shaped feldspar, together with grains of magnetite. These are not mingled with complete uniformity throughout the rock sections examined, there being spots which are mostly glass and others mostly crystals. The lath-shaped feldspars are plagioclase, whose exact position in the albite-anorthite scale has not been determined. Besides these microlites, there are small rectangular and lath-shaped feldspars with large extinction angle, probably labradorite, and small anhedrons and prisms of pyroxene and crystals of magnetite. These are slightly larger than the smallest microlites of the groundmass, but are still microscopic and may be classed as microlites.

NO. 89. HORNBLENDE-DIORITE-PORPHYRY.

(FROM SOUTH SIDE OF BUCKSKIN GULCH, 2½ MILES ABOVE ALMA, MOSQUITO RANGE, PARK COUNTY, COLORADO. DESCRIBED BY WHITMAN CROSS.)

Occurrence.—This rock occurs as an intrusive sheet in Silurian strata. Near the point of collection the sheet is 20 feet or less in thickness and it has been traced for several miles with no great increase at any point, although often less than 20 feet thick on account of splitting into two or more parallel sheets. While following the same horizon for long distances, the rock locally cuts obliquely to slightly higher or lower planes of stratification, and in the cliff sections of the gulches it is not always continuous.

The rock maintains the structure and texture of the specimens in this collection except in narrow contact zones, where it is finer grained.

General description.—The freshest rock obtainable has a general greenish-gray tone, and consists of numerous phenocrysts of plagioclase and hornblende lying in a somewhat subordinate fine-grained, greenish groundmass. The phenocrysts vary in size, but seldom if ever reach a diameter of 1 centimeter. Pinkish crystals of orthoclase are usually developed in very small numbers, and biotite may occasionally be distinguished, though commonly altered to chlorite or epidote.

Microscopical examination shows the groundmass to consist of orthoclase, hornblende, and quartz, with a small quantity of plagioclase and magnetite. The accessory constituents, apatite and zircon, are present as usual, with a little titanite, and, sporadically, minute prisms of allanite, which can not be found in all the thin sections. Allanite was not observed megascopically.

The phenocrysts.—The abundant plagioclase phenocrysts are developed in various forms, but chiefly in tabular crystals parallel to the brachypinacoid, often elongated somewhat parallel to the brachyaxis *a*. Twinning is common according to the albite, Carlsbad, and pericline laws, and all three are often combined. Zonal structure indicating change in composition during crystallization is frequently very plain, but the variation in extinction between center and periphery is not great. Primary inclusions are few, apatite and magnetite being most common.

Optical examination shows that labradorite is the predominant member of the series here developed. The maximum of extinction noted is about 30°, and in crystals combining albite and Carlsbad laws of twinning the extinctions in the zone normal to the lamellæ indicate labradorite of the composition 1 albite + 1 anorthite to be most common. Some andesine is thought to be present in crystals characterized by very fine albitic twinning.

The hornblende is the common green variety, with normal pleochroism and extinction. Its crystals are usually well terminated by the common pyramid and dome faces. There is no resorption, and alteration to chlorite has begun externally and on many cleavage fissures. The phenocrysts vary in size and seem to grade rapidly downward to the needles of the groundmass, which have the same characteristics of color and form.

Biotite has not been seen in fresh condition, but stout prisms believed to represent this mineral, now entirely altered to chlorite and epidote, may be found in nearly all sections.

The few orthoclase crystals are clinopinacoidal tablets, usually of irregular boundary, including small plagioclase crystals. This is regarded as an exceptional development of orthoclase during the general groundmass period.

Groundmass.—The groundmass is a distinctly granular mixture of predominant orthoclase with abundant hornblende needles, and some quartz and plagioclase. Orthoclase is developed in irregular grains, plagioclase in small, stout crystals, and quartz either in clear grains or most commonly in a cement for the other constituents, and then usually oriented over small areas so that it practically includes several grains and causes a rudimentary micropoikilitic structure.

The hornblende needles are not very acicular, but they are long enough and numerous enough to express a fluidal structure had there been movement after their formation. As such a structure is not found, these hornblendes are considered as crystallizing during the groundmass period.

Plagioclase is very subordinate, and while its small crystals probably belong to oligoclase or andesine, this has not been proved. Magnetite seems to have formed in two periods, a scanty dust through the groundmass belonging to the later period.

Chlorite, epidote, calcite, and muscovite are secondary products of variable development in the different specimens collected.

Chemical composition.—The average rock has the composition of the following analysis by W. F. Hillebrand:

Analysis of hornblende-diorite-porphyry from Colorado.

	Per cent.
SiO_2	56.62
Al_2O_3	16.74
Fe_2O_3	4.94
FeO	3.27
MnO	.15
CaO	7.39
MgO	4.08
K_2O	1.97
Na_2O	3.50
H_2O	.92
CO_2	1.15
P_2O_5	trace
Total	100.73
Sp. gr., at 16° C, 2.77.	

The analysis agrees very well with the mineral constitution as described. It is clear that the plagioclase must be one containing much lime, and the contents in potash is sufficient to represent a considerable amount of orthoclase in the groundmass. Calcite and chlorite must have been well developed in the material analyzed. It would seem necessary to have some free silica in the rock in view of the large proportion of hornblende and labradorite.

Literature.—This rock and its occurrence, together with the associated eruptives of the Mosquito Range, were described in Monograph XII, United States Geological Survey, Geology and Mining Industry of Leadville, Colorado, by S. F. Emmons, with Petrographical Appendix by Whitman Cross; 1887, pp. 228–240, 334–340. The rock was there called hornblende-porphyrite.

No. 90. DACITE-PORPHYRY.

(FROM CLEAR CREEK, SHASTA COUNTY, CALIFORNIA. DESCRIBED BY J. P. IDDINGS.)

This rock occurs in Smiths Gulch, Shasta County, California. It consists of a dense, greenish-gray, aphanitic groundmass, filled with phenocrysts of white plagioclase feldspar, 15^{mm} long and smaller, and numerous rounded quartzes, the largest of which have a diameter of 7^{mm}, besides much biotite in small crystals, 2^{mm} across, and numerous hornblende prisms, 4 or 5^{mm} long. There are also many very small crystals of these minerals in the groundmass. The specimens collected are probably not all of the same degree of freshness, for in the specimen examined the hornblende crystals are unaltered, while in the thin sections prepared from chips of the same rock the hornblende is decomposed. The rock presents a fine example of porphyritic texture, which is emphasized by the contrasted colors of the feldspar phenocrysts and the groundmass. By porphyritic texture is understood that appearance which is produced when the mass of a rock, having any texture whatever, is sprinkled with crystals larger than those constituting the main mass of the rock. They usually stand out prominently in contrast to the groundmass.

In thin sections of this dacite-porphyry the large feldspars are seen to be twinned according to the albite law, with thin lamellæ, whose symmetrical extinction angles range from 0° to 4°, and are undoubtedly oligoclase. Other modes of twinning, after pericline and Carlsbad laws, are rarely seen in these feldspars. A zonal structure, which shows itself faintly between crossed nicols, is sometimes observed. The crystals are idiomorphic, and exhibit outlines in cross section due to the faces commonly developed in the feldspars of similar rocks, i. e. (001), (010), $(1\bar{1}0)$, (110), $(\bar{1}01)$, $(\bar{2}01)$, and sometimes other subordinate faces. In a few cases the outlines of the sections of feldspar are irregular and are interrupted by "bays" of the groundmass.

The feldspar is partly altered, and as a consequence is clouded white in places by innumerable, minute, irregularly shaped inclusions, which appear colorless in thin section and have a lower refraction than the feldspar substance. Their exact mineral nature is indeterminable. These minute inclusions are sometimes confined to alternate lamellæ of the polysynthetic twins, the intermedite lamellæ being free from them. In other cases they occur in irregularly shaped clouds across all the twin lamellæ of one crystal.

Some of the feldspar phenocrysts inclose green hornblende and brown biotite with sphene, zircon, apatite, and possibly epidote. In one instance the biotite is the same size as that in the adjacent groundmass and lies near the margin of the feldspar. The inclosed mica is parallel to that in the groundmass, which exhibits a fluidal arrangement. This indicates that the feldspar phenocrysts continued to grow after the motion in the groundmass ceased without showing signs of any break or interruption in the act of crystallization. Hence, the growth of these phenocrysts probably took place in the molten magma at a period immediately preceding the solidification (crystallization) of the groundmass of the rock.

The quartz phenocrysts are almost as numerous as those of feldspar. Their outlines are partly idiomorphic, partly rounded, and sometimes exhibit "bays" of groundmass. In some cases the outline is quite sharp against the surrounding groundmass, in others it is jagged and uneven in consequence of the merging of the quartz of the phenocrysts into that of the small grains in the groundmass, proving that the quartz phenocrysts continued to grow in the period of crystallization of the groundmass. Sometimes several quartz phenocrysts have grown in juxtaposition without there being any evidence of definite relation between their orientations. Most of the quartzes exhibit uniform extinction between crossed nicols and optical homogeneity. Others, however, show an irregularly banded extinction, as though they were twinned in lamellæ. These ill-defined, fairly broad bands appear to be parallel to a principal optic section, that is, they may lie in the prismatic zone. In one instance there are also extremely thin, poorly defined bands nearly at right angles to the broad bands. In another case these thin bands cross the broad ones at an inclination of 32°. They may be parallel to a rhombohedral face. A rhombohedral cleavage is marked in some cases and in others there are minute inclusions parallel to the broader bands. The exact nature of these striations has not been determined. They may be the result of molecular readjustment produced by dynamical strains.

The quartz crystals carry inclusions of groundmass, zircon, sphene, monoclinic pyroxene, and very abundant, minute particles, irregularly shaped, apparently fluid inclusions with gas bubbles; in some cases simply gas inclusions.

Biotite occurs in bent flakes, which are crudely hexagonal plates with irregular outline. In thin sections they show an arrangement in lines according to the flow of the magma before solidification. They are strongly pleochroic, being pale yellow for light vibrating parallel to the $\mathfrak{a}$ axis, i. e., nearly at right angles to the cleavage; and dark brown to almost black for light vibrating parallel to the cleavage and at right angles to the $\mathfrak{a}$ axis. The angle between the optic axes is apparently zero, and the mineral behaves as an optically uniaxial crystal.

The hornblendes in the rock sections studied are completely replaced by calcite and chlorite, with numerous colorless prisms of apatite, formerly existing as inclusions in the hornblende. In some cases calcite preponderates over chlorite, or alone constitutes the pseudomorph after hornblende. In other cases chlorite occurs alone.

There is some sphene present in small, sharply idiomorphic crystals, easily confused with those of zircon, which also occur. It possesses the usual optical properties. Zircon is sparingly present in small 4-sided prisms with pyramids of the other order. There is considerable apatite in stout, colorless crystals of small size, having prismatic, basal, and subordinate pyramidal faces.

Epidote occurs in comparatively large, irregularly shaped individuals, and also in sharply defined prisms. Repeated twinning is present in some crystals. There is faint pleochroism in thin sections, from colorless to yellow. From the arrangement of the epidote prisms it is evident that they existed in the magma before the crystallization of the groundmass, for they take part in the flow structure, and the mica plates bend around them in some instances. Either they are primary crystals of epidote that crystallized from the molten magma before its final solidification, or they are pseudomorphs after hornblende prisms, having the b axis of the epidote parallel to the c axis of the hornblende. No cross sections of the prisms that might have shown the characteristic angles of either mineral were observed. While epidote is a frequent product of the alteration of hornblende, it does not appear probable that these epidote crystals have been formed in that manner. They are simple or twinned crystals in each case, and not aggregations of minute anhedrons, as is usual when forming pseudomorphs. Moreover, no epidote was noticed in association with the chlorite and calcite pseudomorphs, which is its most frequent mode of occurrence when secondary after hornblende. The study of rock sections from specimens in which hornblende is not altered might settle this question.

Calcite occurs in comparatively large, but microscopic, anhedrons; sometimes alone, with numerous apatites, and probably replacing a ferromagnesian mineral; sometimes with chlorite, replacing hornblende.

The groundmass of the rock is a microgranular aggregate of feldspar and quartz in allotriomorphic anhedrons of various sizes from .0009$^{\mathrm{mm}}$ to .0025$^{\mathrm{mm}}$ in diameter. The larger anhedrons are mostly striated feldspar, a few only being unstriated and idiomorphic. With these are mingled many microscopic crystals of magnetite, mostly

4-sided, and probably octahedrons, bits of chlorite, and curved plates of biotite, besides many minute, rounded anhedrons having high refraction, and probably epidote.

The very fine grain of the groundmass, which is microcrystalline and megascopically aphanitic, together with its composition, places the rock among the dacite-porphyries.

The chemical composition of this rock is shown in the accompanying analysis by J. Edward Whitfield. The absence of CO_2 and the low content of H_2O indicate that the material analyzed was free from calcite and very slightly altered. The marked preponderance of soda over potash is to be noted.

Analysis of dacite-porphyry from Clear Creek, California.

	Per cent.
SiO_2	64.24
TiO_2	.76
Al_2O_3	18.67
Fe_2O_3	1.40
FeO	1.96
MnO	trace
MgO	1.48
CaO	4.11
Na_2O	4.14
K_2O	1.71
Li_2O	none
P_2O_5	.08
SO_3	.22
Cl	.25
CO_2	none
H_2O	1.18
Total	100.20
Less O for Cl	.05
Total	100.15

NO. 91. MINETTE.

(FROM FRANKLIN FURNACE, SUSSEX COUNTY, NEW JERSEY. DESCRIBED BY J. P. IDDINGS.)

This rock was first described as micaceous diabase by B. K. Emerson[1] in 1882, and has been referred to subsequently as mica-diabase and kersantite. It is, however, minette—that is, a more or less porphyritic holocrystalline rock, poor in feldspar which is some variety of alkali feldspar, orthoclase or albite, or both, and rich in biotite and monoclinic pyroxene. It is a lamprophyre in Rosenbusch's sense.

The rock is dark greenish gray and dense, with a small hackly fracture. Abundant small micas are the only mineral constituent that is recognizable megascopically. There are besides occasional lumps of a white mineral which appears to be either feldspathic or zeolitic. Accord-

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[1] B. K. Emerson, On the dikes of micaceous diabase penetrating the bed of zinc ore at Franklin Furnace, Sussex County, New Jersey: Am. Jour. Sci., 3d series, Vol. XXIII, 1882, pp. 376–379.

ing to Emerson the rock effervesces freely with acid, owing to the presence of calcite. In thin section the rock is seen to be holocrystalline, with a hypidiomorphic granular texture. The ferromagnesian minerals and iron oxide are idiomorphic with respect to the feldspar. Together they also preponderate over the feldspar, which is more abundant, however, than any other one kind of mineral. Taken in the order of their relative abundance the constituents are feldspar, monoclinic pyroxene, mica, magnetite, epidote, calcite, apatite, pyrite; but this order of abundance varies with the degree of alteration, and is different in different parts of the rock.

The feldspar is in part twinned with polysynthetic lamellæ. In some cases twinning is not recognizable. The index of refraction of the feldspar in both cases being lower than that of Canada balsam indicates that the feldspar is albite or orthoclase, or both. It is quite possible that the unstriated crystals, more or less clouded by alteration products, are orthoclase. They sometimes yield long, rectangular sections arranged in fan-like groups, an arrangement often assumed by alkali feldspars. The less clouded, polysynthetically twinned crystals are undoubtedly albite, since their maximum symmetrical angles of extinction are about 15° to 17°, which corresponds to those of albite or andesine, but the lower index of refraction as compared with that of balsam proves it to be albite. The minute flakes and anhedrons scattered through the feldspar appear to be epidote, calcite, and some little chlorite. There are also microscopic crystals of apatite.

Pyroxene is more abundant in some sections than in others, having become more or less altered to epidote and chlorite. The pyroxene crystals are idiomorphic to a high degree, and are bounded by the prism and two pinacoids, the terminal planes not being determinable. The crystals are short, stout prisms. The outlines are sometimes indistinct, owing to the partial alteration to epidote. The prismatic cleavage is distinct, and a zonal structure is occasionally observed. The color in thin section is pale brown, which renders it difficult to discriminate between the pyroxene and epidote. It is monoclinic, with a high extinction angle, and is probably augite. Pleochroism is not noticeable. Inclusions of magnetite and pyrite are numerous. The pyroxene has been replaced, in some cases almost completely, by epidote, and to a less extent by chlorite, quartz, and calcite.

Biotite occurs in abundant crystals, which are six-sided plates, comparatively thick. They are idiomorphic with respect to the feldspar, having crystallized before it; but they are allotriomorphic with respect to the pyroxene, sphene, and magnetite, having crystallized later than these minerals. It partly incloses these minerals, besides numerous small crystals of apatite. Some of the mica crystals are bent and distorted. Twinning is present in some cases. The color in thin section is reddish brown, with strong pleochroism and absorption, between light brown or yellow and dark reddish brown. In convergent polarized light the mineral appears uniaxial, the angle between the optic axes is so small. Alteration has not affected the biotite to the same extent as the pyroxene. Many biotites exhibit no alteration. In some crystals there are lenticular inclusions, placed between the laminæ, which appear to be aggregations of minute grains of epidote, exhibiting aggregate polarization. Chloritization has set in at the margin of some mica crystals.

Sphene is very abundant in comparatively large idiomorphic crystals, yielding the characteristic sharply rhombic cross sections. Cleavage is pronounced. The color in thin section is pale brown, with slight absorption. The index of refraction is somewhat higher than that of pyroxene, and the double refraction is somewhat lower. Otherwise its resemblance to this mineral is very close, and the two are easily confused. It is rather free from inclusions of other minerals, even magnetite, which occur rarely.

Magnetite is present in numerous small crystals and in some anhedrons. Pyrite is quite abundant in crystals apparently bounded by faces of the cube and rhombic dodecahedron in combination. Apatite is also abundant in small, stout prisms, often sharply outlined and bounded by the prism, a pyramid and the basal pinacoid. It occurs scattered through the other minerals—feldspars, micas, and pyroxenes.

Epidote, a secondary mineral in this rock, occurs in aggregates of crystals usually having allotriomorphic outlines, sometimes occupying the place of former pyroxene, sometimes scattered irregularly through the rock in larger or smaller anhedrons. It has nearly the same color as the pyroxene and sphene, but is noticeably pleochroic, with yellow color. Its index of refraction is almost the same as the minerals just named, but its double refraction is higher.

Calcite is present in irregularly outlined anhedrons and to a variable extent. It was not abundant in the thin sections studied. There is also a little secondary quartz and chlorite.

The chemical composition of the rock, as determined by L. G. Eakins, is given in the accompanying analysis, except for the fact that titanium has not been determined.

Analysis of minette from Franklin Furnace, New Jersey.

	Per cent.
SiO_2	40.71
Al_2O_3	19.46
Fe_2O_3	7.46
FeO	6.83
MnO	.18
MgO	6.21
CaO	11.83
Na_2O	1.80
K_2O	3.26
CO_2	.74
H_2O	1.53
Total	100.01

The rock is very low in silica and high in alumina, with comparatively low magnesia, high lime, and relatively high alkalies, chiefly potash. The alumina must have entered largely into the augite together with lime and iron, which accounts for the abundant production of epidote. The formation of alkali feldspars in a magma so rich in lime and alumina and so low in silica is noteworthy. It followed the crystallization of these elements into pyroxene, the alumina having entered largely in the hypothetical subsilicate molecule.

No. 92. Camptonite.

(From Campton Falls, Grafton County, New Hampshire. Described by J. P. Iddings.)

"At Campton Falls there are several dikes which furnish handsome specimens for those who admire dark, porphyritic rocks. The black crystals of hornblende are not large enough to determine with the unaided eye, but they are very brilliant and numerous."[1] These rocks, originally called diorite by Hawes, who recognized their extremely basic character, have become the type of Rosenbusch's camptonite group. The rock in the educational collection is compact and bluish black, with crystalline luster, reflecting light from minute needles. It carries numerous small phenocrysts of hornblende.

It occurs in an 8-foot dike in mica-schist, according to a subsequent description by Hawes.[2] In this description he also furnishes a more complete analysis of the rock, which will be cited later on. In thin section the rock is seen to be holocrystalline and to consist of abundant hornblende crystals and a subordinate amount of feldspar, with some augite and iron oxide, a little biotite and apatite and pyrite, and in some cases an isotropic mineral, which appears to be analcite or sodalite. There is also a variable amount of calcite, serpentine, or chlorite. The preponderant constituent is hornblende, which forms long prisms that are idiomorphic in the prismatic zone, having the prism faces (110) and clinopinacoid (010) well developed. In some cases the clinopinacoid is more developed than the prism faces. Twinning parallel to the orthopinacoid (100) is sometimes present. The color in thin section is chestnut-brown, with marked pleochroism $\mathfrak{c}$ and $\mathfrak{b}$ strong brown, $\mathfrak{a}$ light brown $\mathfrak{c}>\mathfrak{b}>\mathfrak{a}$. The inclination of $\mathfrak{c}$ to c appears to be about 12°. A study of the chemical analysis of the rock in connection with its mineral composition indicates that the hornblende is rich in alumina and contains considerable soda. Its exact chemical composition has not been determined.

The next mineral in abundance is feldspar, which appears to be of

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[1] G. W. Hawes, Mineralogy and Lithology: Part IV of the Geology of New Hampshire, Vol. III, p. 161, Hitchcock, Concord, 1878.

[2] G. W. Hawes, On a group of dissimilar eruptive rocks in Campton, New Hampshire: Am. Jour. Sci., 3d series, Vol. XVII, 1879, p. 147 et. seq.

several varieties. The greater number of crystals exhibit little or no polysynthetic twinning, and have very low angles of extinction. These crystals are probably oligoclase and orthoclase. They occur in long, slender prisms, sometimes with a tendency to divergent arrangement. They have a lower refraction than those feldspars in the rock which exhibit more pronounced twinning in thin lamellæ, and yield symmetrical extinction angles as high as 20°. These feldspars may be andesine. They are subordinate to the more alkaline ones in amount. So that it appears that the feldspars of this rock are decidedly alkaline and are not basic, as they were supposed to be by Hawes.[1]

Some of the rock sections contain a colorless, isotropic mineral in comparatively large individuals. Its outline is irregular, and it is traversed by irregular cracks, and no distinct cleavage cracks. It is probably analcite, but no determination of its exact nature has yet been made. Its quantity varies in different rock sections; from some it is absent.

There is a variable amount of monoclinic pyroxene present. It is quite abundant in some sections and scarce in others. It is pale yellow to violet in thin section, and is slightly pleochroic. The violet color may be due to titanium, which, according to Hawes's analyses,[1] is present in the rock in considerable amount. The pyroxene is more or less altered to serpentine. In some sections the change has been complete. When unaltered it has the usual form and cleavage, and sometimes the twinning parallel to the orthopinacoid. Some crystals of pyroxene inclose brown hornblende. The pyroxene is probably augite.

A brown mica, biotite, is also present in comparatively few large crystals; its outline is ill-defined, and it incloses numerous crystals of other minerals. The rock contains many small crystals of iron ores, mostly in well-defined crystal forms, which yield sections with 3 and 4 sides. They are white by incident light, and appear to be partly altered to leucoxene. They may be titaniferous magnetite, or ilmenite. Some of the opaque anhedrons of iron ore are pyrite, having a brassy color in incident light. There are numerous microscopic needles of colorless apatite. There is considerable calcite and serpentine which do not occupy spaces that may be certainly referred to former pyroxene crystals. These are secondary minerals.

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[1] Loc. cit.

The chemical composition of the rock is given by the following analyses, I by G. W. Hawes, and II by L. G. Eakins:

Analyses of camptonite from Campton Falls, New Hampshire.

	I.	II.
	Per cent.	*Per cent.*
SiO_2	41.94	38.45
TiO_2	4.15	....
Al_2O_3	15.36	19.68
Fe_2O_3	3.27	4.01
FeO	9.89	11.15
MnO	.25	trace
MgO	5.01	6.65
CaO	9.47	9.37
Na_2O	5.15	2.77
K_2O	.19	1.72
CO_2	2.47	4.82
H_2O	3.29	1.49
Total	100.44	100.11

These analyses differ from one another considerably, chiefly in the alumina and alkalies and in the determination of titanium oxide. The rock varies in the content of analcite, but it is doubtful whether the high alumina percentage given in II is correct. Titanium is undoubtedly present in considerable quantity. The difference in carbon dioxide may well be due to variability in the amount of calcite present.

No. 93. DIORITE.

(FROM MIDDLE BRUSH CREEK, AT BASE OF THE TEOCALLI MOUNTAIN, GUNNISON COUNTY, COLORADO. DESCRIBED BY WHITMAN CROSS.)

Occurrence.—This diorite occurs as a very irregular stock with ramifying dikes cutting through the Carboniferous in the southern Elk Mountains. The part of the stock included within the Crested Butte quadrangle is more than 10 miles in length and it extends northward into the Aspen quadrangle for several miles more. Large stocks of the same rock occur elsewhere in the Elk Mountains and in other parts of Colorado. The specimens collected show the average grain and composition of the diorite mass, but variations in grain are occasionally met with, and a subordinate porphyritic structure is locally developed.

Description.—The rock is light gray, fine grained, composed chiefly of plagioclase, orthoclase, quartz, biotite, and hornblende. The light-colored minerals predominate, with but slight variation in the ratio of biotite to hornblende, over large areas; but, locally, quartz decreases in amount and then augite often appears as the associate of the other dark silicates. Magnetite is quite subordinate. The rarer accessory constituents, seen only under the microscope, are apatite, titanite, zircon, pyrite, allanite, and an unknown dark-brown mineral.

Plagioclase is the most important element of this diorite. It occurs almost entirely in idiomorphic crystals, varying in size between 0.5^{mm} and 1.5^{mm}. These are developed in tabular form parallel to the brachypinacoid. Twinning according to the albite laws is usual, united with the Carlsbad and pericline laws in many cases. Zonal extinctions are very marked, indicating a change in composition of the feldspar molecule as crystallization progressed. The main part of the crystals seem to be labradorite, as the symmetrical extinctions in the zone normal to the albitic twinning reach nearly to 40°. Tests on crystals showing both Carlsbad and albitic twinning point to labradorite of the composition 3 albite + 4 anorthite as most common. Doubtless andesine and oligoclase are present as outer zones in some cases.

Orthoclase is much subordinate to plagioclase, but is still a very important constituent. It occurs only in irregular grains, or added to the plagioclase crystals in oriented position, especially in the zone of the ortho (macro) axis. Quartz appears in irregular grains exactly analogous to the orthoclase, these two minerals being the last elements to form, and mutually interfering with each other.

Biotite is reddish brown in color, in thin, irregular leaves. Hornblende occurs in irregular prismatic grains, green in color. Now one of these dark minerals predominates, now the other. They are of similar size, seldom reaching 2^{mm} diameter, and are both more or less altered, chlorite and epidote being common products.

Of the accessory constituents magnetite, apatite, and zircon occur in common forms. Titanite appears in irregular grains, seldom in characteristic crystals. Allanite was seen in two slides, out of a large number examined. It was there developed in irregular grains.

An unknown mineral is present in some sections in minute, dark-brown, strongly pleochroic, and absorptive prisms, included in feldspar or quartz.

Chemical composition.—An analysis of the fresh diorite by L. G. Eakins yielded the following:

Analysis of diorite from Elk Mountains, Colorado.

	Per cent.
SiO_2	62.71
TiO_2	undet.
Al_2O_3	17.06
Fe_2O_3	3.79
FeO	2.74
MnO	trace
CaO	5.51
MgO	1.78
K_2O	2.96
Na_2O	3.54
H_2O	.24
Total	100.33
Sp. gr., at 30° C., 2.79.	

These figures show silica to be so high as to explain the quartz content, and the relative strength of potash explains the abundance of orthoclase. The lime is strong enough to produce a plagioclase rather rich in this element.

Literature.—The geological occurrence of this rock is illustrated in the Anthracite-Crested Butte Folio, No. 12, Geologic Atlas of the United States.

No. 94. Diorite.

(From Electric Peak, Yellowstone National Park. Described by J. P. Iddings.[1])

This diorite occurs as a part of a stock of igneous rock which was forced through Cretaceous strata in early Tertiary times. The surrounding sandstone and shale have been metamorphosed by the contact with the intruded lavas. The stock and connecting dikes were once part of a volcano which built its cone upon the surface of the Cretaceous rocks. The interior of the volcano has been laid bare by faulting and erosion.

The diorite mass has a variable grain, but is for the most part coarsely crystalline, the clusters of feldspars and of ferromagnesian minerals ranging from 5^{mm} to 2^{mm} in diameter. These clusters, which give the apparent texture to the rock, are composed of from two to a dozen crystals of feldspar and an intermingled aggregate of ferromagnesian minerals. The constituent minerals are hypersthene, augite, hornblende, biotite, lime-soda feldspar, orthoclase, quartz, magnetite, with apatite. Of these, augite, hornblende, biotite, and plagioclase are the most abundant. The structure is hypidiomorphic granular. The plagioclases are more nearly idiomorphic than the other constituents, but are not strictly so. They are rectangular to lath-shaped. They were formed in large part early in the course of crystallization. Some are found penetrating brown hornblende. Orthoclase is present in some cases in small amount, and either surrounds crystals of plagioclase as a partial border or forms irregular grains as cement between them. Quartz also forms irregular grains between the other minerals, as though the last mineral to crystallize. It carries fluid inclusions. Hornblende, pyroxene, and biotite rarely exhibit crystal boundaries. Their outlines are usually very irregular, and they penetrate one another in a most complex manner. Magnetite is scattered through the rock in crystals or grains, being most commonly found within the ferromagnesian minerals. Apatite occurs in short, stout crystals, not very well formed, and is colorless. Zircon is rare.

The plagioclase feldspars exhibit the characteristic polysynthetic twinning and sometimes zonal structure. Some carry abundant minute inclusions. In some cases these are colorless rectangular bodies of an

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[1] The eruptive rocks of Electric Peak and Sepulchre Mountain, etc.: Twelfth Ann. Rept. U. S. Geol. Survey, 1892, pp. 569-664.

indeterminable nature, but suggesting glass. Others are dots and minute rods or needles in swarms. Small grains of the ferromagnesian minerals may also be included.

Hypersthene is not always present, but occurs in parts of the rock. It exhibits a faint pleochroism in thin sections, green $\parallel \mathfrak{c}$, yellow $\parallel \mathfrak{a}$, and light red $\parallel \mathfrak{b}$. Its outline is irregular, and it is generally surrounded by hornblende, occasionally by augite or biotite. The augite is pale green in thin sections and is not pleochroic. It seldom exhibits crystallographic outline, but forms irregular grains, and is generally surrounded by hornblende. Biotite is dark brown to yellow in thin sections, with strong absorption. Its outline is irregular. It occurs outside of the pyroxenes in most instances, as though a younger mineral, but it may be partly inclosed by them, as if to some extent contemporaneous.

Hornblende is in part green, in part brown, the latter kind being usually within the former. The green hornblende often surrounds pyroxene and biotite wholly or partially. Generally they form an intricate intergrowth, as though they had crystallized at about the same time. The problem of this intergrowth is discussed at length in the article on The Eruptive Rocks of Electric Peak and Sepulchre Mountain, Yellowstone National Park, by J. P. Iddings, in the Twelfth Annual Report of the Director of the United States Geological Survey, for 1890-91, page 606 et seq.

The chemical composition of the diorite as determined by J. E. Whitfield is given in the analysis:

Analysis of diorite from Electric Peak, Yellowstone National Park.

	Per cent.
SiO_2	56.28
TiO_2	.84
Al_2O_3	14.23
Fe_2O_3	4.69
FeO	4.05
MnO	.16
CaO	7.94
MgO	6.37
Li_2O	.01
Na_2O	2.98
K_2O	1.23
P_2O_5	.40
SO_3	trace
Cl	.17
H_2O	.93
	100.28
Less O for Cl	.04
Total	100.24

GABBRO-BASALT FAMILY.

NO. 95. VOLCANIC SAND.

(FROM SNAG LAKE CINDER CONE, LASSEN COUNTY, CALIFORNIA. DESCRIBED BY J. S. DILLER.)

Volcanic sand is sand that has been produced from molten rock material by a volcanic explosion. Taken with volcanic dust, it is often referred to as volcanic ash, but is not ash in the same sense as is that resulting from the burning of wood or coal. In order that its formation may be more clearly understood, it is necessary to consider some of the conditions and surface features of volcanic eruptions.

Deep borings, mines, and wells have been sunk at many points on the earth's surface, and wherever observations have been made the temperature has been found to increase downward toward the earth's interior. The increase is by no means regular, and yet the rate generally does not vary greatly from an average of about 1° F. for every increase of 57 feet in depth.

If the temperature increased at this rate regularly to a depth of 20 miles, the temperature would be over 1,850° F., and at 50 miles over 4,600° F., or far higher than the fusing point of all rocks under ordinary conditions.

We need not stop here to inquire further into the condition of the earth's interior, whether it be solid or liquid, or as to the source of heat, whether it is a residue of the original incandescent earth, or is due to chemical action, or is produced by the mechanical crushing of rocks. Let it be sufficient for our purpose to know that the interior portion of the earth, below a depth of a few miles from the surface, is very hot.

Rain falls on the mountain slopes. Some of it gathers into rills, runs into brooks, creeks, and rivers, and finally finds its way back into the sea whence it came. Another portion enters the soil, and, under the influence of gravity, passes through the pores, cracks, and fissures of the rocks to various depths within the earth. On the lower slopes of the mountains and in the valleys much of the water which entered above reappears from springs, most of which are cool and refreshing. In some cases, however, the water penetrates so far into the earth before reappearing in springs that it is warmed by the internal heat. Thus warm springs, hot springs, and boiling springs are produced.

In those boiling springs in which the outlet is large enough to allow the heat to escape, the movements of the water are comparatively uniform; but in certain cases the outlet is narrow in proportion to the length of the more or less vertical tube in the ground, and there is not sufficient opportunity for the heat to escape. The heat increases until the expansive force of the highly heated water and steam is sufficient to produce an explosion. The overlying water and steam, as illustrated in Pl. XIV (p. 92), are thrown into the air by the eruption. Such springs are geysers, and steam is the motive power in their eruption.

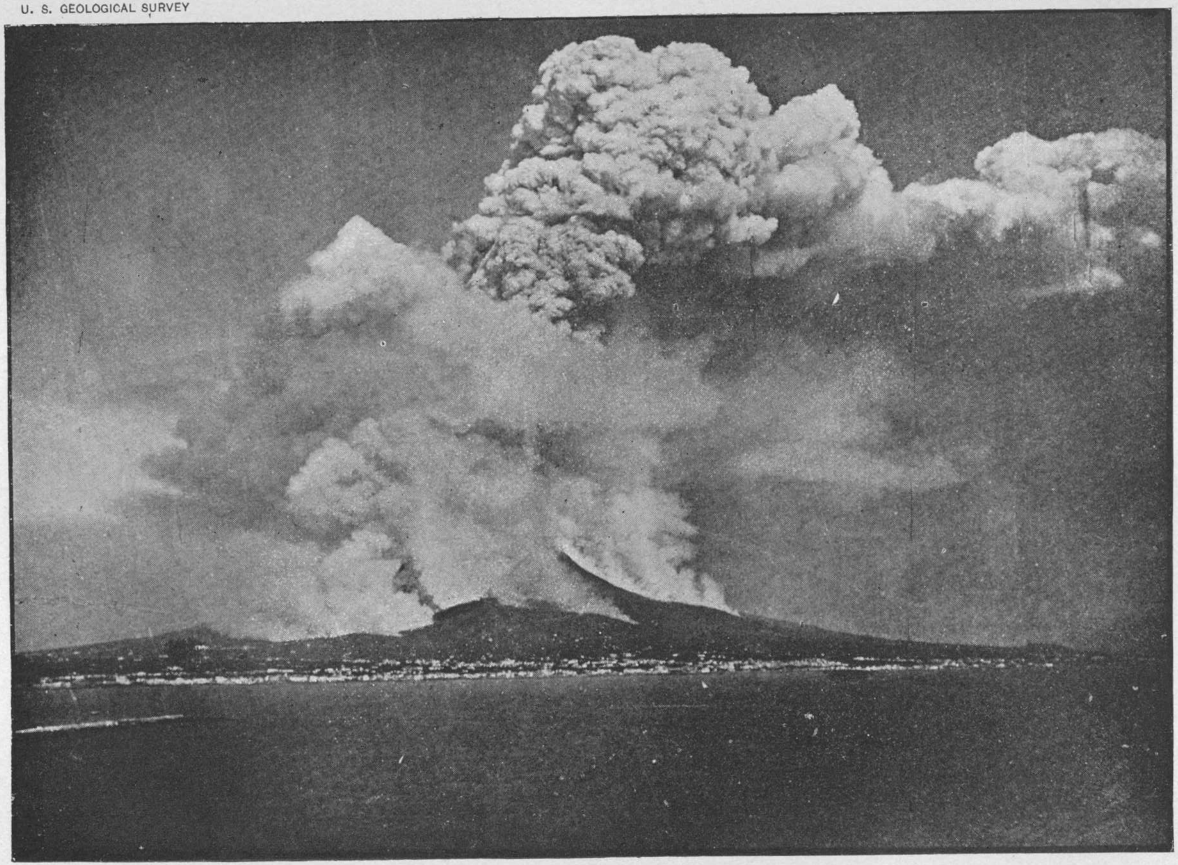
Next more important than eruptions of water in geysers are eruptions of mud. A notable one occurred in 1888 at Bandai-san in Japan. Large quantities of mud, saturated with steam or highly heated water under pressure, were developed a short distance beneath the surface. A great explosion occurred, removing the whole side of the mountain. A vast quantity of steam escaped, and streams of mud flowed down the valley, damming water courses to form lakes, and destroying a number of villages.

In true volcanic action the material transferred from the interior of the earth to the surface is neither simple water, as in the geyser, nor mud, as in the semivolcanic eruption at Bandai-san, but melted rock. It may come from greater depths than either of the others, where the temperature is higher, and the rocks may be either in a molten condition or so hot that when the pressure upon them is relieved they fuse and become eruptible.

A fine sample of a truly volcanic eruption is afforded by the stupendous explosion of Krakatoa, in the Straits of Sunda, in August, 1883. The explosion was heard for a distance of more than 150 miles, and a mass of matter 1⅛ cubic miles in bulk was blown to pieces and hurled high into the air in the form of pumice, ashes, and fine dust. The dust, very like that of specimen No. 58, was thrown to a height of 17 miles in the air and spread far and wide by the winds. Some of it fell hundreds of miles from its source. The air wave set in motion by this great explosion traveled around the earth three times, and the sea in the neighborhood was thrown into waves, one of which was computed to have risen more than 100 feet above tide level, destroying villages and 38,380 people.

The eruption at Krakatoa differed from that at Bandai-san chiefly in that the material was, at least in large part, not in the form of mud, but in a state of aqueo-igneous fusion, i. e., actually molten. In the geyser and the eruption of mud the material is impelled to the surface by steam. The same is true also in the final delivery of molten rock, or magma, in such eruptions as that of Krakatoa, where the explosion must have been due chiefly to the expansive force arising from water or its component elements. In that case, however, all the molten material was blown out by the explosion. None of it flowed out.

The large quantities of steam given off by volcanoes in eruption, as shown in Pl. XXXIII, is illustrated by the great clouds of vapor which rose from Vesuvius during its eruption in April, 1872. The steam clouds were given off not only near the summit of the mountain where the eruption took place, but also from the streams of molten rock coursing down its sides. These streams are marked by lines of vapor. On the left the lava reaches the very base of the mountain, while on the right are two separate streams reaching nearly to its base. This eruption differed from those already noted in that some of the material was blown out by explosion at the mountain's summit, while the larger



VESUVIUS IN ERUPTION, APRIL 26, 1872.

part of the molten material flowed out and formed lava streams or coulées.

It must not be supposed from the fact that attention has been called to the action of steam in volcanic eruptions that it is the principal agent involved; such a conclusion would be incorrect; steam has probably little to do with the raising up of great masses of molten material from the earth's interior; the cause of such upraising is not well understood, but when the molten material has reached the earth's surface, steam has much to do with the form of its delivery.

Volcanic eruptions are of two forms—explosive and effusive. In the first form the material is blown to fragments and violently hurled into the air; in the second, the magma—that is, the molten rock material—wells up within the volcano and flows out upon the surface, forming coulées. In some cases the volcanic eruption is wholly explosive, as at Krakatoa; in others it may be wholly effusive, as at Mauna Loa, in Hawaii, but generally both forms occur together, as at Vesuvius.

The same was true also at the small volcano at Snag Lake, 10 miles northeast of Lassen Peak, California, where the products of the explosive and effusive eruptions are quite distinct, one forming the cinder cone, and the other a lava field, both of which are illustrated in part by Pl. XXXIV.

Volcanic sand, specimen No. 95, was obtained from the sand field shown in the foreground in Pl. XXXIV. Lapilli, specimen No. 96, came from the cinder cone in the distance, and quartz basalt, specimen No. 101, was collected from the lava field to the right, where the lava was not covered by sand as in the view.

The finest material blown from this volcano, volcanic sand, spread in all directions from the vent, covering the ground as a sheet for a distance of about 8 miles. The coarser fragments fell close to the vent, and, piling up, formed the cinder cone, surmounted by a cup-shaped crater from which its material was blown.

The maximum thickness of the sand at the base of the cinder cone could not be distinctly ascertained. It is loose and slides easily, so that a great deal of excavating is required to get through it where the layer has considerable magnitude. One-fourth of a mile from the base of the cone, where specimen No. 95 was collected, the sheet of fragmental material is 4 feet 4 inches thick. It consists of two portions. The upper part is properly called volcanic sand; the lower part, however, is composed of small, light brown pumiceous fragments, ranging in size from that of a pea to an inch in diameter. The fragments are very vesicular but still not sufficiently light to float on water like ordinary pumice (No. 59). They are very rough and jagged, with surfaces torn by the bursting cells once filled with steam or other eruptive gases. Some of them were produced by concussion. The pieces hurled violently into the air frequently struck others, and all were partially pulverized as in a great mill. This sort of sediment is more abundant in the volcanic sand which overlies the pumiceous material, and was therefore ejected at a subsequent stage of the eruption. Many of the sand grains are vesicular, but less so than the pumiceous fragments, and are generally rounded. Other grains are angular and composed of compact lava with few vesiculæ. They are bounded by fracture surfaces, and were evidently produced by the violent concussion of larger fragments. A few grains of quartz, feldspar or olivine of early crystallization, are present.

The sand exhibits irregular stratification, due to the sorting action of the atmosphere upon the subsiding particles during the eruption. The thin layers are lenticular in shape and continuous for short distances only, not as sharply defined as beds laid down in water, but indicating a decided tendency to form beds under favorable conditions. This tendency is most clearly manifested a short distance away from the volcanic vent, where the air was not so much disturbed by the violent current expelled from the crater.

The selective influence of the atmosphere may be seen not only in the imperfect stratification of the sand, as exhibited in a vertical section, but also in its distribution upon the surface. Near the cinder cone the sand is coarse and the bed thick, but the bed becomes thinner and the sand becomes finer as the distance from the cone increases.

On the borders of the large circular field covered by the sediment thrown out from the crater the fine material is sand, and there is no evidence to show that any considerable amount of volcanic dust or material still finer than the finest sand was formed.

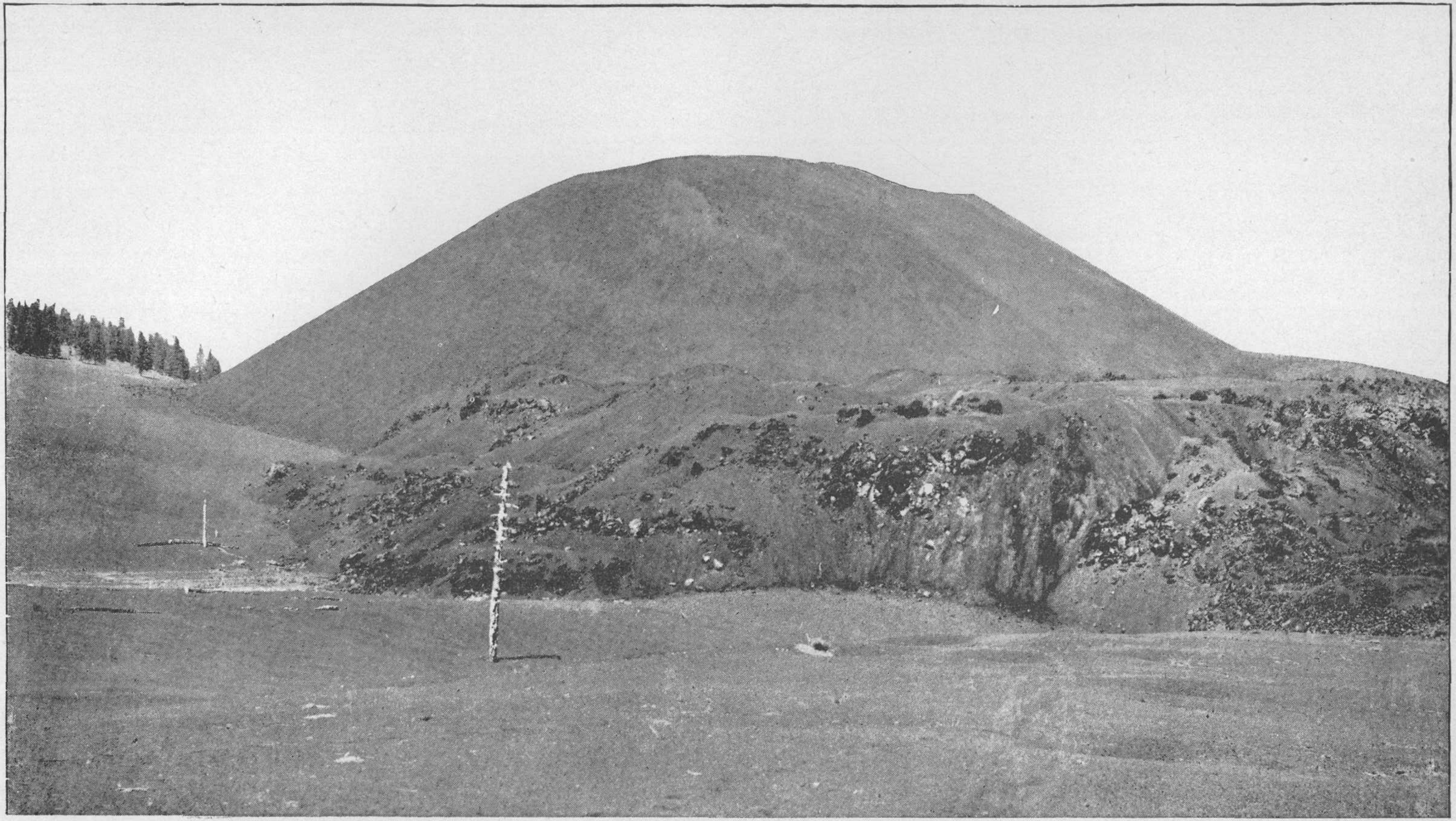
The almost complete absence of volcanic dust in this case is surprising when we consider the highly explosive character of the eruption, and it may be attributed in part, perhaps, to the viscous condition of the magma at the time of the outburst. Had the pumiceous fragments in the layer already referred to contained sufficient eruptible gases at the time of the ejection to blow them to atoms, considerable dust would doubtless have resulted.

For an illustrated description of the volcanic phenomena exhibited at this recently active center, reference may be made to Bulletin No. 79, United States Geological Survey, and to the Lassen Peak Folio.

No. 96. Lapilli.

(From Snag Lake Cinder Cone, Lassen County, California. Described by J. S. Diller.)

The volcanic fragments next larger than grains of sand are lapilli. They are usually very porous and differ from the sand particles chiefly in size, ranging from that of a pea to several inches in diameter. Most of them are black, but shades of red and yellow prevail locally, and when abundant may give color to the whole cone. The lapilli of the cinder cone illustrated in Pl. XXXIV, from which specimens 96 were obtained, are generally black, giving it a somber aspect. A cinder cone in Arizona, northeast of Flagstone, noted for the brilliant colors



CINDER CONE, 10 MILES NORTHEAST OF LASSEN PEAK, CALIFORNIA.

of its lapilli, is called Sunset Peak. Lapilli are also called "volcanic cinders;" hence the name *cinder cone*, applied to all cones of loose volcanic material about the vent from which it issued.

The lapilli of the Snag Lake cinder cone remained long enough in the air to become completely solidified before striking the ground, for they show no signs of flattening by impact, nor do they show upon their surfaces any lines of flowage, such as are so plainly marked in the next specimen (No. 97), from the cinder cone of another locality.

The following chemical analysis of lapilli from Snag Lake cinder cone, made by W. F. Hillebrand, shows that its composition is essentially the same as that of the lava in the lava field (No. 101). Both are quartz basalt.

Analysis of lapilli from Snag Lake Cinder Cone, Lassen County, California.

	Per cent.
SiO_2	56.53
TiO_2	.54
Al_2O_3	17.50
Cr_2O_3	trace
Fe_2O_3	1.35
FeO	5.03
MnO	.12
CaO	8.07
SrO	trace(?)
BaO	trace
MgO	5.94
K_2O	1.55
Na_2O	3.51
Li_2O	trace
H_2O	.27
P_2O_5	.15
Total	100.56

No. 97. SCORIA.

(FROM ICE SPRING CRATERS, MILLARD COUNTY, UTAH. DESCRIBED BY J. S. DILLER.)

The volcanic fragments of some cinder cones have surfaces like slag, showing lines of flowage. Such fragments, especially when cellular, have been called *scoria*. The cinder cone from which specimen No. 97 was taken shows many traces of the original molten condition of its material. Upon the surface of the lava which escaped from this cone there are distinct flow lines, and also upon the inner slopes of the crater where the subsiding magma left trickling remnants.

The fragments of scoria in many cases show by flattening that they were yet soft when they fell, and other well-preserved flow forms indicate that they were not hurled violently from the crater. If that were the case they would have been broken by collision or rounded by impact, as specimen No. 96. Instead they were ejected gently—that is, sputtered out—and were so soft and sticky as to mold themselves and adhere to that upon which they fell. Mr. Gilbert graphically describes them as "volcanic bombs whose aerial flight was too short to permit them to harden." For a description of the volcanic features of Ice Spring craters reference should be made to Gilbert's monograph on Lake Bonneville, Monographs United States Geological Survey, Vol. I, pp. 320 to 325.

NO. 98. VOLCANIC BOMB.

(FROM NEAR MOUNT TRUMBULL, YAVAPAI COUNTY, ARIZONA. DESCRIBED BY J. S. DILLER.)

Besides the sand and various forms of lapilli ejected from an active volcano there are other fragments, generally larger, designated *volcanic blocks* or *bombs*. The angular ones are blocks and the round ones are bombs. The latter are illustrated in Pl. XXXV, which is a photograph of those at the base of the Snag Lake cinder cone. They were hurled into the air, fell upon the steep slopes of the cinder cone, and rolled to its base. They are compact throughout, excepting upon the surface, where they are more or less vesicular. This vesicular covering shows that their form is not due to the impact of the neighboring particles during the eruption, but to some earlier cause. Some of these bombs are over 8 feet in diameter, and it is difficult to believe that they became round and cool while flying through the air, for that would postulate an unreasonable rapidity of cooling. That they were solid when they struck the ground is evident, because they did not flatten as did those ejected from the Ice Spring craters of Utah, the Mono craters of California, and many others. It appears probable that these large bombs were the first part of the lava to solidify and were suspended in the magma before the eruption, when they were hurled out of the crater in their present form. This view of their origin explains also their compact structure as compared with the vesicular character of the other ejected material.

The volcanic bombs collected for this series were obtained from one of the cinder cones on the Uinkaret platform, a short distance southeast of Mount Trumbull, Arizona. On this platform are a number of symmetrical cinder cones, the result of geologically recent volcanic activity, the eruptions from which cascaded over the cliffs for thousands of feet to reach the bottom of Grand Canyon. Among the fragmental material of which these cones are made up are found great numbers of these "lava balls," ranging in size from that of a pea to 5 feet or more in diameter. The average size is nearly that of the specimen in the collection. Many of them are red from the oxidation of the iron, but others are dark, with surfaces ramified by a series of cracks.

The origin of these bombs is believed to be similar to that of those at Snag Lake cinder cone, where they were certainly ejected as independ-

VOLCANIC BOMBS AT BASE OF CINDER CONE, 10 MILES NORTHEAST OF LASSEN PEAK, CALIFORNIA.

ent fragments. Their spherical form is generally attributed[1] to rotation while flying through the air. Professor Dana[2] says that at Hawaii such forms are produced "by the rolling movement of the front of the stream due to friction at the bottom." They sometimes have a center of olivine or more scoriaceous lava.

Some of the bombs near Mount Trumbull were found containing olivine nodules, such as specimen No. 104, which were evidently solid at the time of the eruption, and may have been shot into the air like a bullet. The same mineral nodules occur also in the lava stream, especially in its vesicular portions, and when they are released by weathering closely resemble volcanic bombs.

The volcanic phenomena of that region are described by C. E. Dutton in Vol. II of the Monographs of the United States Geological Survey, p. 101 to 112, to which the student is referred for further information. A fuller discussion, On the Fragmentary Ejectamenta of Volcanoes, is given by H. J. Johnston-Lavis in the Proceedings of the Geologists' Association of London (1885–86) Vol. IX, pp. 421 to 432.

No. 99. BASALT TUFF.

(FROM BATTLE CREEK MEADOWS, TEHAMA COUNTY, CALIFORNIA. DESCRIBED BY J. S. DILLER.)

Fine fragmental, volcanic material, such as dust, sand, and small lapilli, when cemented so as to be more or less firmly coherent is *tuff*. The term, as explained under andesite tuff (No. 79), is made to cover all pyroclastic rocks of which the component fragments are finer than coarse volcanic conglomerate. It varies greatly, owing to the character and size of the component parts, from a very fine granular, light-colored rock, such as would result from lithifying volcanic dust like specimen No. 58, to a conglomerate made up of lapilli, such as specimen No. 96, and is designated according to the kind of lava fragments it contains, as basalt tuff, andesite tuff, rhyolite tuff, etc.

Specimen No. 99 was obtained near the summit of a cone from whose base issued a stream of basalt that flowed down the canyon of Battle Creek for miles. The cone was made up by the accumulation of volcanic sand and lapilli about the orifice from which they issued, but instead of being loose material, as at the Snag Lake cinder cone, it is cemented and forms a tuff cone. The cementation probably occurred in connection with the volcanic outbreak. Eruptions are generally accompanied by rains from condensed steam. When the rain is sufficiently copious the saturated mass of fragmental material may flow as mud and become consolidated, forming tuff. Mud flows are sometimes disastrous. Pompeii was buried by such a stream from the slopes of Vesuvius. Cones made of tuff are tuff cones. They are generally less steep than cinder cones, and distinctly stratified.

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[1] Geikie, Text Book of Geology, 3d edition, pp. 200 and 201. Also Judd's Volcanoes, p. 70.

[2] Dana, Manual of Geology, 4th edition, p. 289.

The basalt tuff, specimen No. 99, is strongly contrasted with the andesite tuff (No. 79), not only in the size and composition of its fragments but especially in its distribution with reference to the source of material. The sand and dust of which the andesite tuff was made spread far and wide over the country, and may have been derived from numerous distant volcanoes about Lassen Peak. They were deposited in a body of water and formed part of an extensive bed. On the other hand, the basalt tuff presented by specimen No. 99 is a land-made deposit, limited in its distribution to one small cone. It is somewhat stratified parallel to the slope of the cone. This arrangement is due to assorting done by the air and the sliding of the material down the steep slopes.

NO. 100. CELLULAR BASALT.

(FROM ICE SPRING CRATERS, MILLARD COUNTY, UTAH. DESCRIBED BY J. S. DILLER.)

By the expansion of gases contained in lava cavities are developed. If the cavities are small the lava is *porous*. If they are large and rather regular, either spherical or elongated, the lava is *vesicular*. When the vesicles are so abundant, as in specimen No. 100, that the space between them is reduced to a fine wall, the structure is *cellular*.

Specimen No. 100 was obtained from the interior portion of a large ejected fragment or bomb near the eastern base of the Mitre, the same crater upon whose slope the specimen of scoria (No. 97) was collected. Much of the lava of this region is vesicular, but it is rarely cellular.

The lava having the cellular structure (No. 100) is basalt. Vesicular structure is common in basalts, but is rare or entirely wanting in the more siliceous lavas. The vesicles in many cases are elongated by movements of the mass, and show the direction of the flow. When the vesicles are filled with secondary minerals, such as occur in specimen No. 139, the structure becomes amygdaloidal.

NO. 101. QUARTZ-BASALT.

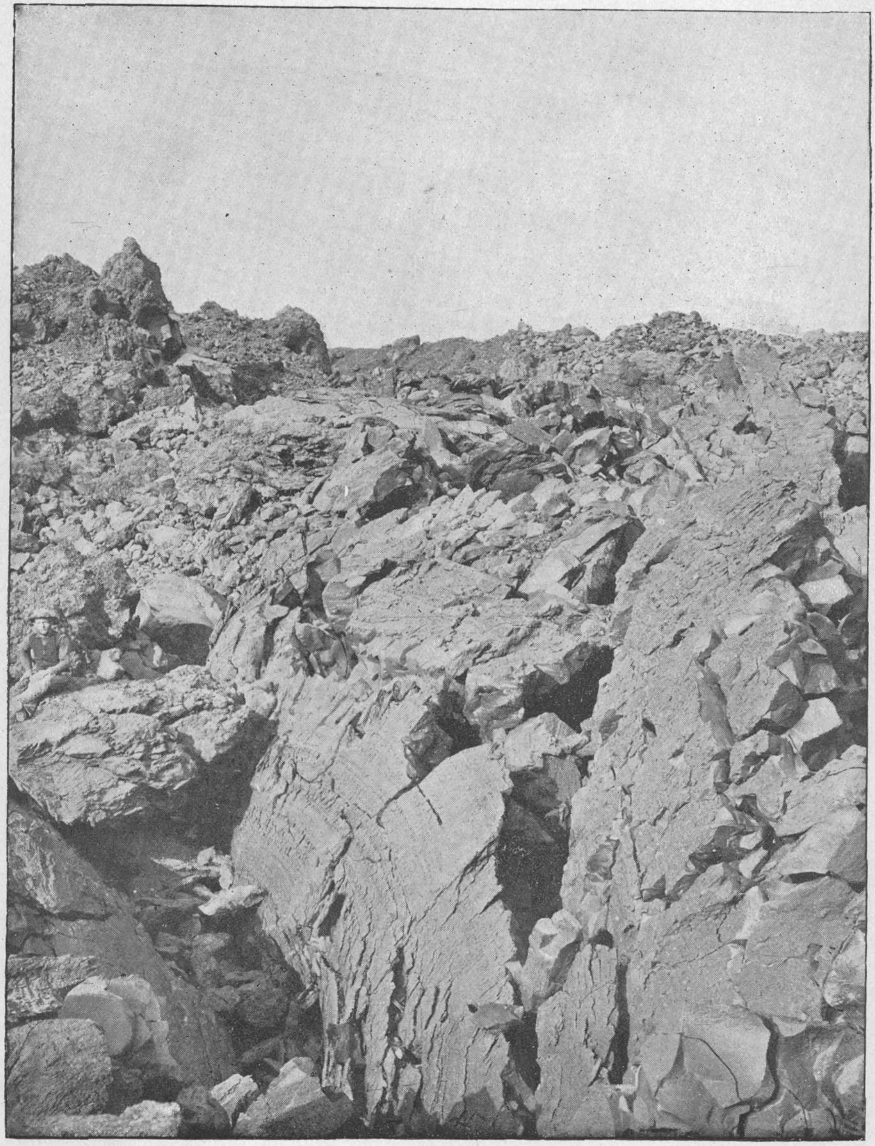
(FROM SNAG LAKE CINDER CONE, LASSEN COUNTY, CALIFORNIA. DESCRIBED BY J. S. DILLER.)

Quartz-basalt is basalt which is characterized by the presence of primary quartz.

One of the latest volcanic eruptions in this country, so far as is yet definitely known, occurred a little more than 200 years ago near Snag Lake, 10 miles northeast of Lassen Peak, California. The cinder cone, ash field, and lava field, seen in Pl. XXXIV, look as fresh as though the eruption took place only yesterday.

There were two lava flows from the base of the cinder cone. The older is partially covered by volcanic sand, as shown in Pl. XXXIV. The surface of the younger flow is shown in Pl. XXXVI to be without any covering of volcanic sand. Specimen No. 101 was collected from the younger flow.

The lava is quartz-basalt. It is a dark, compact, more or less porphyritic rock in which crystals and grains of quartz are distinct, but



SURFACE OF LAVA FIELD 10 MILES NORTHEAST OF LASSEN PEAK, CALIFORNIA.

Latest lava, not covered by sand.

usually not conspicuous. Under a microscope it is seen to be composed of quartz, plagioclase feldspar, pyroxene, and olivine, together with accessory magnetite and a large proportion of unindividualized material which is generally globulitic. The feldspar is most abundant; then follows pyroxene in nearly equal amount, with less olivine and quartz. The globulitic base makes up nearly 25 per cent of the whole mass.

The olivine occurs in grains or well defined crystals, which often include small coffee-brown isotropic crystals, supposed to be picotite. It is one of the first minerals to crystallize in the magma, and is rarely surrounded by a dark border. The pyroxene is chiefly hypersthene, but augite is sparingly present, especially in the shells surrounding the quartz.

The feldspar occurs in two sets of crystals. The largest have their interiors clouded by a multitude of glass and globulitic inclusions, and their irregular outlines indicate that their initial forms were modified by the corrosive action of the magma. The other feldspar crystals are lath-shaped, polysynthetic twins, such as are common in rocks of this class.

Grains and crystals of quartz in considerable numbers occur uniformly distributed throughout the lava, and are especially remarkable on account of the shell of augite and glass by which they are enveloped. This feature is illustrated in Pl. XXXVII, where it is seen that the quartz is occasionally wholly resorbed by the magma, and its place marked by a group of granular augite.

The chemical composition of the quartz-basalt from Snag Lake is given below, as determined by W. F. Hillebrand. It shows a large percentage of silica, but this feature can not be considered as necessarily the one which determined the presence of quartz; its origin may be referred to other causes.[1]

Analyses of quartz-basalt from Snag Lake lava field, Lassen County, California.

	Per cent.
SiO_2	57.25
TiO_2	0.60
Al_2O_3	16.45
Fe_2O_3	1.67
FeO	4.72
MnO	0.10
CaO	7.65
SrO	trace
BaO	0.03
MgO	6.74
K_2O	1.57
Na_2O	3.00
Li_2O	none
H_2O	0.40
P_2O_5	0.20
Total	100.38

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[1] See Bulletin U. S. Geol. Survey No. 66, by J. P. Iddings.

Quartz-basalts are relatively rare. They hold essentially the same relation to basalts that the dacites do to the andesites, or the rhyolites to the trachytes. A fuller illustrated description of the quartz basalt (No. 101) and its associated volcanic phenomena may be found in Bulletin No. 79, United States Geological Survey, by J. S. Diller.

No. 102. Basalt.

(From Watchung Mountain, Orange, New Jersey. Described by J. P. Iddings.)

The basalt which forms a sheet intercalated in the red sandstone (Juratrias) of New Jersey and constitutes a capping to the ridge known as the First Mountain of the Watchung Range was undoubtedly a sheet of lava that flowed over the surface of the country in Juratrias times. The rock in the collection is from the large columns exposed in John O'Rourke's quarry, near those illustrated in Pl. IV (p. 20), in West Orange Township, and is, therefore, from the lower portion of the lava sheet.

The rock is dark bluish-gray when freshly fractured, usually turning greenish upon exposure. It is compact and breaks with an even-grained texture. Megascopically it is finely crystalline to aphanitic, sometimes slightly porphyritic, with small phenocrysts 1^{mm} or 2^{mm} long. Owing to its durability and to the readiness with which it is broken into regular blocks, it is extensively quarried for paving stones, and is also crushed for road metal and used for macadamizing many miles of roads in this region. It is frequently columnar, or exhibits less regular prismatic jointing, and is the well-known "trap" rock forming the crests of the Watchung Range, Bergen Hill, and the Palisades on the Hudson River.

In thin sections, under a microscope, the rock is seen to consist of abundant monoclinic pyroxene and much plagioclase feldspar, with magnetite and scattered patches of microlitic and globulitic glass base, and a variable amount of serpentine or chlorite. The pyroxene, which is in excess of the feldspar, is mostly malacolite, being pale green to colorless in thin sections, with high double refraction and poorly developed cleavage. It may easily be confounded with olivine. However, the occurrence of completely altered areas inclosed in perfectly fresh pyroxene indicates that the serpentine represents a much more easily altered mineral, such as olivine. The pyroxene of similar basalts and diabases occurring in Connecticut was analyzed by G. W. Hawes[1] and shown to be an iron-lime-magnesia pyroxene, low in alumina, corresponding to the composition of malacolite. In the basalt of Orange Mountain it does not exhibit the basal parting, or twinning, or the idiomorphism that characterize salite. It is probable that olivine was present in the rock before decomposition set in. A few partly

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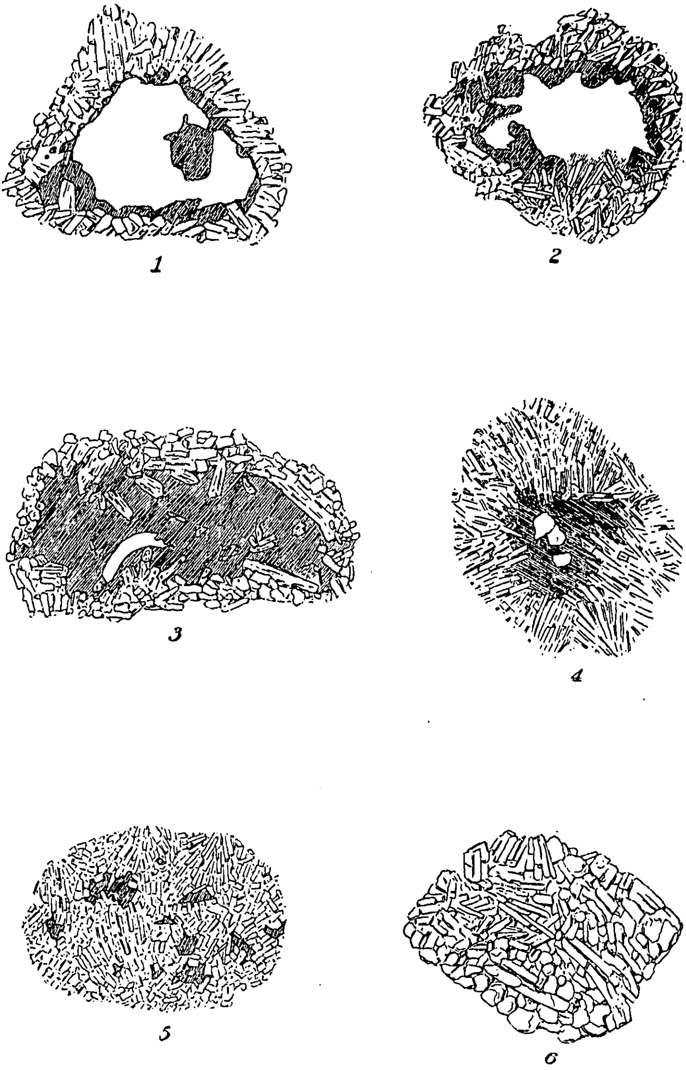
[1] G. W. Hawes, On the mineralogical composition of the normal Mesozoic diabase upon the Atlantic border: Proc. U. S. Nat. Museum, 1881, pp. 129-134.



SECTIONS OF QUARTZ GRAINS AND SURROUNDING SHELLS OF GLASS AND AUGITE FROM LAVA FIELD 10 MILES NORTHEAST OF LASSEN PEAK, CALIFORNIA.

altered crystals of this mineral have been observed in some thin sections. In others there are brown serpentine pseudomorphs which are unquestionably decomposed olivines. It is possible that the scattered patches of serpentine which have been deposited in irregularly shaped spaces have resulted from the alteration of olivine. But serpentine may also be derived from the decomposition of the malacolite.

The plagioclase feldspar forms lath-shaped crystals with polysynthetic twinning, often with only 3 or 4 stripes. The high extinction angles and relatively strong double refraction show it to belong to the more calcic species, probably labradorite. Hawes has shown that two species of feldspar often occur together in these rocks, and has demonstrated the presence of labradorite and anorthite.[1]

The feldspar is in part altered to an almost colorless, brilliantly polarizing mineral, without definite crystallographic boundaries, probably prehnite.

Remnants of a glass base are occasionally observed. They form angular patches, the glass being colorless with globulites and microlites, mostly of augite with attached grains of magnetite. The magnetite is sometimes present in small aggregations. In places this residual base is holocrystalline, possibly through alteration. A study of the whole rock-mass showed that glass was more abundant in the upper portion of the lava sheet.

The chemical composition of this rock is shown in the analysis made by L. G. Eakins:

Analysis of basalt from Watchung Mountain, New Jersey.

	Per cent.
SiO_2	51.36
Al_2O_3	16.25
Fe_2O_3	2.14
FeO	8.24
MnO	.09
NiO	.03
CaO	10.27
MgO	7.97
K_2O	1.06
Na_2O	1.54
H_2O	1.33
CO_2	......
Total	100.28

For a description of the columnar structure of this rock, see The columnar structure in the igneous rock on Orange Mountain, New Jersey, by J. P. Iddings: Am. Jour. Sci., 3d series, Vol. XXXI, May, 1886, pp. 321–331.

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[1] G. W. Hawes, loc. cit., p. 131.

No. 103. Columnar Jointing in Lava.[1]

(From Karnak Ridge, Montezuma Range, Churchill County, Nevada.
Described by J. P. Iddings.)

The occurrence of this rock, under the name of rhyolite, is described by Messrs. Hague[2] and King[3] in the Reports of the U. S. Exploration of the Fortieth Parallel, where illustrations of its columnar structure are given.

> Along the crest of this [Karnak] ridge the rhyolite forms a series of clusters of prismatic columns of all sizes from 3 feet down to an inch in diameter. They show from 3 to 7 sides, most frequently 5, but in many cases the fifth side will be much longer than the other four, with a slightly curving outline and a tendency to develop a sixth side. The four-sided figure would seem to be the least common. Usually they stand in an approximately vertical position, that is, above an angle of 60°. The tendency to columnar structure shows itself in various degrees of perfection, from the symmetrical prism to a single set of parallel planes diagonal to the bedding of the rock. The most perfect prismatic forms are found near the summit, becoming less and less sharply developed farther down the slopes. The exterior of the columns, generally of a dark, almost chocolate brown color, fades in many instances into a reddish gray. The interior is an exceedingly brilliant, pure gray.

The microscopical characters of the rock have been described by Zirkel[4] and referred to those of rhyolite, but they are those of hornblende-mica-andesite or possibly of some form of dacite.

The rock has a light-gray, aphanitic groundmass, with many small phenocrysts of feldspar, biotite, and hornblende. The feldspar phenocrysts are all lime-soda feldspar in idiomorphic forms, with marked zonal structure and numerous glass inclusions. The values of the symmetrical extinction angles are such as to indicate that the feldspars are labradorite in part. The glass inclusions are colorless in some cases and dark brown in others. Other inclusions in the feldspars are thin prisms of apatite, magnetite, zircon, and occasionally hornblende and biotite.

The hornblende phenocrysts are very small and have poorly developed forms. Cross sections show the presence of the unit prism (110) and clinopinacoid (010). The crystals are sometimes irregularly shaped anhedrons. Pleochroism is pronounced from greenish brown and brown to light brown: $\mathfrak{c}$ = greenish brown, $\mathfrak{b}$ = brown, and $\mathfrak{a}$ = light brown. The absorption is $\mathfrak{c}>\mathfrak{b}>\mathfrak{a}$. Some crystals in thin section exhibit a narrow border of magnetite grains and augite microlites; others are free from it.

Biotite occurs in thin plates and also in comparatively thick crystals with more or less irregular outline. It has a brown color similar to that of hornblende, with strong absorption. It carries inclusions of

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[1] This rock, although a quartz-bearing mica-andesite or dacite, is given this place in the series because columnar jointing is most common in basalts.—J. S. D.

[2] A. Hague, U. S. Exploration of the Fortieth Parallel, Vol. II. Washington, 1877, p. 761.

[3] C. King, ibid, Vol. I. Washington, 1878, p. 644.

[4] F. Zirkel, Microscopical Petrography: Vol. VI, U. S. Geol. Expl. Fortieth Parallel. Washington, 1876, p. 177.

magnetite, sometimes in the central part, sometimes in the margin; besides few opaque needles.

Magnetite occurs in minute crystals. Apatite forms numerous long, slender prisms with dust-like inclusions. Zircons are very few and small. There are a few phenocrysts of quartz with rounded and irregular outlines, carrying glass inclusions.

The groundmass is holocrystalline, consisting of irregularly shaped anhedrons of feldspar and quartz in micropoikilitic growth, the whole being clouded by minute particles, probably gas cavities in most cases. There are, besides, microscopic idiomorphic feldspars with rectangular outlines, sometimes forked at the corners. These exhibit polysynthetic twinning in some cases, but not in others. The smaller ones have a low extinction angle and are probably oligoclase. It is questionable whether any may be orthoclase. In places there are idiomorphic crystals of quartz surrounded by a clouded zone of quartz and feldspar in micropœcilitic intergrowth. The groundmass also contains minute crystals of magnetite and scales of mica, besides microscopic prisms of apatite.

Columnar structure, or the separation of a rock into prisms more or less straight and parallel to one another, is not confined to any one kind of rock, although it is most frequently developed in igneous rocks and especially in basalts. The most familiar examples of columnar rocks are basalts, notably the Giant's Causeway and Fingal's Cave in Ireland, the columnar lavas in the Auvergne in central France, and those of the Snake River Canyon in Idaho and of the valley of the Columbia in Oregon. Excellent columnar structure occurs in the basalt or trap of the Palisades on the Hudson and of Watchung Mountain, west of Orange, as shown in Pl. IV (p. 20), and at Paterson and Little Falls, in New Jersey. But equally good columns are found in the rhyolites and obsidian in numerous localities in western America, notably in the Yellowstone National Park and in Nevada. They also occur in andesites and other kinds of igneous rocks, and even in granite in rare instances. Less perfect columns are sometimes observed in limestone, baked clays, and coal. In all cases the prismatic cracking is the result of a contraction of the rock mass, either through cooling, as in the case of volcanic lavas, or through loss of substance upon drying or baking, when water or vaporizable portions of the mass have been driven off by the heat of adjacent intruded rocks.

In igneous rocks the prismatic cracks start at right angles to the plane or surface of cooling, and if the rate of cooling is uniform over the surface the cracks continue in a straight line, producing straight prisms. If the cooling is not uniform at the surface, the columns or prisms become curved, often in diverging groups. When the rock mass is perfectly homogeneous and the cooling is uniform, the columns are hexagonal and of uniform thickness; but these conditions are seldom realized in nature, and the number of sides may vary, as may also the thickness of different prisms. The slower and more gradual the shrinkage of the mass, the larger the columns. And since the rates of cooling at the upper and lower surfaces of a lava sheet resting upon the surface of the earth are usually quite different, it often happens that the lower portion of a lava sheet will be separated into larger columns than the upper portion. Moreover, since the cooling at the bottom is generally uniform, while that from the top may be irregular, the bottom columns are usually straight and normal to the bottom plane, and the upper columns are curved in diverging groups. Small prisms in volcanic lavas sometimes correspond exactly in shape to the well-known starch prisms which have been produced by the drying of a mass of starch. For a discussion of the production of columnar structure, consult the following articles:

On the origin and mechanism of production of the prismatic (or columnar) structure of basalt, by R. Mallet: Philosophical Magazine (4), vol. 1, 122, 201.

On columnar fissile and spheroidal structure, by T. G. Bonney: Quart. Jour. Geological Society, 1876, p. 140.

The columnar structure in the igneous rock on Orange Mountain, New Jersey, by J. P. Iddings: Am. Jour. Sci., 3d series, vol. 31, 1886, p. 321.

No. 104. Olivine Nodule from Basalt.

(From near Mount Trumbull, Yavapai County, Arizona. Described by J. P. Iddings.)

The rock which carries these nodules is a recent lava flow whose place of occurrence is illustrated and described in Monograph II, United States Geological Survey, pp. 111 and 112. These nodules are found not only in the lava flow, but also as bombs among the ejected material of the cinder cone from whose base the coulée issued.

The rock is a basalt, in part highly vesicular and scoriaceous, having a dark gray to black color, and in part solid and compact. In the vesicular portion the nodules are several inches long and thick; in the compact rock they are small, nearly the size of lima beans or almonds or walnuts. The shape of the nodules is quite irregular, some being rounded, others angular with smooth surfaces. A megascopic examination shows that in some cases the nodules are composed of several kinds of minerals, though chiefly olivine. Some appear to consist of diallage or a mixture of diallage and olivine. The small ones in the compact basalt seem to be nearly pure olivine in nearly all cases. The basalt also carries comparatively large crystals of black hornblende and feldspar, which are less noticeable than the nodular inclusions.[1] These nodules are granular crystalline aggregates of pale-green olivine,

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[1] In the field, when the nodules of olivine and diallage were collected, crystals of hornblende and feldspar, occasionally an inch in diameter, were seen. The outer surfaces in nearly all cases were irregular, showing embayments due to the corrosive action of the magma. J. S. D.

with a variable amount of green pyroxene. The olivine crystals have a vitreous luster and subconchoidal fracture.

The vesicular basalt containing the nodules when seen in thin section is found to have an almost opaque groundmass, filled with small cavities, abundant small olivines and occasional augite crystals, besides relatively few lath-shaped microlites of lime-soda feldspar. In places these microlites are more abundant and the groundmass is partly transparent and is crowded with minute opaque dots. The opaque matter is undoubtedly magnetite in very minute grains, or crystals so numerous as to prevent the transmission of light through rock sections of the ordinary thinness. In the very thinnest edges it is possible to make out the presence of other constituents, whose character, however, is not determinable directly.

The almost microscopic phenocrysts of olivine scattered through this groundmass are generally idiomorphic, with the outlines usual to such crystals—that is, the sections are rhombs or six-sided figures; but some of the crystals are imperfectly developed and have irregular outlines, or are skeleton forms of growth, with jagged outline and numerous pockets or bays of groundmass, and also inclosures of groundmass. Such forms result from rapid crystallization in a quickly cooling magma. The olivine is nearly colorless, with strong double refraction, yielding brilliant colors between crossed nicols. Some of the crystals are twinned, so that two crystals cross one another, or are in juxtaposition, with their vertical axes inclined to one another at an angle of about 60°. This arrangement may be brought about when the twinning and composition planes are the unit brachydome (011), an observed mode of twinning in olivine. Augite crystals about the size of the olivines are scarce. They form somewhat rounded and irregularly shaped crystals, which are pale green in thin section and are not pleochroic. They are also strongly doubly refracting, and are brilliant between crossed nicols, being distinguished from olivine by their color and more marked cleavage, which is the usual pyroxene cleavage in the prismatic zone. The inclined extinction angles measured against these cleavage cracks reach as high as 42°. The augites are full of irregularly shaped inclusions of glass, and of multitudes of minute dot-like inclusions, which also may possibly be glass.

There are still less frequently irregularly shaped crystals of dark brown hornblende with strong pleochroism, which contain inclusions of groundmass. They are the same as the large megascopic crystals of black hornblende already mentioned.

The feldspar microlites are exceedingly small, are in many cases forked at the ends, and are twinned in two strips parallel to the long axis of the microlite. The symmetrical extinction angles, reaching 32° in some instances, indicate that the feldspar is labradorite.

The nodules in thin section are seen to consist of anhedrons of olivine, with a subordinate amount of pyroxene, which is in part orthorhombic, in part monoclinic.

The olivine is colorless and has wholly allotriomorphic outlines. In some cases it is without cleavage, in others there is a more or less distinct pinacoidal cleavage. In general the substance is quite pure, but inclusions are numerous in some individuals. They are in part negative cavities having the form of hollow crystals of olivine; in part they are rounded, or form an irregular network of cavities. These seem to be filled with gas in some cases and with liquid in others, there being a moving gas bubble within the liquid inclusion. Occasionally the cavities are cut in making the thin section, and balsam enters and partly fills them. There are also rod-like inclusions of a brown mineral, which lie in parallel lines. They appear to be the same as stouter inclusions of similar shape, which have the same direction and the same color. They also occur in irregular shapes and as rounded grains like the larger brown grains which have a higher index of refraction than olivine, are isotropic, and are either picotite or chromite. Some individuals of olivine, when seen between crossed nicols, exhibit a parallel banding, as though composed of comparatively broad lamellæ with slightly different angles of extinction, which might be due to polysynthetic twinning.

The pyroxene resembles the olivine very closely, but has a grayish-green tinge, with no pleochroism, but with marked cleavage as in pyroxenes. Some of it has the parallel extinction and lower double refraction of orthorhombic pyroxene, and is probably enstatite. Other individuals have higher double refraction and inclined extinction, and are probably diopside. Both pyroxenes in some cases carry numerous gas and fluid inclusions with moving bubbles, which have the shape of crystals of the matrix, or may be irregularly shaped. Occasionally the pyroxene is striated as though by polysynthetic twinning.

In one section examined there is a little violet-brown glass between crystals of olivine within the nodule. When olivine lies in contact with this glass it has its proper crystal form, which indicates that the glass is a remnant of the matrix out of which the olivine crystallized. This kind of glass was not observed around the margin of the olivine nodule.

The outline of the margin of these nodules in thin section is irregularly jagged, with minute bays and pockets of the groundmass of the surrounding basalt penetrating into the crystals of olivine and pyroxene. There is no sign of crushing of the olivine along the margin of the nodule.

In mineral composition these nodules resemble certain varieties of peridotite, since they consist of olivine with picotite, or olivine with diopside and enstatite and picotite, and might possibly be considered inclusions of fragments of such rocks. But the olivine is the same as that in the basalt, and in some cases there is brown glass within the nodule. It is probable that these nodules are segregations that have formed within the molten basalt magma, either in lumps the size of the present nodules or in larger masses which have been cracked upon the eruption of the basalt magma. Analogous segregations of hornblende often occur in andesites. Similar nodules of olivine are found in basalt in various localities, some of them being very large masses. For a review of the different hypotheses that have been advanced to explain the formation of olivine nodules, the student is referred to Prof. Zirkel's Lehrbuch der Petrographie, Second Edition, Vol. II, p. 931.

NO. 105. DOLERITE.

(FROM VALMONT, BOULDER COUNTRY, COLORADO, THREE MILES EAST OF THE TOWN OF BOULDER. DESCRIBED BY WHITMAN CROSS.)

Geological occurrence.—The rock to be described occurs as a vertical dike, running east and west, 20 to 40 feet wide, and nearly 2 miles in length. The formation cut by the dike is the Fox Hills, or upper division of the Montana group of the Cretaceous, a series of sandy shales and friable sandstones. The locality is on the plains, 4 miles from the foothills, and the shales are nearly horizontal. The specimens were obtained from the west end of the dike, just above the village of Valmont. Here the dike rises about 200 feet, with vertical walls near the top and débris-covered slopes below.

It is supposed that this rock was erupted during the Denver period of the post-Laramie, and that at the time of eruption there may have been a thickness of 2,000 feet, more or less, of sedimentary rocks above the horizon at which the dike is now exposed. Basaltic magma of practically identical composition was erupted at this time at several places, some 14 to 16 miles nearly south from Valmont, and the product is now seen in dikes and in the surface flows of Table Mountain at Golden. It is considered probable that the Valmont dike also represents a channel through which the basaltic magma rose to the surface. Aside from analogy with the occurrence near Golden, a further support of this supposition is afforded by the uniform texture and structure of the Valmont rock from wall to wall and from end to end of the dike. This is interpreted to mean that the magma cooled at a very uniform rate, such as could be experienced only where the adjacent shales had become highly heated by the long-continued passage of lava through the fissure conduit.

General description.—The Valmont dolerite is a very dark porphyritic rock, whose most distinct phenocrysts are dark augite prisms, with a maximum length of 1^{cm}, while most of them are less than 0.5^{cm} long, and there is a regular gradation down to those less than 1^{mm} in length. By careful search a few glassy olivine crystals may be seen, especially where serpentinization has begun. Reflection from the curved fissure planes of the fresh olivine phenocrysts often gives them a metallic luster. Some olivine crystals reach a length of 3^{mm}, but the average is about 1^{mm}.

Feldspar phenocrysts are rarely discernible with the naked eye, but examination with a lens shows the dark-gray mass in which olivine and augite crystals are embedded to consist very largely of plagioclase tablets, whose narrow cross sections exhibit a very fine striation on the basal cleavage plane. These tablets lie irregularly, and their boundaries seem indistinct. The lens also shows the dark color of the mass to be largely due to many minute black and green particles regularly disseminated through the whole.

Microscopical examination of thin sections shows the rock to consist of the minerals already mentioned, with the addition of orthoclase and biotite and the accessories magnetite and apatite. The dark specks giving color to the mass are magnetite, augite, and biotite. The angular spaces left between the plagioclase tablets are for the most part filled by orthoclase. No glassy or globulitic base exists in this rock.

The constituents are fresh, excepting some of the olivines, which are partly changed into golden-yellow serpentine, and patches of feldspar, which are cloudy.

Characteristics of constituents.—The augite is of a dull, greenish-gray color, occasionally exhibiting a yellowish tinge or becoming nearly colorless in certain zones. The phenocrysts are stout prisms of the usual forms, but the outlines as seen in thin sections are almost always somewhat irregular lines. Zonal structure is rarely seen, but a few crystals show a colorless zone near the outer border. This is free from inclusions, while the green portion commonly contains numerous round or irregular sack-shaped brown glass inclusions, together with grains of magnetite, olivine, and prisms of apatite. Very rarely these are arranged in zones, though an irregular kernel of the crystal is frequently free from inclusions. Biotite leaflets are sometimes included in augite.

There are many small phenocrysts of augite, but there is a decided gap between these and the irregular greenish grains of a second generation, which average 0.05 to 0.20^{mm} in diameter.

Olivine is developed in a manner closely corresponding to that of augite. Its most distinct phenocrysts show prisms and domes. Inclusions of magnetite, apatite, and glass are numerous. The latter are usually small and round and show black globulitic devitrification. They are sometimes zonally arranged. Biotite leaves are rarely found in the olivine.

All stages of serpentinization can be seen in almost every thin section, but the majority of the crystals are very fresh. The fibrous golden-yellow product contrasts markedly with the colorless olivine. It develops in fibers normal to the various fissure planes in the crystal.

Plagioclase is so developed in this rock that it is difficult to determine what varieties are present. The larger crystals are tablets parallel to the brachypinacoid, but their other boundaries are either imperfect or are obscured by the later growths. There are probably at least two varieties of the lime-soda series present. The older of these forms the larger tablets, 1 to 3^{mm} long, and quite narrow. These usually present very thin laminæ, twinned according to the albite law, and such polysynthetic parts are often further twinned by the Carlsbad law. In addition, twinning by the pericline law is often found. The maximum observed extinction in the zone normal to the predominant pinacoid is nearly 40°, which indicates that such crystals must be at least as rich in lime as labradorite.

Probably different from these larger crystals are the small staves of plagioclase, which are abundant. It is also difficult to make out the form of these crystals.

Orthoclase is probably an element of considerable importance in the Valmont dolerite, but it is practically impossible to prove its identity in most thin sections. The cause of this difficulty lies in the manner in which it is developed—in irregular grains, as the last crystallized mineral, between other constituents. But there are some cases where plagioclase crystals are more or less completely surrounded by an irregular border of apparent feldspathic substance which extinguishes uniformly parallel to the pinacoidal line of sections normal to the laminæ. That this substance and many of the simply polarizing grains are orthoclase is strongly indicated by the chemical analysis of the rock and by analogy with the basalts of similar composition near Golden, where the development is much more distinct.

Biotite occurs abundantly and very regularly distributed throughout the rock in little greenish-brown flakes having a tendency to attach themselves to olivine and magnetite. They are apparently included both in augite and olivine. No large leaves have been noticed. Only rarely do the flakes have a hexagonal form.

Magnetite is scattered through the rock, but is less abundant than in most basalts. It is the most abundant inclusion in the olivine and augite crystals.

Apatite is present in characteristic prisms, but is not so prominent as in andesite. No zircon crystals have been observed, and no titanium minerals.

Structure.—The large augite and olivine prisms distributed through the dense feldspathic mass of the rock give it a porphyritic structure, but microscopical study shows that there is not quite that relation between phenocrysts and groundmass which is commonly found in porphyritic rocks. The distinct crystals of augite and olivine lie in a mass which also contains crystals of labradorite, but these grade downward in size to correspond with a probably distinct feldspar occurring in staves, while orthoclase with some oligoclase fills the interstices between the older tabular crystals.

It is true that augite occurs in what is apparently a second generation in small irregular grains, which are embedded in or lie between the feldspar crystals. This rock has therefore a peculiar structure not commonly met with, and it serves to illustrate one way in which porphyritic structure may be produced without a second generation of the chief minerals; for while the augite and possibly other minerals may have had a second period of formation, the porphyritic structure seen is not due to that cause.

Chemical composition.—Below is given the analysis of the typical rock (I), and that of augite isolated from the same (II). Both analyses are by L. G. Eakins.

Analyses of dolerite from Valmont, Colorado, and of augite therefrom.

	I.	II.
	Per cent.	*Per cent.*
SiO_2	48.25	49.10
TiO_2	.89	....
Al_2O_3	16.73	7.95
Fe_2O_3	3.99	trace
FeO	6.28	8.30
MnO	trace	....
CaO	8.32	22.54
BaO	.013	....
MgO	5.77	12.37
K_2O	4.08	trace
Na_2O	3.24	trace
H_2O	1.72	....
P_2O_5	.68	....
Cl	.08	....
SO_3	.12	....
Total	100.163	100.26

The greater part of the titanic acid of the rock is undoubtedly contained in the augite, but it was not determined in the analysis of this latter.

The analysis is that of a typical basalt, except as to the alkalies. The high amount of potash found confirms the belief that the last feldspar crystallizing in this basalt is orthoclase. In the closely allied basalts of Table Mountain at Golden there is likewise a larger amount of potash than soda. Perhaps the presence of biotite is also due to this abundance of potash. This mineral is also developed in the Golden basalt.

Literature.—The basaltic occurrences of this region are fully described in Monograph XXVII of the United States Geological Survey, Geology of the Denver Basin, Colorado, by S. F. Emmons, Whitman Cross, and G. H. Eldridge.

NO. 106. DIABASE.

(FROM WEST ROCK, NEW HAVEN, CONNECTICUT. DESCRIBED BY L. V. PIRSSON.)

Northward from the city of New Haven there extends through Connecticut and into Massachusetts a long, narrow area of sandstones which, from their fossil contents, are known to be of Triassic age. The length of this belt is about 110 miles and its width about 20. The rocks composing it are chiefly red sandstones which pass, on the one hand, into coarse conglomerates and, on the other, into sandy shales. The belt itself lies in a great trough of upturned crystalline metamorphosed rocks of uncertain, but probably Paleozoic, age. The thickness of the Triassic strata in this trough is not known, but artesian borings down to 4,000 feet made in New Haven have not passed through it. The belt is one of a system occurring in independent areas along the Atlantic border, which represent deposits made in Mesozoic time and to which the name of the Newark group has been given. The belt extending northward through Connecticut and Massachusetts is known as the Connecticut Valley area.

The general structure of this area has produced the belief that the trough was the former valley of the ancient Connecticut River, which, through submergence, passed into an estuarine condition, and was then filled with the sediments. The character of these beds, their frequent cross bedding, and the sudden changes from sandstone into conglomerates show rapid shifting of currents and powerful stream action.

A small outlying area of these sandstones about 15 miles west of the main one indicates that the formation had once a wider area than at present, but denudation since its emergence has carried away an unknown amount, leaving, however, the thicker mass lying in the former trough.

The beds in this area are not in their original horizontal position. After their emergence, by the action of orogenic forces, they were faulted into a series of great blocks, which dip eastward and have their upthrow on the western side. They thus form a series of monoclines which give rise to north and south ridges.

The type of topography to which this structure has given rise is strongly accentuated by the fact that the upturned blocks of sandstone contain numerous intrusions of diabase, or "trap rock," as it has been commonly called. These intrusions are of all sizes and of thicknesses up to 250 feet. The sandstone which formerly covered the intrusions has been largely carried away, especially along the crests of the faulted blocks, by denudation and glacial erosion, thus exposing the igneous rock. It therefore produces a series of curved north-and-south ridges which, on account of the upthrow on the westward side, face toward the west and southwest with bold precipitous cliffs with columnar faces. These projecting masses of diabase dominate the topographic character of the region and form the most striking element in its scenic features.

It is admitted by all geologists who have studied the region that the diabase occurs in intrusive masses, but in regard to the period at which the intrusions took place there has been much discussion. Concerning this, two views have been held. One of these supposes that the main portion, at least, of the intrusions took place after the upturning of the beds. The magma rose through fissures, often passing along between the bedding until, nearing the top, it lifted the upper layers and, sometimes abrading the upturned beds on the lower side, formed large intrusive masses. This view has been chiefly upheld by the late Prof. J. D. Dana.

The other view supposes that the intrusions of diabase took place before the upturning of the strata, and that it was injected between them in immense horizontal intrusive sheets conformable with the bedding, or poured out in contemporary lava flows as the sediments were deposited. Later, when the sandstones were faulted into blocks with upthrow to the west, the trap sheets were brought to light. This idea has been chiefly urged and developed by Prof. W. M. Davis. It would be out of place here to enter into a discussion of these two conflicting views; suffice it to say that some features of the area seem to be best explained by the former, others by the latter, and that it is by no means certain that either view is everywhere correct. The main point is that the igneous rock described here is intrusive in origin, and that the peculiarities of structure and texture it exhibits are due to an igneous mass cooling and crystallizing under at least a moderately heavy cover of sediments. Those who desire more information in regard to the structure and occurrence of these intrusive masses of diabase will find it in the works given in the list of literature at the end of this article.

West rock is the name given locally to the extreme southern end of the most western of the "trap" ranges mentioned above. The ridge, which has here a height of about 400 feet above tide, breaks off along the western front and southern end in a bold cliff from which the mass slopes back toward the east at a moderate angle until it merges into the lower country.

Along the crest the rock exposures are those of the diabase itself, the sedimentary covering having been carried away; but down the slopes toward the north and east the covering sandstones are met with. Along the western side and southern front the cliff gives an excellent section, and it may be seen here that the diabase is in part unconformable to the strata, and then dips and passes in between the planes of bedding of the upturned sandstones. The thickness of the mass above the sandstones on the west front is about 200 feet. It is cut by a series of joint planes which divide it into rude columns, so that the cliff front, viewed from below, has a pronounced columnar structure.

The rock has long been quarried and used as a building stone and for road metal in the city of New Haven. For this latter purpose it is especially well adapted by its hardness and tough, resistant qualities. For building purposes material having smooth planes of the natural joint faces is especially sought, as these, from the oxidation of the iron-bearing minerals, are covered by a thin skin of varying shades of brown which produce a very pleasing effect in surfaces of masonry. The quarry is at the extreme southern end of the cliff, and is in the village of Westville, one of the suburbs of New Haven, and about 2 miles from the center of the city. It is from this quarry that the specimen in the collection has been taken.

The diabase of the New Haven region possesses a special interest from the petrographic standpoint in that it was, so far as known, the first rock in America to be investigated by modern petrographical methods. This investigation was made in 1874 by Hawes and E. S. Dana, who showed by analyses and by examination of thin sections by the polarizing microscope, that the "trap" rocks of the Connecticut valley area were composed of augite, iron ore, and a feldspar to which the composition of labradorite was assigned, with at times the addition of some chlorite. Later, by analyses and separations, Hawes showed that two varieties of feldspar were commonly present in these rocks.

The specimen shows a rock of a very dark stone-gray color, heavy, and rather dense in texture. On a close examination with the eye, this dark color is seen to be due to the spotting of shapeless masses of a blackish mineral (mostly augite) with tiny flecks of white (feldspar). It may be noticed that at times the white flecks take the form of minute rods. The clean fractured surface of the rock is nearly devoid of luster. The lens only serves to bring out these features more strongly, and to show that the light and dark minerals are mingled in shapeless masses. It does not bring out any pronounced feature which would serve to characterize the rock. The rock, indeed, does not megascopically show any pronounced features which would serve to classify it, beyond its weight and the dark color due to a large proportion of a ferromagnesian mineral, characters which would at once place it among the basic rocks of basaltic habit.

On examining a thin section of the rock under the microscope, however, its structure and mineral composition are at once clearly seen, and it also proves a very interesting one for petrographic study.

The minerals composing it are found to be apatite, iron ore, biotite, pyroxene, plagioclase feldspar, orthoclase, and quartz, while chlorite and serpentine-like minerals occur as secondary products produced by weathering. The minerals are given in the order of their formation, which is told by the younger including the older, or by the latter projecting into the former with crystal boundaries. The pyroxene and plagioclase feldspar are by far the most abundant and constitute the chief mass of the rock.

Apatite is not common. It occurs in small stout prisms, which are apt to be associated with the colored components, and long slender needles, which occur almost wholly in the feldspar. It is colorless and easily told by its high single refraction, low double refraction, and optically negative extension. It may occur in any of the other components, and is therefore the oldest.

Iron ore, though well distributed throughout the section in black opaque masses, is by no means abundant. It is undoubtedly in part ilmenite, since the analysis of the rock shows a considerable amount of titanic oxide present, and there is no other mineral to which it can be referred, except that pyroxene sometimes carries a small amount. When it enters into their composition, however, they are almost invariably of violet color and have a marked dispersion of the optic axes, which is not the case in the pyroxene of this diabase. Both magnetite and ilmenite are present, as shown later.

There are two varieties of pyroxene present. The one is the usual brownish kind characteristic of this class of rocks; the other is a white or colorless one, which has a tendency to be more idiomorphic than the brown, in columnar shapes. The difference between them, since the brown one is light in tone, is not extremely marked, but it can be easily seen by studying the section with a rather low power, so that a considerable number of the augites are brought into the field at once. The exact nature of the white augite is not known. It occurs very commonly throughout the diabase of the Connecticut valley area. It is also found in occurrences of diabase in Sweden, in northern England, at Rio Janeiro, Brazil, and in Nova Scotia. It was formerly supposed that the mineral was the same as that variety of pyroxene found at Sala, in Sweden, and hence called salite. From this the rock has often been called salite diabase.[1] Recently, however, E. O. Hovey[2] has investigated the salite from Sala and has found that the angle of the optic axes in air $2E_a = 112° 30'$, while the mineral under discussion is characterized by a remarkably small angle for a pyroxene $2E_a = 32° 39'$ (Brazil), $34° 47'$ (Halleberg, in Sweden). Hence it can not be salite, and this name should no longer be given to this variety of diabase. The mineral has a good prismatic cleavage and also a pronounced cross parting parallel to the base. It is sometimes twinned with *a* (100) as the twinning plane. It is more idiomorphic than the brown variety, and therefore older. It suffers from alteration much more easily than the brown, and while the latter is very fresh the colorless one is everywhere beginning to be attacked by processes which are converting it into a fibrous serpentine-like substance. This fact also helps to distinguish it from the brown. In this respect the section is a very instructive one, as it shows very clearly how such processes of alteration by weathering go on, whereby minerals rich in magnesia are converted into serpentine-like substances.

The process begins on the outside and works inward, or it starts from cleavage cracks, which have enabled the capillary moisture to creep into the mineral, and works from both sides. The first stage consists in the production of a number of fine, parallel, colorless fibers which pass from the edge or crack into the mineral. They look like a series of fine parallel scratches on the surface of the otherwise unaltered

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[1] See Rosenbusch, Mass. Gest. 1887, p. 202.

[2] Tschermak's Min. Mitt., vol. 13, p. 218. 1893. Also p. 213.

mineral, and are to be seen best with very high powers. From this stage they grow more and more numerous, until finally that portion of the mineral attacked is converted into a cloudy opaque substance of a brownish or yellowish color.

The brown pyroxene is of the usual aluminous variety of augite found in diabases. It is generally much fresher than the white. It has a much larger optic angle. Both varieties have a large angle of extinction in sections parallel to *b*(010) or nearly so, which sections are easily told by the high polarization colors they exhibit. The brown variety has an excellent prismatic cleavage, a very poor parting parallel to *b*(010), which may be occasionally observed, and a much better one parallel to *a*(100), on which face it is also frequently twinned.

The pyroxenes in this rock have been chemically investigated by Hawes. He did not know, however, that there were two species present, and the analysis probably represents a mixture of both of them. The material probably contained also a little feldspar. It is of value, however, for it shows the nature of the average augitic component of the rock and enables us to determine the average composition of the feldspar from the mass analysis.

Analysis of pyroxene of West Rock, New Haven, Connecticut; by G. W. Hawes.

	Per cent.
SiO_2 (silica)	50.71
Al_2O_3 (alumina)	3.55
FeO (ferrous oxide)	15.30
MnO (manganous oxide)	.81
CaO (lime)	13.35
MgO (magnesia)	13.63
Ignition	1.17
Na_2O K_2O (alkalies and loss by difference)	1.48
Total	100.00

The analysis does not, of course, yield ratios which can be construed into satisfactory formulas. It must stand, however, until means for the separation of the two pyroxenes have been devised, which has not yet been successfully done.

The plagioclase feldspar occurs in the shape of intergrown laths, sometimes long and slender, sometimes short and broad, which may attain a length of 1^{mm}. It is clear, colorless, and very fresh. Twinning according to the albite law invariable; according to the Carlsbad law very common; pericline twinning also occurs, but is much less common.

The chemical and microscopic work of Hawes and Dana had early shown that the general composition of the feldspar was that of labradorite. Later, Hawes, by means of separations made by heavy liquids, showed that the feldspars in a similar diabase from Jersey City consisted of labradorite and andesite. Since in a dike cutting West Rock there occurred phenocrysts which analysis proved to be anorthite, Hawes seems to have concluded that there was also more than one feldspar present in the West Rock diabase, and that therefore it was made up of a mixture of anorthite and albite feldspars, not of mixtures of these constituting intermediate species, as in the Jersey City diabase. This singular idea was justly and promptly combated by the late Prof. J. D. Dana.

As a matter of fact, the feldspars do belong to intermediate species, and range from a rather basic labradorite to andesite, or say from Ab_2An_3 to Ab_3An_2. This would give them as an average the composition of an acid labradorite, which is exactly what the chemical work calls for.

The section is very well adapted for the study of the plagioclases according to the excellent methods elaborated by Michel Lévy[1] and Fouqué,[2] based on optical properties.

Thus, if sections oriented in the zone of *a* (100) on *c* (001), which are easily told by their equal illumination of the albite twins when the twinning plane coincides with the cross hairs or is 45° from it, are studied, the angles of extinction are found to be large, usually above 20°, and therefore indicative of a basic feldspar. Such sections may be easily recognized by the disappearance of the albite twinning in the 45° position, while in parallel position to the cross hairs the twinning lamellæ, though equally illumined, are separated by fine, black hair lines of the sutures. The 45° position offers the best method of discrimination between the albite and Carlsbad twinning, the former disappearing and the latter becoming very evident, especially in the basic feldspar.

A number of such sections were selected and measured, of which the following will serve as examples:

Angles of extinction of labradorites.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
	°	°	°	°	°
Albite twin 1	35	15	20	25	30
Albite twin 1′	35	15	18	27	30
Carlsbad twin 2′	22	40	6	3	....

Referring now to the tables given by Michel Lévy, it will be seen that No. 1 is that of a labradorite of about the composition Ab_2An_3, and that the section is inclined about 10° from *a* ($\bar{1}00$) on *c* (001). No. 2 is that of a labradorite a little more basic, the section cut inclined 40° from *a* (100) on *c* (001). No. 3 is a labradorite, Ab_2An_3, the section cut about 50° from *c* (001) toward *a* (100). No. 3 has the composition of

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[1] Détermination des feldspaths, Paris, 1894.

[2] L'Étude des feldspaths des roches volcaniques, Paris, 1894.

about Ab_2An_3, the section being cut about 65° from *a* (100), sloping toward *c* (001). No. 4 is Ab_1An_3, the section inclined 50° from *a* ($\bar{1}00$) on *c* (001). No. 5, which does not show the Carlsbad twinning, indicates a probable labradorite.

It will be noticed that the feldspars are frequently zonally built. Often in such sections as those mentioned above this is shown by a decreasing angle of extinction from center to periphery. If sections are chosen for study parallel to *b* (010), this is still more marked, and extinction angles referred to the trace of the cleavage parallel to *c* (001) will be found to vary from 20° to 10° (negative direction), or from basic labradorites to andesites. It must be said, however, that everything indicates that labradorite is by far the predominant type of feldspar in this rock.

The small amount of potash in the rock, shown by the analysis, indicates a little orthoclase to be present. The chance of recognizing a scattered grain or two in the section is naturally very small, but as the mineral mostly occurs associated with quartz in micropegmatite intergrowths it is easily seen. These intergrowths will be found in little angular interspaces between the laths of labradorite. They can be studied only by the use of moderately high powers, and though well distributed, are not very common. Sometimes a little quartz alone will be found in the interspaces. This micropegmatitic intergrowth of quartz and feldspar, or of quartz alone, is the very last product of crystallization in the rock.

Biotite will only very rarely be found in the section, and may be wanting. It may sometimes occur as an irregular small leaflet of the usual brown color and strong pleochroism. Sometimes it is bleached to a greenish color, but more often it is changed into chlorite.

The distinct idiomorphic lath-shaped form of the plagioclase is characteristic for diabases, and it conditions angular interspaces which are sometimes filled with augite, sometimes with glass, and sometimes with greenish fibrous material held to be chlorite. The occurrences of these masses has been called *mesostasis*. The exact nature of the greenish substance is not known. It has received the name of *viridite* and *chloropite*, which are, of course, only a cover for ignorance and under which various substances are thrown together.

In the West Rock diabase it will be found, on studying the section with a high power, that the angular interspaces between the feldspars are frequently filled with material of this kind. It occurs in fibers, sometimes packed in bundles which extinguish simultaneously, sometimes in divergent or radial masses, often in intertwined irregular little clumps. It will be noted to have a pale-greenish to yellowish color. It extinguishes, so nearly as can be told, parallel to the fibers, and they are extended in an optically positive direction. The maximum double refraction of the quartz in one section reached a tone of very pale yellow, which shows that the section has a thickness of .03^{mm} (the average thickness of the sections). In this, the fibers under discussion attain a double refraction color of a brilliant yellow inclining to orange. This shows the maximum double refraction of the mineral to be about 0.012, and therefore that it is not the ordinary variety of chlorite commonly found in eruptive rocks and frequently an alteration product of mica, as the latter has an extremely low double refraction. With the means at present available it can not be said what the precise nature of this substance is; it resembles members of the chlorite group of minerals in many respects, and, as suggested by Rosenbusch,[1] is best designated as the "chlorite-like substance." Its derivation from augite as an alteration product seems clear from study of the section. It is found around it, and in many interspaces the ratio of the amount of the mineral is inversely proportional to that of the augite.

The structure of the rock is conditioned by the amount and order of formation of its chief components and the conditions under which they crystallized. Pyroxene and labradorite are the chief constituents—all others in amount compared with them are insignificant—and they give the rock its character. Of them, the white pyroxene crystallized first, followed by labradorite, and finally the brown augite. The latter began crystallizing, however, before the labradorite had finished. It is this crystallization of the labradorite in idiomorphic lath-shaped forms, filled in and surrounded by the brown pyroxene, that gives to diabase its characteristic structure, termed "ophitic" by the French and well-named "intersertal structure" by Zirkel. The West Rock diabase shows this very well, but not in so marked a degree as may at times be found.

The chemical composition of the rock has been carefully studied and discussed by Hawes, to whom we owe the following analysis of the West Rock diabase:

Analysis of West Rock diabase, New Haven, Connecticut.

	Per cent.
SiO_2	51.78
TiO_2	1.41
Al_2O_3	12.79
Fe_2O_3	3.59
FeO	8.25
MnO	.44
CaO	10.70
MgO	7.63
Na_2O	2.14
K_2O	.39
Ignition	.63
P_2O_5	.14
Total	99.89

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[1] Massige Gesteine, 1887, p. 183.

This analysis expresses very clearly what the study of the section has already indicated—the large amount of ferromagnesian minerals, shown by the high iron, lime, and magnesia, and that the feldspar must at least be a plagioclase of medium basicity, shown by the great preponderance of lime over soda. The small amount of potash shows that orthoclase can be present only in very limited amount, while the titanic oxide shows that part of the iron ore must be present as ilmenite.

Hawes[1] on the basis of his analyses has calculated the proportion by weight in which the various minerals enter into the composition of the rock. With some rearrangement, this is shown in the following table:

Minerals composing the West Rock diabase.

	Per cent.
Ilmenite	2.7
Magnetite	1.8
Augite	54.5
Plagioclase (labradorite and andesite)	37.7
Orthoclase	2.3
Apatite	.3
Total	99.3

The above expresses the average composition very well; a minute amount of quartz is neglected, as are also the products of alteration.

The rock from West Rock is a normal diabase, consisting chiefly of labradorite and augite; the minerals in one generation arranged in intersertal structure. It is of rather fine grain and quite fresh. It is distinguished by containing an augite of a light color in addition to the ordinary augite of such rocks.

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[1] Proc. U. S. Nat. Mus., 1881, p. 132.

No. 107. OLIVINE-DIABASE.

(FROM PIGEON POINT, COOK COUNTY, MINNESOTA. DESCRIBED BY W. S. BAYLEY.)

No. 107 is a representative of the rock that has always been called an olivine-gabbro in the writings of students of Lake Superior geology.[1] The specimen was obtained from the north shore of Pigeon Point, the northeastern extremity of Minnesota. Here the rock occurs as a large dike-like mass, cutting Huronian slates and quartzites. Its best exposures are on the north shore of the point at the water's edge, where the rock forms high cliffs whose face is always kept perpendicular through the action of frost, which penetrates joint cracks, and by the force of its expansion loosens large blocks that fall to the base of the cliff and there form a talus of fresh material. It is from one of the freshest of these blocks that the specimen in the collection was taken.

The rock is a medium-grained, gray, crystalline aggregate, in which two components may easily be extinguished. One of these is a white or nearly colorless mineral with glistening cleavage faces, often occurring in long, narrow crystals, upon whose surfaces may usually be detected longitudinal striations. Its color, cleavage, and structure indicate a plagioclase. The other component macroscopically distinguishable is a jet-black substance also possessing glistening cleavages. Under favorable circumstances this substance, which is a pyroxene, may be seen to surround the feldspar crystals in such a way that the latter appear embedded in the former. Close inspection of the specimen will also discover small areas of a finely granular texture and of a yellowish tinge. These areas consist chiefly of olivine. From a macroscopic examination, then, we learn that the rock is a nonporphyritic, crystalline aggregate of augite and plagioclase; in other words, that it is either a diabase or a gabbro. The long, narrow development of the plagioclase suggests a diabase.[2]

The density of the rock varies between 2.927 and 2.970, according as the specimen investigated contains a larger or smaller proportion of feldspar. Its chemical composition, as found by Mr. W. F. Hillebrand, is as follows:

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[1] Aug. Streng, Neues Jahrb. f. Min., etc., 1877, pp. 113-138; R. D. Irving, Geol. of Wisconsin, Vol. III. pp. 168-183; Alex. Julien: Geology of Wisconsin, Vol. III (1880), pp. 233-238; R. D. Irving, The copper-bearing rocks of Lake Superior, Mon. U. S. Geol. Survey, Vol. V, pp. 37-50.

[2] Although the specimen in the collection is not porphyritic, in certain areas on Pigeon Point the same rock is so developed that porphyritic crystals even 6 or 7 inches in length are not uncommon. The crystals are exactly similar to the crystals of plagioclase in the groundmass of the rock, except in point of size.

Analysis of olivine-diabase from Pigeon Point, Minnesota.

	Per cent.
SiO_2	49.88
TiO_2	1.19
ZrO_2	none
Al_2O_3	18.55
Fe_2O_3	2.06
FeO	8.37
MnO	.09
CaO	9.72
SrO	trace
BaO	.02
MgO	5.77
K_2O	.68
Na_2O	2.59
Li_2O	none
H_2O	1.04
P_2O_5	0.16
Cl	trace
Total	100.12

Its thin section, when examined under the microscope, is seen to be composed essentially of the three minerals above mentioned, viz, plagioclase, olivine, and augite. The plagioclase comprises about 60 per cent of the sections. In ordinary light it appears as a colorless groundmass in which everything else lies embedded. Under crossed nicols this apparently homogeneous matrix breaks up into numerous long, narrow crystals, ranging in length from 1 to 20^{mm}. Each of these is composed of a number of smaller individuals which, by their union, often give rise to broad lath-shaped forms, like those so characteristic of some of the European gabbros, notably those from Volpersdorf, in Silesia, and from the Harz.[1] Each of the smaller crystals is polysynthetically twinned according to the albite law, in which the brachypinacoid ($\infty P \breve{\infty}$) is the twinning plane, and often two of them unite to form a Carlsbad twin with the macropinacoid ($\infty P \bar{\infty}$) as the twinning plane and the brachypinacoid ($\infty P \breve{\infty}$) as the composition face. The material of the crystals is very fresh, and is often almost as glassy as the feldspar of modern volcanic rocks. It contains as inclusions only a few particles of dust and minute flakes of brightly polarizing fibrous kaolin, except in those rare cases where slight alteration has developed a larger quantity of the latter mineral, when the feldspar substance becomes cloudy, and under crossed nicols is observed to be full of little needles, showing brilliant polarizing colors.

The polysynthetic twinning lamellæ noticed in nearly every piece of the feldspar would lead to the suspicion that this is a plagioclase, but their occurrence is not positive proof of this, as a repeated growth of Carlsbad twins would give rise to the same phenomenon. The angles made by its two systems of cleavage lines, however, are 85° and 95° on

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[1] Rosenbusch, Mikroskopische Physiographie, II, 1887, p. 155.

the macropinacoid, and the cleavages are never at right angles to each other in any sections. Moreover, the maximum symmetrical extinction of lamellæ on each side of a twinning line is 24°. These results indicate a triclinic feldspar belonging in the lower portion of the labradorite group.[1] If a fragment of the rock is powdered and sifted, and its constituents are separated by means of one of the heavy solutions used for this purpose, it will be found that most of the plagioclase will fall when the density of the solution is between 2.700 and 2.716. If a portion of the material that falls at 2.700 be analyzed, it will give the figures in column I. In column II is given for comparison the composition of a labradorite[2] of the formula Ab_3An_4, and in III that of a plagioclase[3] with a specific gravity 2.700, from a European locality.

Analyses of plagioclases of olivine-diabase.

	I.	II.	III.
SiO_2	53.75	53.60	54.55
Al_2O_3	30.39	29.80	28.68
Fe_2O_3	1.26	....	1.03
CaO	10.84	11.70	11.28
Na_2O	3.76	4.90	4.62
Total	100.00	100.00	100.16
Specific gravity	2.700	2.703	2.700

It will thus be seen that the density and the chemical composition of the mineral, as well as its optical and physical properties, agree very well with those of a basic labradorite consisting of a mixture of three albite molecules and four of anorthite.

The olivine constitutes about a tenth of the rock. It is undoubtedly older than the augite, since it is surrounded by this mineral (see Pl. XXXVIII, *A*), and is probably older than most of the labradorite, although in a few instances it may be seen to include portions of crystals of the feldspar. Its period of crystallization must have overlapped that of the plagioclase, i. e., while the chief portion of the olivine separated from the magma before the feldspar had begun to form, a small portion of it solidified after the labradorite began to crystallize. The mineral is in rounded grains of a light yellowish-green color. It has a high index of refraction and consequently a rough surface, and is traversed by irregular cracks filled with green decomposition products. Excepting the feldspar crystals included in the olivine above referred to, no inclusions other than dust-like particles, like those in the feldspar, and certain green acicular secondary substances are met with in it. In but very few sections does the olivine remain unaltered. In even the freshest varieties a little chloritization has taken place, and this shows itself as a green rim around the edge of the grains and in the cracks. The small, brown, strongly pleochroic flakes, with a well-marked cleavage, sometimes intermingled with the chlorite,

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[1] Iddings's Rosenbusch's Microscopical Physiography, p. 300.

[2] Schuster, Tschermak's Min. u. Petrog. Mitth., III, 1880, p. 153.

[3] Tschermak, Sitzungsber. d. K. Akad. Wiss. (July 1, 1869), Band LX, Abt. I, 1870, p. 145.

are biotite plates, produced, like the chlorite, by decomposition of the olivine, and the bunches of dark-green fibers that penetrate the fresh mineral are probably some form of hornblende.

The youngest of the essential components, augite, is entirely allotriomorphic. It fills the interstices between the other constituents, and thus has its contours molded by these. (See Fig. *A*, Pl. XXXVIII.) Often several feldspar laths are included in a single augite plate, which, when broken, reflects the light uniformly from its surface, leaving dull areas in those places occupied by the feldspar. This kind of intergrowth gives rise to what is known macroscopically as luster mottling.[1] The microscopic structure produced by it has been denominated pœcilitic.[2] The greater part of the augite is perfectly fresh, and, like the feldspar and the olivine, it contains no true inclusions other than the dust-like particles scattered throughout its mass. Its color is purplish-pink, with a faint pleochroism; the 𝔞 and 𝔠 rays being a deep purplish-pink, in highly-colored pieces, and the 𝔟 ray yellowish-gray. The two series of prismatic cleavage lines are very distinct in pieces cut parallel to the basal plane, where they make the usual pyroxene angles of 87° and 93°. In other sections they form a series of parallel lines that are sometimes gently curved as the result of pressure. (See *a*, Pl. V, Bull. U. S. Geol. Survey, No. 109.) The diallagic parting parallel to the orthopinacoid is only rarely seen. The extinction on plates cut parallel to the clinopinacoid is 44° against the single cleavage.

The augite of nearly all Lake Superior rocks is uniformly tinged with purple, whereas that of foreign rocks is generally greenish, so that some explanation must be sought for the difference. Knop,[3] who made an exhaustive study of the augite of the Kaiserstuhl in Baden, found that all the varieties of this mineral rich in titanium and poor in iron have a purple color in thin section. Although investigations in other regions do not fully substantiate Knop's conclusion, it is interesting to note that the purple augite in the Pigeon Point rock contains a large percentage of titanium and a comparatively small proportion of iron. A partial analysis of the augite powder separated from the specimen was made in the laboratory of the United States Geological Survey by R. B. Riggs. His figures, indicating a very pure diallage, are:

Analysis of diallage of olivine-diabase from Pigeon Point, Minnesota.

	Per cent.
SiO_2	48.34
Al_2O_3	2.90
Fe_2O_3	4.68
FeO	14.15
CaO	15.10
MgO	11.34
TiO_2	1.98

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[1] R. Pumpelly, Proc. Amer. Acad. Adv. Sci., XIII, p. 260; and R. D. Irving, Copper-bearing rocks, p. 42.

[2] G. H. Williams: Am. Jour. Sci., 3d series, Vol. XXXI, 1886, p. 30.

[3] Groth's Zeitsch. f. Kryst., X, p. 58.

In addition to the essential components, the rock contains only apatite and titaniferous magnetite as primary constituents. The apatite is only sparingly present in long, narrow, colorless crystals, with a parting parallel to the base. The magnetite appears both in idiomorphic and in allotriomorphic forms, the latter predominating. A large number of the grains, especially in slightly altered specimens, are surrounded by rims of reddish-brown mica, and not a few show the beginning of an alteration into cloudy-white or gray leucoxene. A little quartz and a few flakes of brown and red biotite, strongly pleochroic masses of green chlorite, and some undeterminate substances, filling cracks in the essential components and occupying corners between them, may be found in some sections. The quartz is in micropegmatitic intergrowths with feldspar; the biotite is an alteration product of olivine, augite, and magnetite, and the chlorite a product of the decomposition of the first two of these.

As has already been stated, the rock has been pronounced a gabbro by all geologists who have studied it. Its pyroxene has the composition of diallage, and it sometimes possesses the orthopinacoidal parting characteristic of this mineral.[1] Its structure, however, is more nearly that of the diabases than of the gabbros (see Pl. XXXVIII, *A*). Its plagioclase is in lath-shaped crystals, embedded in augite, so that its texture is not granitic, but ophitic. The texture, then, if alone considered, would place the rock with the diabases, while its mineralogic composition would place it among the gabbros. Recent investigations have shown that many holocrystalline basic rocks, which no one would for an instant regard as gabbros, contain typical diallage. Therefore the possession of this constituent is not characteristic of gabbros; so there remains only the structure as a means of distinguishing between these rocks and the diabases. Professor Judd[2] has suggested that we limit the term gabbro to those rocks composed of plagioclase and pyroxene, that possess the granitic structure, i. e., that have their constituents developed in approximately equal sized grains, without crystal contours, and that we designate as diabases all rocks of this composition in which the structure is ophitic. According to this view, the Pigeon Point rock is a coarse-grained olivine-diabase.[3]

No. 108. Gabbro.

(From Mount Hope, Baltimore County, Maryland. Abstract by J. P. Iddings from the description by G. H. Williams.)

The occurrence and petrographical characters of this gabbro have been fully described by the late Prof. George H. Williams, and it will

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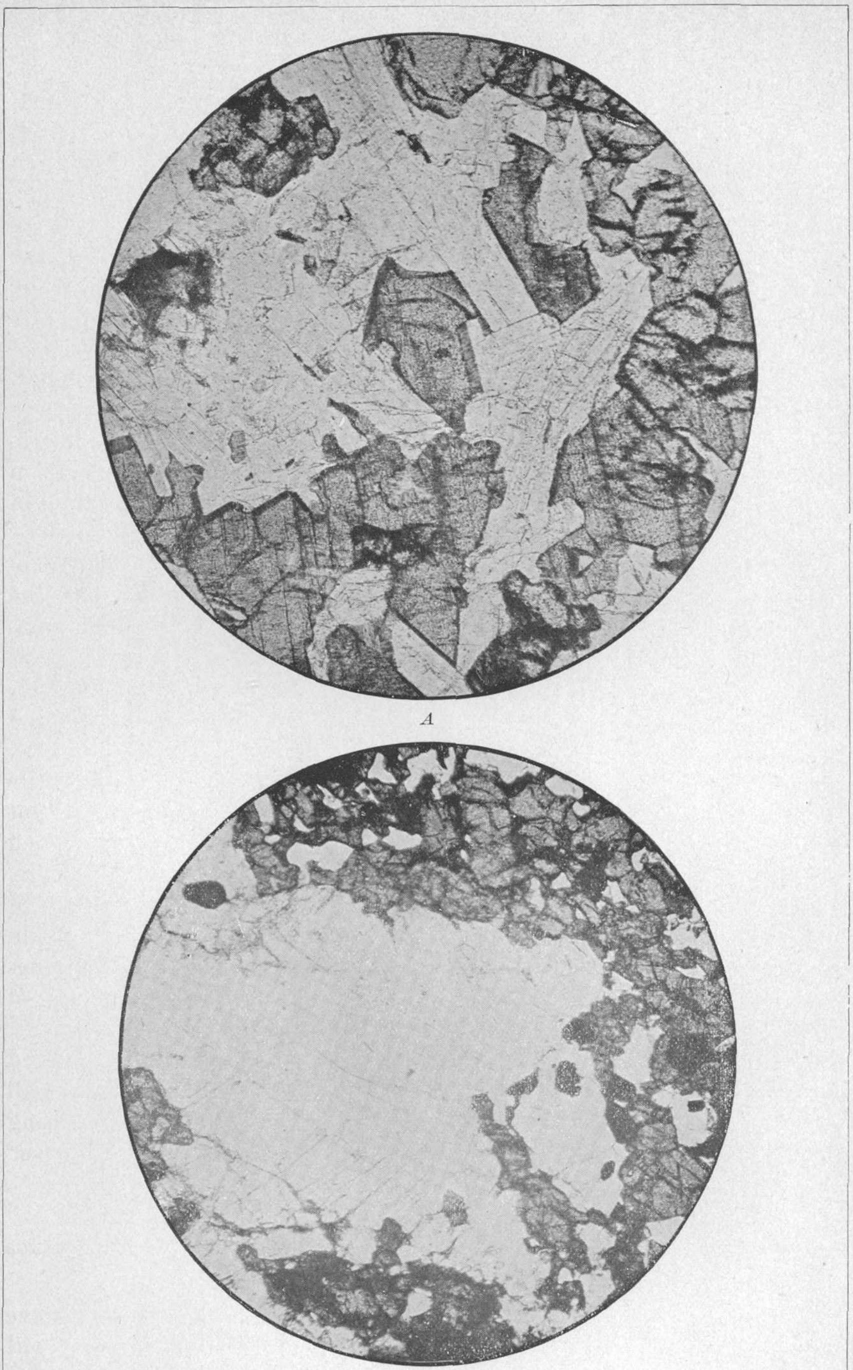
[1] For a résumé of the opinions of different investigators on the value of the orthopinacoidal parting as a characteristic of diallage, as distinguishing it from augite, see Wadsworth, Bull. No. 2, Geol. and Nat. Hist. Survey, Minnesota, pp. 55-57.

[2] Quart. Jour. Geol. Soc. London, 1885, pp. 354-418.

[3] For a fuller description of the rock, both in its fresh and altered condition, see W. S. Bayley, The eruptive and sedimentary rocks of Pigeon Point, Minnesota, and their contact phenomena: Bull. U. S. Geol. Survey No. 109, 1893.



THIN SECTIONS AS SEEN UNDER A MICROSCOPE.

A. Olivine-diabase from Pigeon Point, Minnesota, × 40.

B. Garnetiferous gabbro from Granite Falls, Minnesota, × 33.

The light-colored, long, narrow crystals of *A* are plagioclase, in which dust inclusions and twinning striations may easily be seen. Surrounding these are large plates of diallage, with a series of parallel cleavage lines well developed. The rounded grains at the right of the section and elsewhere are olivine. They are traversed by irregular cracks and have apparently a fibrous texture. This appearance is due to the strong refraction of the mineral, and is purely a light phenomenon. No indication of fibrous texture is noticed in the thin section. The olivine and the plagioclase are clearly older than the pyroxene, which fills in the spaces left between these minerals, giving rise to the ophitic texture so characteristic of diabase.

only be necessary to quote what he has published on the subject in Bulletin 28 of the United States Geological Survey, which is entitled, The Gabbros and Associated Hornblende Rocks Occurring in the Neighborhood of Baltimore, Maryland. To this paper the student is referred for fuller details than can be given in this place.

The gabbro is well exposed in a railroad cut at Mount Hope Station on the Western Maryland Railroad, where it grades into hornblende-gabbro-gneiss (diorite).

> As a rule the two rocks alternate with each other in every direction—horizontally and vertically—in the most perplexing manner, and it is frequently impossible to tell on the spot whether a given specimen is gabbro or diorite (hornbende-gabbro-gneiss). . . . Just west of the bridge which crosses this cutting the gabbro shows a decided tendency to spheroidal weathering so often characteristic of basic massive rocks. [The hypersthene gabbro and the hornblende-gabbro-gneiss at this place are clearly one geological mass.]
>
> Excellent exposures of the hypersthene-gabbro are very abundant within the Baltimore area, especially in the northern portion of it. . . . Perhaps the best place to obtain fresh and typical specimens is at Mount Hope Station, although they may be secured from the huge bowlders which strew the surface at almost any spot within the area.
>
> The rock is always very massive in appearance, rarely exhibiting the banded and nowhere the schistose structure, which is frequently seen in the associated hornblendic rocks. Its irregular polygonal blocks are often covered with a thin coating of a deep red color due to decomposition, beneath which, however, the rock is surprisingly fresh. . . .
>
> The color of the hypersthene-gabbro is on the whole uniform, although it may vary from a purplish black to gray.
>
> The most striking feature in the texture of the unaltered gabbro is the repeated and abrupt change in the coarseness of the grain which is seen at some localities. This phenomenon, as is well known, is one frequently observed in very ancient massive rocks which cover considerable areas. . . . Irregular patches of the coarsest kinds lie embedded in those of the finest grain without regard to any order. In other cases a more or less pronounced banded structure is produced by an alternation of layers of different grains or by such as have one constituent developed more abundantly than the other. Such bands are not, however, parallel, but vary considerably in direction, and show a tendency to merge into one another, as though they had been produced by motion in a liquid or plastic mass. . . .
>
> The mineral constituents of the gabbro which are discernible with the unaided eye are plagioclase, diallage, and hypersthene. A black hornblende, which is brown in transmitted light, is also sometimes seen in good-sized crystals, and has every appearance of being a primary component. Magnetite and apatite are shown by the microscope to be universally present, although in varying quantities. Olivine was observed in only one specimen, collected near Orange Grove. With the exception of certain indeterminable inclusions, no other minerals were discovered in the wholly unaltered rock.
>
> The grain of the hypersthene gabbro is, as a rule, uniform and fine, the component minerals averaging from 1 to 2^{mm} in diameter. Exceptionally, however, the grain becomes coarser; in a few specimens the individuals of pyroxene and feldspar measured from 25 to 35^{mm} in length. The coarsest varieties are rarely altogether fresh.
>
> The feldspathic constituent of the hypersthene-gabbro is bytownite, corresponding to a mixture of six molecules of anorthite with one of albite. Stauroscopic measurements on the feldspar extracted from a Mount Hope specimen of the gabbro gave extinction angles (measured against the cleavage lines) of -16° to -19° on OP (001) and of -28° to -30° on $\infty P \breve{\infty}$ (010).

A chemical analysis of this feldspar, made by W. S. Bayley, gave the following percentages:

Analysis of feldspar in gabbro from Mount Hope, Maryland.

	Per cent.
SiO_2	46.17
Al_2O_3	35.23
CaO	16.29
Na_2O [a]	2.31
Total	100.00
Specific gravity, 2.74.	

[a] Difference.

In the above-mentioned specimen of gabbro from Mount Hope, the feldspar constitutes somewhat over one-half of the entire mass. This may perhaps be regarded as a fair average, although great variations in the proportions of the component minerals caused the analyses of specimens of the gabbro from different localities to differ widely.

The feldspar individuals are generally quite irregular in shape, giving rise to the granular structure which is characteristic of gabbro in contrast to diabase. Rarely, however, a lath-shaped crystal indicates a slight tendency toward the ophitic structure.

When seen between crossed nicols, the feldspar appears, as a rule, finely striated. Sometimes two systems of striæ are seen to intersect at an angle of nearly 90°. In other cases the striations are very coarse or altogether wanting, in which case the extinction is more or less undulatory and irregular. [In some instances the striations are slightly curved or bent, as though by dynamic stress. J. P. I.]

The minute dust-like inclusions, which are so common in the feldspars of the older basic rocks, are admirably developed in the Baltimore gabbros. They answer very well to the descriptions given of them in rocks from other localities by Zirkel, Hagge, Hawes, and other investigators. When viewed with a low magnifying power the plagioclase appears to be covered with a fine black or brown dust, which, under the highest magnifying power, is resolved into a mass of very minute opaque dots and lines. The arrangement of these inclusions is such that the needles occupy the center of the crystal; this is surrounded by a zone where only the dots or globulites are to be seen. The exterior of the crystal is generally free from inclusions of any kind. Frequently the acicular bodies are altogether absent, and thus the minute dots are arranged in lines which indicate the position of the twinning lamellæ. An occasional inclusion of another kind, like a fluid cavity, an apatite crystal, or a grain of magnetite, is surrounded by a narrow zone which is quite free from the dust-like particles. Neither a microscopical nor a chemical examination served to give any clue to the mineralogical nature of these minute bodies.

The diallage is the constituent of the gabbro next in order of importance to the feldspar, although in some specimens it is not so abundant as the hypersthene. The chemical composition of this mineral from a Gwynns Falls specimen is as follows:

Analysis of diallage of gabbro from Gwynns Falls, Maryland.

	Per cent.
SiO_2	51.41
Al_2O_3	4.32
FeO	9.31
MnO	.04
CaO	20.60
MgO	15.14
Total	100.82
Specific gravity, 3.26.	

In hand specimens the diallage appears black, but when seen by transmitted light in thin sections it has a light green color and exhibits no appreciable pleochroism. This constituent, like all the others, shows no indication of a crystal form; it is present only in rounded or irregularly shaped grains, and appears to have crystallized somewhat later than the feldspar. The prismatic cleavage and the parting parallel to the orthopinacoid are both well developed; frequently a second parting parallel to the clinopinacoid is also present. In sections approximately parallel to either OP (001) or $\infty P \bar{\infty}$ (100) an optical axis—not a bisectrix—appears, when the examination is made with convergent polarized light. Clinopinacoidal sections exhibit an extinction angle as large as 40°.

Twins, according to the ordinary law for augite, where the orthopinacoid is both twinning plane and composition face, are quite common. Instances where the twinning trace is inclined from 25° to 35° to the cleavage lines, as described by Cohen,[1] Rosenbusch,[2] and others, have been also not infrequently observed.

Other systems of fine striations, visible only between crossed nicols, are very often seen traversing the individuals of diallage in several directions. They are by no means always straight in their course nor continuous across the crystal, but appear to be due to some molecular disturbance produced by pressure, to which, as is well known, this mineral is peculiarly sensitive.[3]

In its freedom from inclusions the diallage, as a rule, presents a contrast to the hypersthene, although when such inclusions are exceptionally present they do not appear materially to differ from those of the rhombic pyroxene.

Hypersthene is a constant component of the Baltimore gabbros, although its amount varies widely in different specimens. It is readily detected in the rock by its bronzy luster. . . . This effect is, however, altogether due to inclusions in the hypersthene, and, since these may be wanting, the absence of the metallic reflection is of itself no proof that this mineral is not present. Its chemical composition is as follows:

Analysis of hypersthene of Maryland gabbros.

	Per cent.
SiO_2	52.12
Al_2O_3	1.69
FeO	20.94
CaO	3.20
MgO	21.56
Total	99.51
Specific gravity, 3.35.	

Under the microscope this mineral exhibits no better crystalline form that the diallage, from which, however, it is easily distinguished by its marked trichroism. The ray which vibrates parallel to the brachydiagonal axis ($a = \mathfrak{a}$) is brownish red, the one vibrating parallel to the macrodiagonal ($b = \mathfrak{b}$) is light greenish yellow, while that one which vibrates parallel to the vertical axis ($c = \mathfrak{c}$) is green. The absorption is $\mathfrak{a} < \mathfrak{c} < \mathfrak{b}$, $\mathfrak{c}$, being very nearly equal to $\mathfrak{a}$. . . .

The cleavage parallel to the unit prism ∞P (110) is well developed, but even more pronounced is a parting parallel to both pinacoids $\infty P \bar{\infty}$ (100) $\infty P \breve{\infty}$ (010). . . . The fact that the brachydiagonal axis is the acute bisectrix, and the optical angle comparatively small, is sufficient indication that it is hypersthene and not enstatite or bronzite. . . .

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[1] Geognostische Beschreibung der Umgegend von Heidelberg, p. 69, 1881. Sammlung von Mikrophotographien, etc., Taf. XXVIII, fig. 4, 1881.

[2] Mikroskopische Physiographie, Vol. II: Die massigen Gesteine, p. 410.

[3] Van Werveke: Neues Jahrbuch für Mineralogie, Geologie, und Paläontologie, II, p. 97, 1883.

The peculiar inclusions so generally characteristic of hypersthene are, as a rule, present in great perfection. . . . They are composed of fine needles arranged parallel to all three crystallographic axes and of little plates of a reddish brown color lying parallel to the brachypinacoid. To these latter the peculiar metallic reflection seen in many sections is due. They vary considerably in thickness, as may be seen by the different depths of color which they possess. These plates all extinguish simultaneously with the hypersthene, which may be due to their extreme thinness or to the fact that they have their axes parallel to those of their host. . . . Although generally abundant, they are sometimes entirely absent from the hypersthene.

A yellowish brown hornblende, undoubtedly of primary character, is sometimes met with in the hypersthene-gabbro. . . . This primary hornblende is, in the Baltimore gabbros, strongly pleochroic. The $\mathfrak{a}$ ray, approximately parallel to the clinodiagonal axis, is light yellow; the $\mathfrak{b}$ ray, coinciding with the axis of symmetry, is brownish yellow, while the $\mathfrak{c}$ ray, inclined about 12° to the vertical axis, is yellowish brown. The absorption is, as usual in hornblende, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$ or $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$. This hornblende is sometimes so full of minute black inclusions as to be nearly opaque, even when in very thin sections. These interpositions are, however, not evenly distributed, but are massed in irregular patches. No trace of external crystalline form is discernible. This mineral appears to have been the last to crystallize from the magma, a single individual often covering a considerable space and inclosing smaller grains of both pyroxene and feldspar. It is not infrequently intergrown with pyroxene in such a manner that the orthopinacoids of both minerals are coincident. . . .

The occurrence of this hornblende in the least altered specimens of the gabbro, its compact structure, and the other marked contrasts which it presents to the green, fibrous amphibole, . . . are all a sufficient warrant for its original character.

Green, more or less fibrous amphibole occurs in variable amounts in some sections of the gabbro from Mount Hope. It seldom exhibits idiomorphic outlines, but is in confused aggregates of imperfectly developed individuals. The pleochroism is pronounced, and is that common in hornblende, i. e., the $\mathfrak{a}$ ray, nearly parallel to the clinodiagonal axis, is light yellow; the $\mathfrak{b}$ ray, coincident with the orthodiagonal axis, is yellowish green, and the $\mathfrak{c}$ ray is dark bluish green. The absorption is $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. It appears to be of secondary origin.

Of the other constituents occurring in the hypersthene-gabbro, the magnetite [pyrite] and the apatite present no peculiarities worthy of mention. The former is never very abundant; the latter rarely so, although in one specimen from Mount Hope it was found to compose 12 per cent of the entire mass of the rock.

No. 109. GARNETIFEROUS GABBRO.

(FROM GRANITE FALLS, YELLOW MEDICINE COUNTY, MINNESOTA. DESCRIBED BY W. S. BAYLEY.)

No. 109, like Nos. 140 and 144, is from a rock found interbedded with gneisses and schists in the valley of the Minnesota River, in Minnesota. The specimens in the collection were obtained from a pit some 20 feet in depth that had been blasted in the rock near a quartz vein which had been explored for gold. In the neighborhood of the vein the rock is quite massive, but at a distance of a few feet from the contact it has a distinctly schistose character. The location of the pit is 1,500 paces north of the SE. corner of sec. 4, T. 115 N., R. 39 W., Minnesota.[1]

In the hand specimen the rock has a massive aspect. Its prevailing color is dark green, speckled with large patches of dark red and small areas of greenish yellow or white. Upon close inspection the yellow and white areas are discovered to be the glistening cleavage surfaces of a striated plagioclase. The red areas are the surfaces of a dark-red, transparent, hard mineral. It has no distinct cleavage, and is insoluble in acids. The properties are those of garnet. The nature of the dark-green matrix in which the garnet and plagioclase are embedded can not be determined, though from its dark color it may be assumed to be very basic. The specific gravity of the rock is 3.105.

Under the microscope the thin section shows a granular aggregate of plagioclase, green augite, garnet, and magnetite, with small quantities of green hornblende, a few large grains of quartz, and tiny crystals of apatite.

The plagioclase is in irregular allotriomorphic grains crossed by well-defined cleavage cracks and traversed by irregular fissures filled with decomposition products or stained by iron oxides. The material of the feldspar is clear and colorless except where rendered cloudy by inclusions. The most abundant of these are tiny flakes of chlorite and irregular masses of opaque, earthy substance, besides dust-like particles of magnetite and little nests of a brightly polarizing calcite. All these are quite abundant in the neighborhood of the fissures, but are rare in other parts of the grains. Other frequent inclusions are long, narrow crystals of a strongly refractive, colorless mineral, with a parallel extinction and weak double refraction. In cross sections they possess the hexagonal outline and the isotropic character of apatite. Their average length is about 1^{mm} and their thickness about 0.05^{mm}, though a few have cross sections measuring 0.2^{mm} in diameter. Augite, hornblende, and large masses of magnetite are also included in the plagioclase.

Under crossed nicols the plagioclase twinning becomes very apparent, as fairly wide bands, usually running entirely across the grains. Some of the bands curve slightly, others wedge out as they pass toward the interiors of the grains, and still others spring from the sides of cracks, etc. These phenomena, as explained in the description of No. 77, indicate that the rock has been subjected to pressure since it solidified. In certain restricted areas in the section, notably in the neighborhood of large garnets, there is often a second series of twinning lamellæ cutting the first series at some acute angle. This second series comprises numerous lamellæ, not as distinct as those of the first set, and not as sharply marked off from one another. They cross the bars belonging to the first set and have a more or less undulous extinction. The specific gravity of the greater portion of the plagioclase is somewhere

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[1] See map, pl. 28, Geology of Minnesota, vol. 1, of Final Report, p. 589.

about 2.68, or near andesine, though probably a more basic member is also present, with a density of about 2.72.

The next most abundant component of the rock is a pyroxene. This is in green, slightly pleochroic, allotriomorphic grains which are older than the plagioclase, since the latter conform to the former in shape, and occasionally include them. This augite when fresh is marked by two series of cleavage lines crossing each other at angles of about 90° on basal sections, and on other sections by a single series of parallel lines. The pyroxene may easily be distinguished in these sections from hornblende by the large angles of extinction against the parallel cleavage lines, which often reach as high as 43°, whereas those of hornblende rarely approach 24°, and by the lack of strong pleochroism.

In addition to the two cleavages mentioned as prominent on basal sections, there is often another, presenting itself as a series of closely crowded parallel lines, bisecting the larger of the two nearly rectangular intersections of the more prominent lines. Since the shorter of the two lateral axes in pyroxene is the orthoaxis, this cleavage must be parallel either to the orthopinacoid or to some orthodome. But since sections in the zone of the orthopinacoid and the clinopinacoid show only a single series of parallel lines, it is evident that the cleavage under discussion must be orthopinacoidal. This cleavage is characteristic of diallage. For some time it was regarded as original and the mineral exhibiting it was looked upon as a distinct species of pyroxene. Now, thanks to the investigations of Professor Judd,[1] it is known that the cleavage is secondary and that its origin is often the direct consequence of pressure,[2] to which the rock containing it was subjected.

Though much of the diallage is fresh, a still larger proportion is more or less altered. The interior is often stained brown or yellowish brown, and at the same time is deprived of its power of polarizing brilliantly. A little magnetite in rounded grains separates around the edges of the altered portion, and a more or less fibrous cleavage is developed in it. In other places the yellow substance occurs in little plates or needles arranged in parallel lines inclined to the cleavage, thus giving rise to the appearance of a third set of fine cleavage lines. In some cases, the lines are so straight and narrow that they are with great difficulty distinguishable from true cleavage lines, even under a high power. The origin of somewhat similar inclusions, so common a feature in diallage and hypersthene, has given rise to much discussion, Judd thinking them secondary infiltration products along planes of easy solution,[3] and others regarding them as original inclusions taken up by the mineral during its growth.[4]

Around the outside edges of the diallage another alteration is

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[1] Quart. Jour. Geol. Soc. London, 1885, pp. 378–379.

[2] M. E. Wadsworth: Bull. No. 2, Geol. and Nat. Hist. Survey Minnesota, p. 55 et seq.

[3] Quart. Jour. Geol. Soc. London, 1885, p. 354.

[4] G. H. Williams: Am. Jour. Sci., 3d series, Vol. XXXI, Jan. 1886, p. 33; and Vol. XXXIII, Feb. 1887, p. 143.

observed. Here the pyroxene is surrounded by large plates or small granules of a bright-green substance with strong pleochroism, in yellowish-brown and dark bluish-green tints, and an extinction inclined to the cleavage. This substance, which is a hornblende, surrounds the augite as a narrow rim, which sometimes extends into the pyroxene grain, and at other times is formed of granules that seem to have been added[1] to the grain after its formation. In either case the substance is to be regarded as secondary in origin. In a few cases, when the pyroxene grain was small, the entire substance has been changed, and in its place is now an area of hornblende, that might be regarded as original, were it not for the fact that so much of the hornblende of the rock is undoubtedly secondary.

Another product sometimes formed by the alteration of the pyroxene is biotite. This is in small reddish-brown flakes, mingled with the hornblende on the periphery of the diallage.

The magnetite and pyrite appear as large irregular grains that are present more frequently near the pyroxene and garnet than elsewhere in the rock. Both have resisted alteration, and both are equally opaque, so that the only method of distinguishing between them is by their lustre in reflected light. The magnetite is black and the pyrite brassy yellow.

The garnet is the characteristic mineral of the rock. It is in large cellular masses, sometimes measuring half an inch in diameter. In the section it appears as a highly refractive, isotropic, deep pink substance, filled with inclusions and crossed by many irregular cracks, along the sides of which are stains of yellow iron oxides. So large and so numerous are the inclusions that the garnet substance in its arrangement reminds one of the section of a coarse sponge saturated with various colorless products. The largest and most striking of the inclusions are quartz grains. These are colorless and without cleavage traces. They inclose little mica plates, apatite crystals, dust particles, and thousands of little liquid-filled pores, arranged in lines. Under crossed nicols most of the larger grains break up into an aggregate with the lines of inclusions passing from one grain into another without interruption. Occasionally some of the clear inclusions in the garnet are discovered to be plagioclase, but these are comparatively rare. The other substances inclosed by it are small pieces of biotite, crystals and particles of magnetite, crystals of apatite, and thousands of tiny cavities filled with liquid. As in the quartz, these are arranged in lines, and these lines are sometimes continuous in both substances. This latter phenomenon would indicate that the inclusions are of secondary origin, and that they were formed after the quartz and garnet had assumed their present positions. The age of the garnet is shown by its associations to be younger than that of the other constituents.

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[1] For descriptions of added growths to pyroxene and hornblende, see C. R. Van Hise: Am. Jour. Sci., 3d series, Vol. XXXIII, May 1887, p. 385, and G. P. Merrill, Ib, Vol. XXXV, June 1888, p. 488.

Another form in which the garnet exists is in small granules surrounding magnetite. Here the mineral has the same properties as when in large pieces, except that it contains no large inclusions of quartz and feldspar.

The quartz is in colorless masses, surrounded by garnet, as already mentioned, and also in larger pieces associated with the garnet, but not included in it. It usually occurs most abundantly near the garnet, in those sections containing a great deal of this mineral, and is almost if not totally absent from those sections in which there is none.

Since the garnet is probably secondary, i.e., since it was probably formed after the main portion of the rock solidified, it is also probable that the quartz is of secondary origin, and that the original components of the rock were essentially diallage and plagioclase, with magnetite, pyrite, and apatite as accessory components.

A rock of this composition is a gabbro, if its structure is not schistose. The principal mass of the rock under study is schistose, but it is very probable that this is an imposed structure, since, even in the apparently massive variety represented by the hand specimen, abundant indications of pressure are apparent. The massive phase, since it is characterized by garnet, must be denominated a garnetiferous gabbro, while the schistose variety is a squeezed gabbro or a zobtenite, midway in character between Nos. 135 and 137.

The photograph (Pl. XXXVIII, *B*) shows a large grain of plagioclase, surrounded by garnets, with the interstices between them filled with quartz. The black grains to the right are magnetite and pyrite.

The composition of the rock, as found by H. N. Stokes, is:

Analysis of garnetiferous gabbro from Granite Falls, Minnesota.

	Per cent.
SiO_2	52.31
Al_2O_3	18.35
Fe_2O_3	5.90
FeO	11.06
CaO	7.33
MgO	1.00
K_2O	.49
Na_2O	2.90
Loss	.35
Total	99.69

PERIDOTITE FAMILY.

NO. 110. PYROXENITE.

(FROM PIKESVILLE, BALTIMORE COUNTY, MARYLAND. ABSTRACT BY J. P. IDDINGS FROM THE DESCRIPTION BY GEORGE H. WILLIAMS.)

Together with gabbros and peridotites, the pyroxenites break

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[1] The nonfeldspathic intrusive rocks of Maryland and the course of their alteration: Am. Geologist, July, 1890. Also, Guide to Baltimore, with an account of the geology of its environs, and three maps: Am. Inst. Min. Eng., Baltimore meeting, February, 1892.

through the gneiss and marbles of the eastern part of the Piedmont area of Maryland. The pyroxenites and peridotites are younger than the gabbros, but are connected with them by intermediate varieties, and may be regarded as having originated from a gabbro-magma by a diminution in the alumina and silica.

The pyroxenites of Maryland are of two types. One, having darker color and being heavier, consists of bronzite or hypersthene and diallage; the other, having lighter color, consists of bronzite or hypersthene and diopside. The first is the more common. It is generally evenly granular in texture, with allotriomorphic crystals 1 or 2^{mm} in diameter, and sometimes 8^{mm} in length. Its fracture is hackly and very uneven. Its color is a mixture of dark brown and greenish black.

In thin section the rock consists almost wholly of anhedrons of reddish and greenish pyroxenes, both orthorhombic and monoclinic. The mineral composition is monotonous and simple, there being in addition to pyroxene only occasional specks of iron oxide or magnetite.

The pyroxenes are diallage and enstatite or bronzite. The diallage is pale green in thin sections, with the customary optical characters; high refraction and double refraction and inclined extinction in all sections except those parallel to the orthopinacoid $\infty P \bar{\infty}$ (100). The cleavage is prismatic and orthopinacoidal. Some sections of diallage exhibit between crossed nicols fine lines which are parallel to the prismatic axis. These are due either to multiple twinning, probably parallel to the orthopinacoid, or to lamellar inclusions of orthorhombic pyroxene. Sometimes these fine striations are crinkled or crumpled as though by mechanical strain. In some sections of diallage there are inclusions of orthorhombic pyroxene in parallel lines crossing the diallage at an inclination to the prismatic axis. These are surrounded by minute inclusions having relatively high refraction. In some places these inclusions take the form of parallel lamellæ of pyroxene, which appears to be orthorhombic, in others the two kinds of pyroxene are intergrown, with quite irregular outlines. The orthorhombic pyroxene in some cases incloses irregularly shaped pieces of diopside or diallage, and also thin lamellæ of this mineral in parallel position. The diallage is diopside or malacolite.

The orthorhombic pyroxene is pale reddish, with slight pleochroism, greenish to colorless parallel to $\mathfrak{c}$ and the prismatic axis, and reddish parallel to $\mathfrak{a}$ and $\mathfrak{b}$ at right angles to this axis. Sometimes there are rodlike inclusions giving the mineral a bronzy luster. In the absence of a chemical analysis it is not possible to determine whether the mineral is more properly enstatite or hypersthene. Professor Williams has called it bronzite or hypersthene.

Both kinds of pyroxenes are more or less dusted by minute inclusions. In some rock sections the orthorhombic pyroxene appears to be in excess of the monoclinic variety, but the following chemical analysis, made by J. E. Whitfield, of the pyroxenite from Johnny Cake road, shows that in this rock diallage is slightly in excess.

Analysis of pyroxenite from Johnny Cake road, Maryland.

	Per cent.
SiO_2	50.80
Al_2O_3	3.40
Cr_2O_3	.32
Fe_2O_3	1.39
FeO	8.11
MnO	.17
CaO	12.31
MgO	22.77
Na_2O	trace
K_2O	trace
H_2O (red heat)	.52
Cl	.24
Total	100.03
Sp. gr., 3.318.	

Magnetite occurs sparingly in rounded anhedrons. There are also small brown grains of chromite or picotite. A characteristic form of alteration of this rock is brought about by the change of the pyroxene into secondary hornblende, and subsequently the change of this into talc, giving rise to extensive beds of steatite, in which the talc is mixed with more or less pale fibrous tremolite and chlorite.

In the vicinity of Pikesville, Maryland, the pyroxenite often has an extremely coarse grain, and not infrequently contains porphyritical crystals of orthorhombic pyroxene an inch or two in length.

This type of nonfeldspathic rock, free from olivine and consisting of enstatite or hypersthene and diallage, has been called websterite by Professor Williams.[1]

No. 111. PERIDOTITE (FELDSPATHIC PERIDOTITE).

(FROM SUDBROOK PARK, BALTIMORE COUNTY, MARYLAND. ABSTRACT BY J. P. IDDINGS FROM THE DESCRIPTION BY GEORGE H. WILLIAMS.)

The peridotites of the Baltimore district have been fully described by the late Prof. George H. Williams in Bulletin 28, United States Geological Survey, from which the following has been taken:[2]

> The rock [peridotite] sometimes occurs in comparatively narrow, well characterized dikes; sometimes in small oval or lenticular patches. In the latter case it is nearly always associated with serpentine, which has originated from its alteration. . . . All the rocks of this class occuring near Baltimore have a strong resemblance to each other. All are dark brown or greenish brown in color, and have a peculiar rough appearance on the weathered surface by which they may be recognized at a considerable distance. This is produced by the decay of the olivine, which leaves the crystals of the more stable bronzite standing out like knobs upon the surface. . . .
>
> A macroscopical examination discloses a compact greenish-black groundmass, in which are embedded large crystals of a glistening yellow bronzite. In some cases no other constituent can be recognized with the unaided eye, but generally much

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[1] Op. cit., page 47.

[2] Pp. 50-54.

smaller crystals of black diallage can be detected. Feldspar is frequently thinly sprinkled in small white grains throughout the rock. . . .

The bronzite varies considerably in both the size and the number of its individuals. These range, even in the same hand specimen, from 1 to 8^{mm} in diameter. In some cases this mineral seems to compose nearly the entire mass of the rock, while in others it is so sparingly present as to appear quite accessory.

Cleavage plates of this bronzite are readily obtained parallel to $\infty P \breve{\infty}$ (010) and ∞P (110). They show, when examined in parallel polarized light, an extinction parallel to the vertical (*c*) axis. In thin sections of the rock this mineral is nearly colorless, and hence can exhibit no pleochroism. In thick plates, however, this phenomenon is plainly visible, viz: $a = \mathfrak{a} =$ reddish-brown; $b = \mathfrak{b} =$ reddish-yellow; $c = \mathfrak{c} =$ green; absorption $\mathfrak{c} > \mathfrak{a} > \mathfrak{b}$. . . . In thin sections this bronzite appears as large yellow or colorless plates. It has often a fibrous structure parallel to the vertical axis. Characteristic inclusions like those found in the hypersthene do not occur, but brightly polarizing spots with a highly inclined extinction angle are very prominent between crossed nicols when the bronzite itself is dark, although in ordinary light they are quite invisible. They seem to be due to an intergrowth of small portions of diallage substance. As alteration of the bronzite commences fine bands of serpentine are seen to be developed along cracks which traverse it. Minute fibers, resembling bastite, are also of common occurrence.

The diallage of the olivine rocks yields in isolated splinters cleavage plates parallel to $\infty P \bar{\infty}$ (100), and ∞P (110). . . . [The latter] show an extinction angle of from 10° to 13° when measured against the vertical axis. In thin rock sections an extinction angle as high as 35° was observed in this mineral.

The diallage shows no pleochroism. Thin sections of it are nearly colorless, while such as are quite thick, but thin enough to transmit light, remain green in all positions, with no perceptible change in the intensity of the color when the transmitted ray is made to vibrate in different directions through the crystal.

The diallage has a much more perfect cleavage than the bronzite. It likewise presents a marked contrast to this mineral in the frequency with which twinning lamellæ occur in it. These seem to be of secondary origin, produced probably by pressure, as was also observed in the case of the diallage of the hypersthene-gabbro [from the Baltimore district]. Such secondary lamellæ are often present in great numbers, and are especially distinct when the diallage crystal has been broken or bent.

The feldspar is shown by all its physical properties to be bytownite. Its specific gravity . . . is 2.722. The average of a large number of stauroscopic measurements on cleavage fragments gave extinction angles on OP (001) of 19°, and on $\infty P \breve{\infty}$ (010) of 32°, values which agree well with the specific gravity. This feldspar is soluble with difficulty in concentrated hydrochloric acid and fuses readily in the flame of a Bunsen burner. This mineral shows a marked freedom from inclusions, differing in this respect from the feldspar of the hypersthene-gabbro. Wherever it comes in contact with the olivine the peculiar reactionary rims of amphibole are finely developed.[1]

The interior zone of these rims next to the olivine is narrow, granular, and almost colorless. Outside of this is a darker-greenish portion, having a feathery appearance. This exterior zone projects in rounded tufts into the feldspar substance, at the expense of which it has apparently been formed.

The main mass of the feldspar is not always fresh. The change which it has undergone is the interesting and unusual one to a zeolite mineral (probably scolecite), instead of the more common one, to saussurite or calcite. While the larger portion of a feldspar crystal remains quite unchanged, radiating tufts or continuous bands of stout, colorless needles may frequently be seen. These show the most

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[1] Bull. U. S. Geol. Survey No. 28, p. 43.

brilliant interference colors in polarized light, even when the section is exceedingly thin, an effect well known to be characteristic of the zeolites. . . .

The olivine, the most characteristic constituent of this class of rocks, exhibits no very striking peculiarities. It is present in small, rounded grains, forming the dark, compact groundmass in which crystals of the other minerals are porphyritically embedded. The structure of these rocks is therefore quite an exceptional one for the family of peridotites: First, on account of the porphyritic character, which is rare in members of this class, and, second, because of the unusual position of the olivine in the groundmass, indicating that it is here the youngest instead of the oldest constituent, as is generally the case. The grains of olivine are always more or less completely changed to serpentine, although in many specimens cores of the original mineral remain intact. The serpentine is of a bright yellow color when seen in a thin section under the microscope, and shows in an admirable manner the well-known process of its formation out of the olivine substance. The fine serpentine fibers are developed along cracks and fissures in the olivine, working their way from these inward until finally none of the olivine remains. A considerable quantity of magnetite in fine shreds and lines is always disseminated through the serpentine, having been separated from the olivine during the process of its alteration.

No other constituents were observed in the olivine rocks of the Baltimore region, except in rare cases small quantities of a compact, brown, strongly pleochroic hornblende, which is filled with minute dustlike inclusions. This mineral is most intimately associated with the diallage, the two being completely intergrown in the same crystal. . . .

Feldspathic peridotite is the commonest type of peridotites in the Baltimore region. The feldspar in it does not compose over 5 per cent of the rock. The following chemical analysis, prepared by Dr. Leroy McCay, was made from a specimen from a dike on the Western Maryland Railroad, north of Howardsville.

Analysis of peridotite from Maryland.

	Per cent.
SiO_2	41.00
Al_2O_3	7.58
Fe_2O_3	5.99
FeO	4.63
MnO	trace
CaO	10.08
MgO	23.59
Na_2O	.52
CO_2	3.62
H_2O	4.73
Total	101.74
Specific gravity, 2.989.	

No. 112. KIMBERLITE.

(FROM ELLIOTT COUNTY, KENTUCKY. DESCRIBED BY J. S. DILLER.)

This rock occurs in the midst of the coal fields of eastern Kentucky, where the sandstones and shales of the coal measures are nearly horizontal. It is one of a series of three peridotites found under somewhat similar conditions west of the axis of the Allegheny Mountains among the comparatively little disturbed sedimentary rocks. The other localities referred to are the serpentine of Syracuse, New York, described by Dr. Williams,[1] and the mica peridotite of western Kentucky.[2]

The kimberlite of Elliott County, Kentucky, outcrops at only three points in the same neighborhood, but the form suggested by the residual material of the soil is that of dikes, and the large number of inclusions it contains in places shows that it has been erupted through Carboniferous strata.

It is a compact, dark-greenish rock, with a specific gravity of 2.781. In it are embedded many grains of yellowish olivine, uniformly distributed throughout the mass. Rarely it is fine granular and dense, like many darker colored basalts, but generally the grains of which it is composed are medium sized. Occasionally the olivine grains disappear and the deep-green serpentine pervades the whole mass. Besides the olivine and serpentine, which together form nearly 75 per cent of the rock, there are other minerals which appear in the hand specimen. Most important among these are pyrope and ilmenite, the latter appearing in the form of irregular grains which sometimes attain a diameter of nearly 2^{cm}. A few scales of biotite may be observed. Near the exposed surface the rock becomes yellowish, due to the oxidation of the iron, and softens so that it readily disintegrates. The garnet and much of the ilmenite withstand the atmospheric influences and are found quite fresh and abundant in the residual sand resulting from the disintegration of the peridotite.

The following table is based directly upon estimates made under the microscope of the areal distribution of the various minerals in the freshest portions of the sections from the locality where the peridotite is least altered:

Primary minerals.	Per cent.	Secondary minerals.	Per cent.
Olivine	40	Serpentine	30.7
Enstatite	1	Dolomite	14
Biotite	1	Magnetite	2
Pyrope	8	Perofskite	1.1
Ilmenite	2.2		
Apatite	trace		

It is not claimed, of course, that this table represents with a high degree of accuracy the mineralogical composition of the rock, yet it closely approximates the real proportions in the sections studied. The table clearly indicates that originally at least 80 per cent of the rock was olivine and that ultimately it will be nearly all serpentine—or, perhaps, in some places dolomite—with a small proportion of magnetite, ilmenite, garnet, and perofskite.

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[1] Am. Jour Sci., 3d series, Vol. XXXIV, August, 1887, p. 137.

[2] Am. Jour. Sci., 3d series, Vol. XLIV, October, 1892, p. 286.

The general structure of the rock is illustrated in Pl. XXXIX, figs. A and B, which show the remaining more or less regular phenocrysts of olivine inclosed in a network of serpentine with other products of alteration. The high proportion of olivine in the rock places it among those peridotites which are generally designated dunites, but the presence of some enstatite shows its relationship to saxonite. The more or less distinct porphyritic structure was regarded by Carville Lewis[1] as so important a feature that he designated a similar rock of the Kimberly mines in the South African diamond field as "kimberlite." The original structure of the rock was not wholly porphyritic. In some places, at least, it has a holocrystalline even-granular structure like granite, the irregular grains of olivine interlocking like those of quartz and feldspar in granite.

The olivine grains are generally irregular in form, varying from 0.1 to 1.5^{mm} in diameter, and are penetrated by many fissures. Occasionally, however, as shown in the upper figure of Pl. XXXIX, they are bounded by sharply defined crystallographic planes, a feature which is unusual for the olivine in peridotites. It occurs in the form, which is common in basaltic lavas, of a short prism terminated by brachydomes without the base.

The alteration of the olivine to serpentine takes place rapidly in the cross fractures approximately parallel to the base, but very slowly along the numerous minute fissures in the prism zone. Cleavage parallel to the brachypinacoid is scarcely discernible.

In the process of alteration the olivine is transformed into serpentine with the secretion of magnetite. Among the secondary products there is much dolomite, which appears to result from the transformation of the olivine. The abundance of the carbonate present suggests that the olivine might contain a considerable percentage of lime. This suggestion was proved true by a chemical analysis of the olivine.

Pyroxene plays so small a part among the minerals of this rock that it can not be considered an essential constituent. In the form of irregularly corroded grains, it is distributed throughout the mass with approximate uniformity, but it constitutes not more than 1 per cent of the whole. The cleavage is nearly rectangular, and the extinction in prismatic sections is parallel, indicating with a high degree of probability that the pyroxene is orthorhombic. It is generally transparent, with a sprinkling of fine, dark grains, and is surrounded by a clouded border conforming to the embayed contour.

The embayments of the irregular enstatite sometimes contain olivine, demonstrating that the pyroxene is an earlier product of crystallization than the olivine and owes its border, at least in part, to the subsequent corrosive action of the magma.

The mica is dark colored, strongly dichroic, with a very small optic axial angle in the plane of the principal ray of the radial figure (schlagfigur) produced by puncturing a thin plate of the mica with a

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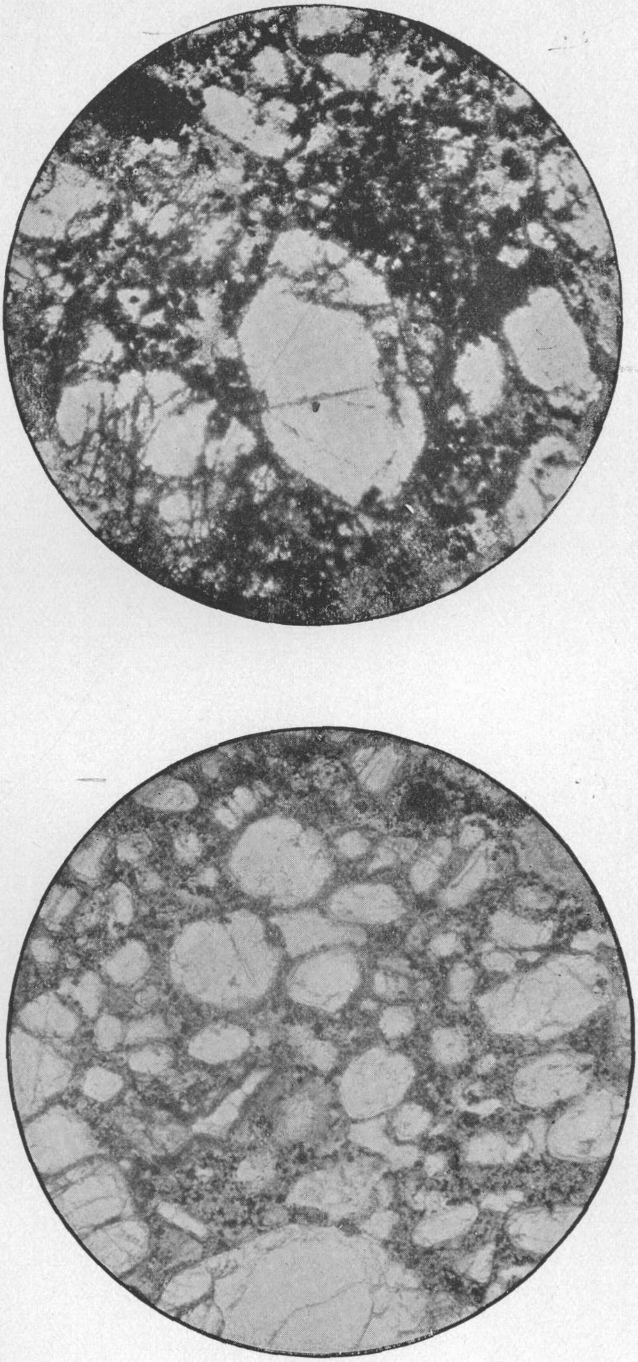
[1] Proc. Brit. Assoc. Adv. Sci., 1887, p. 720.



THIN SECTIONS OF KIMBERLITE FROM ELLIOTT COUNTY, KENTUCKY, AS SEEN UNDER A MICROSCOPE, × 30.

sharp needle. This biotite is sparingly distributed throughout the rock and is surrounded by a prominent border composed of colorless mica and oxide of iron.

Pyrope can not be considered one of the essential minerals in this rock, yet it is among the most prominent. It occurs in spherical and ellipsoidal grains varying from 1^{mm} to more than a dozen millimeters in diameter. They are found abundantly along the line of the dike in the soil resulting from its disintegration. The small, clear, deep-red grains have a specific gravity of 3.673 and are locally regarded as rubies of problematical value, but the paler red, much-fractured fragments of larger size have attracted little attention.

The most interesting feature of the pyrope is prominent under the microscope, where it is seen to be surrounded by a border of radial fibers analogous to that described by Fr. Becke[1] and A. Schrauf,[2] and later critically examined by A. v. Lasaulx.[3] The general character of the border is represented in fig. 16. It is composed of two essentially different substances, both of which are always present, although varying much in proportions. First of these may be mentioned a dark powder, which is frequently so abundant as to render the border opaque. It occurs most abundantly in the outer portion of the border, and is chiefly, if not wholly, magnetite, for when carefully detached by a sharp needle from an uncovered section it is found to be strongly magnetic. The second, usually inner, substance of the ring is of a grayish or reddish brown color, and is generally fibrous in structure. Schrauf studied the fibrous substance enveloping the garnets in the serpentine of Kremze, Bohemia, and named it kelyphite. The investigations of Lasaulx have shown that in some cases the border, instead of being a single mineral, is a mixture of several minerals, chiefly of the pyroxene and amphibole groups. In the example under consideration its composition appears to be exceptional. Although it is commonly made up of closely compacted, very fine parallel fibers, perpendicular to the outer surface of the garnet, it frequently appears as an irregular nonfibrous fringe upon the inner side of the border, or even

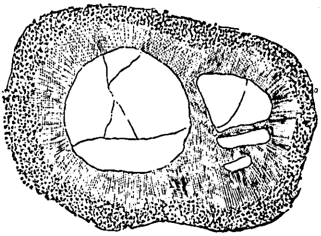


FIG. 16.—Pyrope showing border of biotite and magnetite.

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[1] Tschermak's Mittheilungen, IV, 1881, pp. 189, 285.

[2] Beitrage zur Kenntniss des Associations-kreises der Magnesia-Silikate: Zeitschrift für Krystallographie, 1882, VI, pp. 321–388; also Ueber Kelyphite: Neues Jahrbuch, 1884, Bd. II, p. 21.

[3] Ueber die Umrindungen von Granat. Sitzungsberichte der niederrhein. Gesellschaft in Bonn, 1882, Juli 3; Verhandlungen des naturhistorischen Vereines der preussischen Rheinlande und Westfalens, Neununddreissigster Jahrgang, zweite Hälfte, Bonn, 1882, p. 114.

completely incloses within the garnet, where it is usually of a deep brown color. Generally it is distinctly doubly refracting, and when finely fibrous is sometimes strongly colored red and green between crossed nicols. The nonfibrous form of the substance, although deeply colored, is isotropic and consequently not dichroic, but when fibrous the absorption parallel to the fibers is occasionally almost complete, like that of biotite, which in one section, by its uniaxial, negative, and strongly dichroic character it was proved to be. Ilmenite and magnetite are common and uniformly distributed constituents of the Kentucky peridotite.

Abundantly scattered among the other secondary products in the serpentinous network enveloping the remnants of olivine are yellowish clouded grains ranging in size from .004 to .06^{mm} in diameter. The intensity of the yellowish color varies considerably, with a strong inclination toward brown. Its index of refraction is very high, causing it to rise above the neighboring minerals, but its low grade of translucency scarcely more than allows the observer to discover that the mineral is distinctly doubly refracting without determining certainly its degree. With a very sharp steel point a number of these grains were removed from an uncovered section and dissolved in fused $KHSO_4$. When the product was moistened with a solution of H_2O_2 it turned distinctly yellow, indicating the presence of titanium. At first these grains were supposed to be octahedrite, but Dr. G. H. Williams's discovery of similar grains of perofskite in the serpentine of Syracuse led to the separation and chemical examination of those in specimen 112, and they also were found to be perofskite.

For a fuller description of this rock and its mode of occurrence the student is referred to United States Geological Survey Bulletin No. 38, Peridotite of Elliott County, Kentucky.

No. 113. CORTLANDITE (HORNBLENDE-PERIDOTITE).

(FROM STONY POINT, ON THE HUDSON, NEW YORK. ABSTRACT BY J. P. IDDINGS FROM THE DESCRIPTION BY GEORGE H. WILLIAMS.)

This rock was first described by Prof. George H. Williams, under the head of hornblende-peridotite,[1] at which time it was shown to belong to Bonney's class of hornblende-picrites, and to Cohen's class of hudsonites. The latter term, however, Williams showed had been given to a variety of diallage, and so he proposed the name cortlandtite for the rocks ordinarily classed as hornblende-peridotites. The following description is taken from his paper just cited:

> The best locality for specimens of this type of peridotite is at Kings Ferry on Stony Point, a small prominence on the west side of the Hudson River, somewhat southwest of Verplanck. . . . [Many varieties of peridodite may be found among the blocks thrown out of the railroad cutting near this place.] The most remark-

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[1] Peridotites of the "Cortlandt Series" on the Hudson River near Peekskill, New York: Am. Jour. Sci., 3d series, Vol. XXXI, 1886, pp. 26-41.

> able among these varieties is a dark green, at first sight apparently fine-grained, rock, which, however, when held in a proper light, exhibits glistening, bronze-colored cleavage surfaces, often measuring 3 by 4 inches. The reflection from these surfaces is not altogether continuous, being interrupted by small rounded grains of a dull green mineral whose nature can not be determined with the unaided eye, but which the microscope shows to be olivine or serpentine.

This "luster-mottling," as a similar phenomena has been called by Pumpelly,[1] has been termed pœcilitic structure by Professor Williams.[2]

> The glistening surfaces [in this rock], as the microscope shows, are those of a brown hornblende. The individuals of this mineral are very large, being often 4 inches in diameter; but, notwithstanding that they are so abundant as to be everywhere in contact with each other, so full are they of inclusions of the other constituents that they do not of themselves make up one-half of the entire mass of the rock. [The only other minerals recognizable without a microscope] are frequent particles of magnetic pyrites (pyrrhotite) and glistening flakes of a light green mica.

The hornblende is recognized by its characteristic prismatic cleavage with an angle of 124° 30′.

In thin section it is rich brown, which is the color of basaltic hornblende. Its pleochroism is pronounced. The color of rays vibrating parallel to $\mathfrak{c}$, nearly parallel to the prismatic axis, is dark chestnut; that of the rays vibrating parallel to $\mathfrak{b}$, parallel to the orthodiagonal axis, is a slight tinge lighter, while the color for rays vibrating parallel to $\mathfrak{a}$ is a light yellow. The absorption is $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$. Hence some sections exhibit marked pleochroism, and others almost none. The extinction angle in clinopinacoidal sections is 9° to 10° from the prismatic axis, indicated by the direction of the prismatic cleavage cracks in such sections.

> The inclusions in this hornblende are both numerous and characteristic. The most common are opaque black needles, ranging in size from the finest dust to about 0.03^{mm} in length. The majority are arranged either parallel to the vertical axis, or else so as to make an angle of about 45° with this. Others appear quite irregular in their position. More rarely small transparent crystals, the largest of which are 0.05^{mm} long and 0.02^{mm} broad, occur with the opaque needles. The nature of these could not be determined. . . . Still more rarely than these transparent crystals, the hornblende contains inclusions of thin brown plates similar to those which are so characteristic of hypersthene. All of these interpositions, of which the opaque needles as a rule occur alone, show a tendency to concentration toward the center of the hornblende, leaving a border near the edge comparatively free from foreign substances. Often they form irregular patches scattered like little clouds over the brown background.
>
> The hornblende itself never shows any trace of crystalline form. It fills the irregular spaces between the other constituents, a single individual often covering a space some inches square. From its relations to the other minerals in the rock it is evident that it was the last to solidify, while the great size of the crystals would seem to indicate that the process of their formation went on very slowly. . . .
>
> The hornblende seems particularly subject to alteration, which is often far advanced before the olivine or the pyroxene are materially affected. The first change which the hornblende undergoes is bleaching, accompanying which is the

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[1] Metasomatic development of the copper-bearing rocks of Lake Superior. Proc. Amer. Acad., Vol. XIII, p. 260, 1878.

[2] Loc. cit., p. 30; also, On the use of the terms poikilitic and micropoikilitic in petrology: Jour. Geol., Vol. I, p. 176, 1893.

almost total disappearance of the characteristic inclusions. The mineral becomes nearly colorless and consequently nonpleochroic, while retaining the compact structure and optical behavior of the unaltered portion. Later there is developed, particularly around the edge of the hornblende, a bright emerald-green substance, which, on account of its lack of dichroism and very feeble action on polarized light, may be regarded as chlorite.

Next to the hornblende, the most important constituent of this rock is the olivine, which is remarkable both for its freshness and for its beautiful inclusions. It is present in rounded grains or in well-defined crystals, upon which the usual combination of domes, prisms, and pinacoids may be seen. These crystals vary from one-half to 2^{mm} in diameter. The mineral is quite colorless, with a high index of refraction, and is traversed by irregular cracks, along which serpentinization may be frequently seen to have commenced, although in many sections there is hardly a trace of this alteration. . . . They [the inclusions] are black and opaque, having generally the form of minute, rounded grains, or long rods arranged parallel to one or more of the crystallographic axes of the olivine, although they are sometimes more irregular in their distribution. Frequently these rods, instead of being straight, are variously bent and twisted, exhibiting the form of trichites in obsidians. In such cases they show a tendency to form elliptical groups resembling a fine arabesque, as figured by Zirkel.[1] The same author has observed that while these inclusions are very characteristic of the olivine of the older rocks [i. e., the coarser-grained rocks—J. P. I.] they are never found in that of the younger basalts. There seems little doubt that they are composed of magnetite, since they are readily decomposed by acid, and since such grains of olivine as contain them in abundance are attracted by the magnet. . . .

[In the exceptional cases, in which feldspar is present, and is in contact with olivine, there is a zone between the two minerals consisting of two parts.] The inner portion, nearest the olivine, is composed of square grains of nearly colorless pyroxene; the outer one [adjacent to the feldspar, consists] of tufts of radiating actinolite needles of a beautiful bluish-green color and strongly pleochroic. [The olivine is sometimes partly altered to serpentine.]

The pyroxene constituent of the peridotite from Kings Ferry appears to be for the most part hypersthene. It sometimes forms small irregular grains not larger than those of the olivine, but in other cases it is present in individuals which are over a centimeter in length, inclosing the smaller grains of both olivine and hypersthene like the hornblende. In all forms it possesses all the ordinary characteristics of hypersthene, except that it is singularly free from the usual inclusions. Its pleochroism is very strong: $a = \mathfrak{a}$ ray is red; $b = \mathfrak{b}$ ray is yellow; $c = \mathfrak{c}$ ray is green. Its cleavage is well developed parallel to the prism (∞ P) and also still better parallel to the brachypinacoid (∞ P $\breve{\infty}$). A common, nonpleochroic augite, in which a diallage habit is frequently developed by the presence of a parting parallel to the orthopinacoid [100] is also often to be observed in this rock, although in many specimens it is altogether lacking. As this constituent increases in amount the rocks grade into those of the next group [augite-peridotite or picrite].

Biotite is also present in small amounts. This mineral rarely retains its brown color. It is generally so completely bleached as strongly to resemble muscovite in thin sections. It is much bent and twisted, often having small lenses of calcite interposed between its lamellæ. . . . Aside from mere bleaching, the formation of the bright green, chloritic mineral, noticed as an alteration product of the hornblende, is also frequent. The true character of this mica is revealed by its very small axial angle . . . as well as by the fact that rarely sections may be found which have escaped the bleaching. These have the characteristic color, and pleochroism of biotite, and sometimes contain acicular inclusions resembling needles of rutile. . . .

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[1] Zeitschrift der deutschen geologischen Gesellschaft, XXIII, 1871, p. 59, Pl. IV, Fig, II. Mikrosk. Beschaffenheit, p. 214.

Feldspar, though frequently accessory, is never an important constituent of these rocks. [It is a basic lime-soda feldspar, probably bytownite.—J. P. I.]

Magnetite, aside from composing the inclusions in the olivine above referred to, forms small grains which line the cracks in this mineral, and are especially abundant about its edge, where it is in contact with the brown hornblende. The large opaque grains scattered through the rock are almost all pyrrhotite (magnetic pyrites (Fe_7S_8)); chromite or picotite were not observed; another form of spinel, however, pleonast, recognized by its dark-green color and isotropic character, is not uncommon. This mineral is filled with thin opaque plates almost exactly like the inclusions in the well-known hercynite from Ronsperg, in Bohemia. Apatite was hardly ever observed.

NO. 114. SAXONITE.[1]

(FROM NEAR RIDDLES, DOUGLAS COUNTY, OREGON. DESCRIBED BY J. S. DILLER.)

The saxonite, of which specimen 114 is a sample, occupies an irregular area of about 2 miles in extent a short distance directly west of Riddles, Douglas County, Oregon. It is almost completely surrounded by rocks which are considerably metamorphosed, although upon one side it touches for a short distance the Cretaceous shales.

The rock has a dark yellowish-green color and high specific gravity, suggesting at once that it is rich in ferromagnesian silicates. It is holocrystalline granular, and composed essentially of olivine and enstatite, with a small percentage of accessory chromite and traces of magnetite.

The olivine predominates, so that the enstatite forms less than one-third of the mass. Nevertheless, it plays a much more important rôle than in the kimberlite of Kentucky. Here it is of sufficient importance to rank as an essential constituent of the rock, and occasionally shows fine lamellæ twinning. Both the olivine and the enstatite are clear and colorless, but may be readily distinguished by their cleavage and optical properties. They are allotriomorphic and do not contain inclusions, excepting the coffee-brown grains of chromite with a small amount of magnetite and fine ferritic dust.

Notwithstanding the comparatively fresh condition of the rock, it is in places completely permeated by a multitude of cracks filled with serpentine resulting from its alteration. The combination of enstatite and olivine would appear to be particularly favorable for the production of serpentine, as it supplies to the other the material needed besides the water to make serpentine.

Thus saxonite, including the serpentine derived from it, is of particular interest in being the seat of deposit of genthite, a nickel silicate of economic importance. It was discovered by Will Q. Brown, and is associated with quartz in more or less distinct veins, which, according to Mr. W. L. Austin, who has studied the deposits in the field, and mapped them, extend across the entire area in a northeast and southwest direction.

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[1] Saxonite was named by Dr. M. E. Wadsworth in his Lithological Studies in 1884, Cambridge, Massachusetts. It is the same rock that Rosenbusch designates "harzburgite."

The genthite, like the vein quartz, is of secondary origin, and from the fact that the olivine in the saxonite contains nickel, it is regarded as the source of that in the genthite.

The following analyses of the saxonite (I) and of the olivine (II) it contains were made by F. W. Clarke, of the United States Geological Survey:

Analyses of saxonite and its contained olivine.

	I.	II.
	Per cent.	*Per cent.*
Ignition	4.41	0.57
SiO_2	41.43	42.81
Al_2O_3	.04	....
Cr_2O_3	.76	.79
Fe_2O_3	2.52	2.61
FeO	6.25	7.20
NiO	.10	.26
MnO	none	none
CaO	.55	none
MgO	43.74	54.12
Total	99.80	99.36

For fuller description of the mode of occurrence of this rock and its nickel ore the student is referred to United States Geological Survey, Bulletin No. 60, pages 20 to 26; also to a paper by W. L. Austin in the Proceedings of the Colorado Scientific Society of Denver for January 6, 1896, and to a communication by Mr. H. B. von Foullon, Jahrbuch d. k. k. geol. Reichsanstalt, Vienna, 1892, XLII, p. 223.

METAMORPHIC SEDIMENTARY ROCKS.

No. 115. Crystalline Limestone.

(From east base of Modoc Peak, Eureka County, Nevada. Described by J. P. Iddings.)

The crystalline limestone from the Devonian strata was collected at the east base of Modoc Peak, Eureka, Nevada, and is called the Nevada limestone (Monographs U. S. Geol. Survey, Vol. XX, p. 63 et seq.). It is light-gray, quite crystalline and saccharoid, and contains 40.62 per cent of magnesium carbonate. It is not distinctly bedded, being massive. In thin section it is evenly granular and wholly crystalline, with almost no admixture of other minerals than dolomite. A small amount of quartz of subsequent crystallization occurs as scattered patches, forming a filling in minute cavities between the dolomite crystals. No other minerals were observed. The dolomite exhibits the characteristic cleavage, but little or no twinning. There are numerous minute inclusions of an indeterminate nature, probably gas or fluid.

No. 116. MARBLE.

(FROM LEE, BERKSHIRE COUNTY, MASSACHUSETTS. DESCRIBED BY J. S. DILLER.)

Unaltered limestones are well represented in the series by chalk (No. 39), patellina limestone (No. 40), coquina (No. 42), shell limestone (No. 43), cherty limestone (No. 44), compact limestone (No. 46), lithographic limestone (No. 47), and hydraulic limestone (No. 48). Specimen No. 115 is an example of a limestone that has been completely crystallized since its deposition. This process is metamorphic in its nature. Owing to the fact that calcite is readily soluble and much more easily changed than the mass of other rock-making minerals, limestones may become completely crystalline (metamorphosed), while the adjoining rocks remain but little altered.

Metamorphic limestone is sometimes called marble, but the name is usually restricted, as in the trade, to limestone which will take a polish.

The marble of Lee, Massachusetts, is of Cambro-Silurian age, and is a part of the great limestone and marble belt extending from Georgia, through a number of the Southern, Middle, and New England States, into Canada. Specimens Nos. 46 and 150, and probably, also No. 117 are from this belt. In the Middle States the rock is limestone; but in New England, as well as in Georgia and Tennessee, where it has been subjected to much greater disturbance and consequent metamorphism, it is converted into marble.

The Lee marble is a white, uniformly fine-grained rock, which looks to be a remarkably pure limestone; but if so, it should be completely soluble. In Mr. E. A. Schneider's chemical analysis, given below, it is seen to contain only 0.19 per cent of insoluble matter, of whose composition the analysis gives us but little information. The analysis shows that the limestone is rich in carbonate of magnesia, containing over 40 per cent; so rich, indeed, that it may be classed among the dolomites. In this respect it is closely related to the Cockeysville marble (No. 117); also that of Eureka, Nevada (No. 115).

Analysis of Lee marble.

	Per cent.
Insoluble	0.19
Al_2O_3, Fe_2O_3	.24
CaO	30.88
MgO	21.42
CO_2	46.72
Organic matter	....
H_2O, 105°	....
Total	99.45

Under the microscope the Lee marble is seen to be completely crystalline granular, with small grains, comparatively uniform in size.

Many of these show twinning bands, but are generally quite free from visible inclusions. The presence of 0.19 per cent of insoluble material would be expected to reveal itself under the microscope. However, as minerals other than the carbonates were not readily detected in the section, a fragment of the limestone was dissolved, and a residue obtained of clear colorless cleavage plates of a mineral which has a very small optic axial angle and is negative. The interference colors of its cleavage plates are very low, in thin pieces, not even attaining yellow of the first order.

According to Mr. Merrill,[1] much of the marble of Lee and adjoining localities contains crystals of tremolite, which weather out upon exposure, leaving the rock with a rough pitted surface. They are doubtless due to metamorphism. Mr. Hobbs[2] notes their abundant development in the Canaan limestone of the same region along the line of a great fault.

The Lee marble was used in the structure of the Capitol extension, but Mr. Merrill reports that the weathering out of the tremolite crystals in the exterior walls is very noticeable. In England dolomite is considered much more durable than pure limestone, but that view does not appear to be shared in this country.[3]

NO. 117. MARBLE (DOLOMITE).

(FROM COCKEYSVILLE, BALTIMORE COUNTY, MARYLAND. DESCRIBED BY J. S. DILLER.)

This rock is known throughout the Baltimore region as the "Cockeysville marble" because it is extensively quarried at that place. It is completely crystalline, as shown in Pl. XL, which represents it as seen under a microscope of small amplification. The crystalline grains are much larger than those of the Lee marble. The rhombohedral cleavage is especially distinct in the thin section, although not well shown in the illustration, which was taken between crossed nicols in order to bring out the twinning lamellæ. Grains of quartz, several of which are shown in the figure, are common, and account for the high percentage of silica present. Farther westward in Maryland, according to Williams, the limestones are much less crystalline and retain traces of their original sedimentary character. All of these features are obliterated in the Cockeysville marble. The impurities may originally have been distinct, but now, according to Williams, have crystallized and appear as accessory minerals, the original sedimentary character having been obliterated in the metamorphism.

There is little variation visible in the hand specimens, but in the large mass, where quarried, there are considerable variations in the size of the grains, as well as chemical composition and accessory con-

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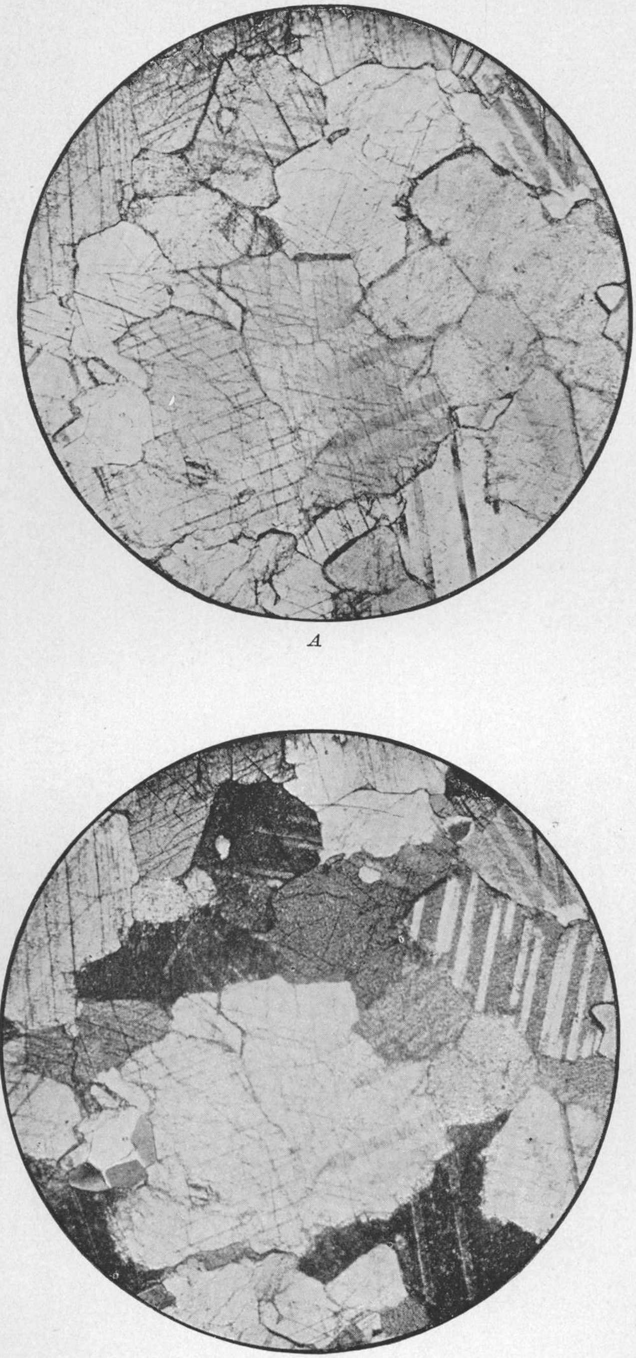
[1] Stones for Building and Decoration, p. 94.

[2] Jour. Geol., Vol. I, p. 794.

[3] Stones for Building and Decoration, by G. P. Merrill, p. 381.



THIN SECTION OF MARBLE, COCKEYSVILLE, MARYLAND, AS SEEN UNDER A MICROSCOPE, × 30.

A. In ordinary light. *B.* Between crossed nicols.

stituents. The coarse-grained variety, which is much coarser than specimen 117, is locally called "alum stone," and is burnt for lime.

Two analyses of this marble are given below. The first was made by J. E. Whitfield,[1] and the second by E. A. Schneider. The second shows the composition of the specimen in this series.

Analyses of Cockeysville marble.

	Per cent.		Per cent.
SiO_2	0.44	Insoluble	5.57
Al_2O_3	1.22	Al_2O_3, Fe_2O_3	.40
FeO	trace	CaO	29.08
CaO	30.73	MgO	20.30
MgO	20.87	CO_2	44.26
CO_2	45.85	Organic matter	
Ignition	1.22	H_2O at 105°	
Total	100.33	Total	99.61

The amount of magnesian carbonate present, as shown by these two analyses, is variable, and averages a little over 39 per cent.

For information concerning the field relations of this rock, the student is referred to the "Guide to Baltimore, with an account of the Geology of its Environs," pp. 97 to 102, by George H. Williams. Its distribution is shown upon an accompanying geological map.

No. 118. QUARTZITE.

(FROM CARIBOU HILL, EUREKA COUNTY, NEVADA. DESCRIBED BY J. P. IDDINGS.)

The quartzite from Caribou Hill, Eureka, Nevada, is of Silurian age, and is designated on the atlas sheets accompanying Monograph XX, United States Geological Survey, as the Eureka quartzite.[2] It is dense, white, and vitreous, in massive beds, with no distinct evidence of its fragmental character visible to the unaided eye.

In thin section it is seen to be a very pure quartz rock, consisting of grains of quartz about 0.25^{mm} in diameter. In general they are very free from inclusions of foreign mineral matter, but usually exhibit minute fluid inclusions. Some grains contain hair-like needles which are probably rutile. The fluid inclusions are often arranged in lines or planes traversing the quartz grains in one or more directions. The shape and outline of the quartz grains in some cases suggest those of granitic quartz, in which each grain has crystallized until interrupted by the neighboring grains; but in many cases it can be seen that the outer portion of the grain is an addition of quartz substance upon a central nucleus of quartz, which itself is a well rounded water-worn grain. The inner and outer portions have the same optical orientation

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[1] Bull. 60, U. S. Geol. Survey, p. 159.

[2] See Monograph XX, pp. 54 and 212.

and appear to be one continuous individual crystal. The line of demarcation between the two portions consists of minute inclusions surrounding the original rounded grain. This secondary enlargement of quartz grains has been described by a number of petrographers,[1] and is due to the crystallization of quartz from aqueous solutions permeating the sandstone, the secondary quartz assuming the same crystallographic orientation as that of the nucleus. This feature may be observed also in the Potsdam sandstone (Pl. X, p. 80). By this process a sandstone may be converted into a dense vitreous quartzite by the action of aqueous solutions without the accompaniment of abnormal pressure or of any increase of temperature.

In the quartzite from Caribou Hill there are veins of chalcedony that traverse the rock in all directions and sink to microscopic proportions. The chalcedony is developed in spherulitic growths, radiating from the surface walls of the veins inward, usually as narrow bands in thin section. In some of the broader veins the chalcedony in the central portion exhibits definite spherulites and in some cases microcryptocrystalline aggregation. It is distinguished from the quartz by lower index of refraction, and by the fact that the axis of greatest elasticity is parallel to the long axis of the chalcedony fibers, which are in a sense optically negative. Minute prisms of quartz would be optically positive, the axis of least elasticity being parallel to the length of the prisms.

It is evident that the sandstone, after being cemented by the secondary enlargement of the quartz grains, and having been converted to quartzite, was subjected to dynamical strain which fractured it into small pieces and minute particles. It was then permeated by solutions which deposited silica in the form of chalcedony in all the fissures and interstices and recemented it into a dense quartzite.

The fractures, which are now indicated by the veins of chalcedony, traversed the grains of quartz and their quartz cement as across a compact mass, and incomplete parallel fractures, which accompany the more perfect ones, are shown by lines and planes of fluid inclusions. These are therefore of secondary origin, are subsequent to the first cementation and contemporaneous with the fracturing, and result from dynamic action.

No. 119. QUARTZ-SCHIST.

(FROM STEVENSON STATION, GREEN SPRING VALLEY, BALTIMORE COUNTY, MARYLAND. DESCRIBED BY W. S. BAYLEY.)

The specimen numbered 119 was obtained from the Shoemaker Quarry, near Stevenson, a station on the Green Spring Valley Branch

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[1] A. E. Törnebohm, Ein Beitrag zur Frage der Quartzitbildung: Geol. Fören. Stockh., 1876, Vol. III, p. 35, reviewed in Neues Jahrbuch für Min., etc. 1877, p. 210. H. C. Sorby: Quart. Jour. Geol. Soc. London, 1880, Vol. XXXVI, p. 62. A. A. Young: Am. Jour. Sci., July, 1882. R. D. Irving: Id., June, 1883. R. D. Irving, and C. R. Van Hise: Bull. 8, U. S. Geol. Survey, 1884. T. G. Bonney and J. A. Phillips: Quart. Jour. Geol. Soc. London, Vol. XXXIX, p. 19. J. P. Iddings: Monograph XX, Appendix B, U. S. Geol. Survey, 1892, p. 346.

of the Northern Central Railroad, in Baltimore County, Maryland. The rock is used for flagging, and for the foundations and abutments of bridges.

Geologically the rock is one of the members of the series underlying the eastern portion of the Piedmont Plateau. This is an elevated base-leveled area, which is divided by Dr. Williams[1] into an eastern and a western portion. In the western portion the rocks are unquestionably metamorphosed sediments (see description of No. 126), while in the eastern portion they are nearly all holocrystalline, though they may originally have been clastic. Some of them possess an obscure conglomeratic habit. They are beneath the metamorphosed sediments of the western plateau region, which are probably Cambrian and Lower Silurian in age, and hence they are regarded as probably Algonkian, or, at any rate, as pre-Cambrian.[2] The rock represented by the specimen occurs along the contact between a dynamically metamorphosed hornblendic and micaceous gneiss and a crystalline dolomitic limestone[3] known as the Cockeysville marble[4] (No. 117). It passes insensibly into the gneiss, of which it may be considered a phase. In the latest map[5] of the district no distinction is made between the two rocks, both being represented by the same color and described as metamorphosed sediments.

Different specimens of the rock present different appearances. All are more or less foliated, and some are platy. The least foliated varieties are light-gray rocks with a sugary texture. They consist of an aggregate of small quartz grains and tiny flakes of a light-yellow glistening mica. The more schistose phases contain much more mica, and so have a little darker color than the less schistose forms. All varieties of the rock are crossed by parallel joint planes whose surfaces are covered with mica scales. In the massive varieties the joints are less numerous than they are in the more schistose ones, in which they are often only a small fraction of an inch apart. The surface of a cross-fracture through a specimen of this kind resembles very closely that of a micaceous gneiss.

No traces of bedding planes can be detected in any of the specimens. Their platy character is determined by the joint planes passing through them.

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[1] G. H. Williams, The Petrography and Structure of the Piedmont Plateau in Maryland: Bull. Geol. Soc. America, Vol. 2, 1891, pp. 301-322; and Guide to Baltimore, with an account of the Geology of its Environs, and three maps, Am. Inst. Min. Engineers, Baltimore Meeting, February, 1892. Prepared by local committee for the use of the institute, pp. 77-124, with maps.

[2] Cf. C. R. Van Hise, Correlation Papers—Archean and Algonkian: Bull. U. S. Geol. Survey No. 86; especially pages 411 and 415.

[3] Good specimens of this marble are seen in the columns and heavy platforms of the Capitol extension at Washington. A large portion of this building, the Washington Monument, and the Post-Office building in the same city are constructed of it, as well as the spires of St. Patrick's Cathedral in New York.

[4] See map in Guide to Baltimore; and Geological Map of Baltimore and Vicinity, G. H. Williams, editor, published by Johns Hopkins University, 1892; also Baltimore sheet, Atlas U. S. Geol. Survey, edition August, 1892.

[5] A Preliminary Geological Map of Maryland, G. H. Williams, editor, 1893: Maryland, its Resources, Industries, and Institutions, prepared for the Board of World's Fair Managers of Maryland, Baltimore, 1893.

A close inspection of the joint surfaces of most specimens will show the presence of small grains of coal-black tourmaline in the midst of the mica scales. Dr. Williams,[1] in his account of the petrography of this schist, states that "its most characteristic feature is imparted to this rock by long crystals of black tourmaline, which have been developed in these muscovite layers. These crystals are invariably broken and their fragments separated along one line, showing that the rock was compressed in one direction and elongated or stretched in another at right angles."

The rock is described by Williams[2] in the following words:

> The least important of the rocks of probably sedimentary origin in the Baltimore region is a peculiar schist composed mostly of quartz and divided into beds of varying thickness by parallel layers of muscovite. . . . Its quartz grains are of different sizes, but are so completely recrystallized that they form an interlocking mosaic. Besides the flakes of muscovite, the only other constituents are iron stains and occasional crystals of tourmaline, microclines, and zircon. Sharply defined areas showing a minute spherulitic polarization are also common. They are identical with those occurring in the Saxon "greisen," and probably represent altered feldspar. The rock shows the effect of pressure in the undulatory extinction of its quartz grains. The cleavage planes of the quartz-schist are due to thin layers of muscovite in good-sized scales, with their basal planes all parallel to the foliation.

With respect to its origin he declares that the rock is probably a "facies of the gneiss, produced by some dynamic agency, for it always shows the effect of internal mechanical action and motion. Moreover, the abundance of tourmaline points to the agency of fumaroles, which are always important factors in the recrystallization of deeply buried rocks."

The platy character of the rock is plainly seen in the hand specimen; its schistosity, however, is not so apparent. Nevertheless, on breaking the rock the fracture is much more easily produced in a direction parallel to that of the cleavage planes than in any other direction, even when the separation is not along the cleavage plane. This is due to the arrangement of the mica scales throughout the body of the rock, with their flattened sides parallel to the cleavage planes.

In the thin section the irregular grains with brilliant polarization colors are quartz; the long, narrow grains with a longitudinal cleavage, a very slight pleochroism, an extinction parallel to the cleavage lines and brilliant mottled polarization colors are muscovite; the opaque crystals and rounded grains are magnetite and pyrite, altered in many cases to limonite or ocher, and the few clear, colorless grains with pale-green polarization colors are plagioclase. Some of these latter are crossed by indistinct twinning bars, and many of them, particularly those near the edges of the section, are traversed by cleavage cracks. In some sections the plagioclase is altered to a cloudy aggregate of scaly minerals and little dust particles. Grains of zircon are rare. They occur as small rounded or elliptical particles, with a very high

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[1] Guide to Baltimore, p. 103.

[2] Op. cit., pp. 102, 105.

refractive index and strong double refraction. The latter property is shown in the bright polarization colors and the former by the dark lines bounding the grains.

The quartz is the most characteristic component. It is in irregularly interlocking grains. These are crossed by continuous lines of tiny dust inclusions and larger liquid inclosures with movable bubbles. The majority of the grains exhibit undulatory extinction, though this property is best seen in the thinnest grains near the edges of the section.

Along certain bands the larger quartzes are embedded in a rubble of smaller grains, and in these bands the muscovite is most common. The mica, the quartz grains, and the feldspars are all elongated in the direction of the banding, producing a well-marked schistosity. In other portions of the section the muscovite also exhibits a tendency to a parallel arrangement, but this tendency is more noticeable when the section is viewed under a low-power hand lens than when examined under the microscope. The mica[1] and the feldspar occur between the quartz grains, the former lying along the boundaries between two grains and the latter occupying angular spaces between several quartzes. Both the muscovite and the plagioclase show pressure effects—the mica in the bending of occasional flakes and the feldspar in the occurrence of secondary twinning lamellæ.

From the microscopic study of the sections we are led to the same conclusion as that reached by the field study of the rock, namely, that it is a dynamically metamorphosed acid rock, which from its composition appears more likely to have been a sandstone than an eruptive. The rock is now a mica-schist in its most micaceous phases, or a micaceous quartz-schist in its less micaceous forms.

No. 120. JASPILITE.

(FROM ISHPEMING, MARQUETTE COUNTY, MICHIGAN. DESCRIBED BY C. R. VAN HISE.)

Macroscopical.—The jaspilites of the Ishpeming area of the Marquette district in the Lake Superior region occur in the Negaunee or iron-bearing formation of the Lower Marquette series. They are banded rocks, the alternate bands consisting mainly of small iron-stained particles of quartz, or jasper, and of iron oxide. The exposures present a brilliant appearance, due to the interlamination of the bright red jasper and the dark red or black iron oxides. The iron oxide is mainly hematite, and includes both red and specular varieties; but magnetite is usually present.

The jasper bands frequently have oval terminations or die out in an irregular manner. The rocks have been folded in a complicated fashion, as a result of which the layers present an extremely contorted

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[1] In a few sections there are present, in addition to the muscovite, a few flakes of a brownish-green, strongly pleochroic biotite. These, when present, are always closely associated with the muscovite. The mineral never occurs in quantity large enough to affect the general character of the rock.

appearance. The folded layers frequently show minor faulting. Because of their brittle character, at many places the bands have become broken through and through, and sometimes they pass into reibungs-breccias. In some cases the movement of the fragments over one another has been so severe as to produce a conglomeratic aspect.

In the folding of the rock the readjustment has occurred mainly in the iron oxide between the jasper bands. As a result of this, the iron oxide has been sheared, and when a specimen is cleaved along a layer it shows brilliant micaceous hematite. This sheared lustrous hematite, present before the last dynamic movement, is discriminated with the naked eye or with the lens from crystal-outlined hematite and magnetite which have filled the cracks in the jasper bands and the spaces between the sheared laminæ of hematite. The jaspilite differs mainly from the ferruginous chert of the iron-bearing formation, with which it is closely associated, in that the siliceous bands of the former are stained a bright red by hematite and the bands of ore between them are mainly specular hematite, while in the cherts the iron oxide is earthy hematite. The jaspilite in its typical form, whenever found, always occupies one horizon, the present top of the iron-bearing formation just below the Goodrich quartzite. In different parts of the area the jaspilite has a varying thickness. With this jaspilite, or just above it, are the hard iron ores of the district; hence it has been called by the miners, to discriminate it from the ferruginous chert, "hard ore jasper."

Microscopical.—In thin section the jaspilites are seen to have a minutely laminated character, each of the coarser bands, as seen in hand specimen, being composed of many laminæ, due to the irregular concentration of the iron oxide. These laminæ are of greatly varying width. They unite and part in a most irregular fashion, producing a mesh-like appearance, and frequently laminæ disappear, as do the coarser bands.

The complex, bright-red jasper bands are composed mainly of finely crystalline cherty quartz, but they are everywhere stained with minute particles of blood-red hematite. The grains of quartz average rather less than 0.01^{mm} in diameter, and each of these minute grains contains one or more particles of hematite. These are concentrated in laminæ, or are separate flecks included in the quartz grains. In some cases the hematite appears to be somewhat concentrated between the grains, but in general it is arranged in entire independence of them, as though it were present before the quartz had crystallized. The ferruginous bands contain a predominating amount of iron oxide, but in them is included much quartz, exactly similar to that of the jasper bands. The original, translucent, red, sheared hematite is easily discriminated from the secondary crystal-outlined hematite and magnetite.

The folding, faulting, fracturing, and brecciation spoken of in hand specimen are beautifully shown under the microscope. The resultant cracks and crevices are filled with secondary quartz and crystal-outlined hematite and magnetite. This quartz is much more coarsely crystalline than the older quartz, the grains in many slides averaging from 0.05^{mm} to 0.1^{mm} in diameter. While much of this secondary quartz occurs in veins that cut across the original lamination of the rock, a good deal of it has entered parallel to the lamination. Its coarseness and its likeness to the vein quartz readily distinguish it from the earlier quartz. The crystal-outlined hematite and magnetite also help to fill the veins and spaces between the micaceous hematite laminæ. These secondary materials usually have entirely filled the spaces, thus completely cementing the rock, and because so much material has entered parallel to the original lamination this structure is emphasized by the secondary impregnations.

It has been noted that the jaspilite is characteristic of the uppermost horizon of the iron-bearing formation; that is, it is immediately below the next overlying series. The contact zone has been one of the great planes of accommodation, and thus the dynamic effects upon the jaspilite are explained. Between the jaspilite horizon and that of the ferruginous cherts is a transition zone. In this the layers of siliceous material sometimes have borders of red iron-stained quartz.

It has been explained that the chief differences between the jaspilites and the ferruginous cherts are the blood-red character of the minute hematite particles and the micaceous character of the ferruginous layers of the former. It appears highly probable, therefore, that dynamic movements have transformed the ferruginous chert into jaspilite, the layers of brown hematite being sheared into micaceous hematite and the inclusions of brown hematite being changed into the blood-red variety.[1]

NO. 121. MAGNETITIC SPECULAR HEMATITE.

(FROM THE REPUBLIC MINE, MARQUETTE COUNTY, MICHIGAN. DESCRIBED BY C. R. VAN HISE.)

The specular hematites of the Marquette district occur at or near the contact of the Upper Marquette and Lower Marquette series, being either at the top of the Negaunee iron-bearing formation of the Lower Marquette series, or at or near the base of the Goodrich quartzite of the Upper Marquette series. The greater quantities of the hard ores are probably in the latter position, and from this horizon the particular specimens described below are derived. These hard ores are all associated with jaspilite, No. 120 of the Educational Series.

The original source of the iron for the iron ores is a silicious siderite. The ore is a secondary concentration produced at favorable places by downward percolating waters. In many cases, after a first concen-

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[1] For relations of the Negaunee formation containing jaspilite to other formations, and a description of the Marquette series, to which the Negaunee formation belongs, see Preliminary Report on the Marquette Iron-bearing District of Michigan, by C. R. Van Hise and W. S. Bayley, with a chapter on the Republic Trough, by H. L. Smyth: Fifteenth Ann. Rept. U. S. Geol. Survey; also Mon. U. S. Geol. Survey, Vol. XXVIII.

tration, there was a mashing of the deposits, and later a further enrichment of the iron ore by infiltration.

The specimens consist mainly of brilliant flakes of micaceous hematite, which are arranged to a considerable degree with their greater dimensions parallel, thus giving the ore a distinct schistosity or rift. Between the flakes of hematite are minute granules of magnetite. Under the microscope the slides are best studied in reflected light. They seem to be made up mainly of numerous closely fitting grains of hematite, the majority of which take an imperfect polish, and have therefore a gray, sheeny, spotted appearance. The grains, which are parted along the cleavage, reflect the light like a mirror. The large number of these reflecting surfaces is appreciated only by rotating the section, which brings successively different ones into favorable positions to reflect the light into the microscope tube. As both the magnetite and the hematite are opaque, the two minerals in general can not be discriminated, although in some cases the crystal forms of magnetite are seen, and a small part of the hematite, much of it in little crystals, shows the characteristic blood-red color.

The accessory minerals are quartz, feldspar, muscovite, and grünerite. Some of the small areas of quartz and feldspar appear to be fragmental. The muscovite occurs mainly in small independent flakes, but some of it is apparently secondary to the feldspar. The grünerite is very sparse. The translucent, red hematite is closely associated with the feldspar, muscovite, and grünerite.

The iron ores and associated rocks of the Marquette iron-bearing district are fully described in the Fifteenth Annual Report of the United States Geological Survey, pages 561 to 589, and in Monograph XXVII, pages 328 to 407.

NO. 122. SLATE.

(FROM MONSON, PISCATAQUIS COUNTY, MAINE. DESCRIBED BY W. S. BAYLEY.)

Specimen No. 122 is an excellent sample of the rocks that are known as clay slates. It is a very fine-grained, bluish-gray variety, with a close crystalline texture. It is so soft that it may easily be scratched with a knife blade, but at the same time it is so dense and elastic that it rings clearly when hit with a hammer. If struck on its side with a chisel whose cutting edge is parallel to the long edges of the specimen, it will split into plates whose minimum thickness is limited only by the skill of the workman. This peculiarity of splitting into thin slabs is the most characteristic property of slates, and is that which gives them their great economic value. The evenness with which they may be cleft and the size of the plates obtainable from them are important elements in determining the suitability of the material for roofing and manufacturing purposes. In a good slate the grain is fine, and the cleavage planes run for long distances without interruption.

The principal localities in this country from which good slates come are the Peach Bottom and neighboring regions in southeastern Pennsylvania and northern Maryland, the Arvon quarries and mines in the western part of the upper peninsula of Michigan, various places in Vermont and Virginia, and the quarries of the Monson Slate Company, at Monson, Piscataquis County, Maine.[1] The specimens[2] in the collection are from the last-named locality.

Though not of as much importance as in the case of stone used in the foundation of large buildings, the strength[3] of various slates serves as a rough measure of their comparative merits. In massive rocks the strength is nearly equal in every direction. In schists and bedded rocks less pressure is required to produce crushing, when applied in a direction parallel to their schistosity or cleavage, than is necessary when applied perpendicularly to these structural planes. A cube of the Monson slate measuring an inch on an edge, breaks across the cleavage, pressure being applied at right angles to the cleavage, when the pressure reaches 30,425 pounds. A slab 12 by 6 by 1 inch, supported on knife edges 10 inches apart, breaks under a stress of 4,000 pounds when the pressure is applied along a line midway between the supports.

The rock occurs in beds[4] of various thicknesses, ranging between 20 feet and 4 inches, interlaminated with hard, fine-grained, dark quartzites. The series strikes about 70° east of north and dips at an angle of about 78° to 83° in a direction north of west. The cleavage is nearly vertical, perhaps inclining about a degree therefrom, and strikes nearly in the same direction as the beds. The difference in the inclination of the cleavage and bedding causes the course of the former to cross that of the latter at a small angle, but since the quartzite is so much harder than the slate, the cleavage planes that are so marked in the softer rock stop abruptly when the contact of the quartzite is reached, or cross it as a few fractures or slight faults. Since the cleavage and the bedding are not coincident, and not even parallel, it is evident that the former is not in any way dependent upon sedimentation. A shale splits easiest along its bedding planes. The Monson slate can not be split along its bedding, but it is easily cleft along its cleavage planes. In other words, the cleavage of shales is an original characteristic, while that of slates must be of secondary origin.

The cause of cleavage in slates has been carefully studied by many geologists. Sharpe,[5] as long ago as 1846, held that the cleavage of

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[1] For amounts quarried in different districts see Mineral Resources of the United States for 1888 and later years, and for descriptions of the districts, consult G. P. Merrill, The Collection of Building and Ornamental Stones in the U. S. Nat. Mus.: Rept. Smithson. Inst. 1885-86, Pt. II, p. 464, et seq.

[2] The specimens in the collection and the thin slabs were kindly furnished by the Monson Company, as were also the results of the strength tests and the analysis.

[3] For statements regarding tests of building stones, see Merrill, loc. cit., p. 489.

[4] Thought by Prof. C. H. Hitchcock to be Cambrian or Lower Silurian. See geological map of Maine in Colby's Atlas of Maine. Houlton, 1884.

[5] Daniel Sharpe, On Slaty Cleavage: Quart. Jour. Geol. Soc. London, 1846, Vol. III, pp. 74-105; Vol. V, 1849, pp. 369-396.

slates is due to the flattening of the constituent grains. Sorby[1] believed that slaty cleavage is caused mainly by the rotation of the mineral particles, and especially mica, until the flat grains assume a position where they may best resist further rotation, namely, a position at or near right angles to the pressure. As favoring this view, he subjected a mixture of clay and iron oxide to pressure, and obtained a cleavage structure at right angles to the pressure. Tyndall[2] and Daubrée[3] have also produced a cleavage in substances by simple pressure. The former used beeswax, clay, etc., and the latter clay mixed with scales of mica. In each case in the resultant cleavable product the flat particles were always found with their broad sides in the plane of cleavage; but Tyndall held, with Sharpe, that in the case of beeswax, as in all cases of nature, the cleavage is produced mainly by the flattening of the constituent particles.

In nature the pressure that produces the cleavage is the same as that which bows and bends the rocks of the earth's crust. Since this pressure is rarely perpendicular to the bedding, it follows that the superinduced cleavage is rarely parallel to the bedding. In many cases it is probable that the force that upturned the rocks at the same time produced in soft beds a cleavage; in other cases the cleavage was produced subsequent to the upturning of the rocks; and in rare cases two cleavages were produced by pressure acting at different times along two different directions.[4] In addition to the cleavage produced in a rock by pressure, it usually happens that this agency causes such a change in the conditions under which the rock exists that crystallization is set up in its material, so that its original nature is largely obscured. Slates are usually interbedded with undoubted fragmental rocks like quartzites, grading into these and into conglomerates. Consequently, it is assumed that its original condition was fragmental, though perhaps no traces of this condition are now discernible. If the original bed was fragmental, the deposit must have been of a very fine grain, like mud or silt. Mr. Hutchings[5] has recently examined such beds in which schistosity has not been produced, and has obtained from them a great deal of information with respect to the course of crystallization set up in them. He concludes that nearly all the mica of slates is a secondary product, derived by the alteration of constituents of the original deposit. Other components of the slate are also new products, formed subsequent to the deposition, and hence the slate in its present condition is composed largely of crystallized secondary material. In this sense the slate is crystalline, and should be classed with the crystalline schists. Since, however, we know that it was originally a sediment, we usually class it among the fragmental rocks, thus placing more

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[1] Edinburgh New Phil. Jour., vol. LV., 1853, p. 137.

[2] Philos. Mag., IV, XII, p. 129.

[3] Géologie Expérimentale, p. 391.

[4] Cf. C. R. Van Hise: Bull. Geol. Soc. America, vol. 2, p. 209.

[5] Geological Magazine, Vol. VII, June and July, 1890, and Vol. VIII, 1891, p. 164.

emphasis upon the genetic relations of the rock than upon its present condition.

Van Hise[1] has recently rediscussed slaty cleavage. He concludes that the structure is due to the arrangement of the mineral particles with their longer diameters or readiest cleavage, or both, in a common direction, and that the cause of this arrangement is, first and most important, the parallel development of new minerals; second, the flattening and parallel rotation of old and new mineral particles, and third, and of least importance, the rotation into approximately parallel positions of random original particles. He further concludes that this structure is developed in rocks when they are so deeply buried as to be in the zone of plastic flow, and that the structure develops in the planes normal to the greatest pressure.

Under the microscope the principal mineral constituents of the Monson slate in the collection are discovered to be quartz, chlorite, muscovite, biotite, magnetite, and a few little black organic particles. These are nearly all in the form of small lenses, with their long axes in the same direction. The largest grains are those of chlorite. This mineral is in light-green masses, with a dark-green pleochroism. Its double refraction is weak, so that between crossed nicols it polarizes in gray or blue tints. Around its grains bend the flakes of muscovite, etc.—a proof that the former must have existed when the cleavage was superinduced in the rock. It is probable that the grains were then plagioclase and that the chlorite has since been produced by its alteration. Chlorite also exists in little shreds between the other components, where it is always elongated in the direction of the foliation.

The next most abundant components are the micas. These occur as tiny shreds and flakes of muscovite that can be detected only between crossed nicols, when it appears with bright polarization colors and as larger, ill-defined masses of brown biotite. The latter sometimes occurs also as small flakes lying parallel to the muscovite plates. It is by no means so common as the muscovite, nor is it always arranged with its flat sides in the plane of cleavage. Since the flakes of muscovite are not crowded around the large masses of biotite as they are around the chlorite grains, it would seem that the biotite must have been formed after the potash mica. It includes shreds of the muscovite, and in its arrangement it by no means follows the rule that the long axes are parallel to the cleavage. Its genesis, consequently, was probably subsequent to the origin of the foliation.

The quartz is not in large quantity. Only occasionally can little grains be detected, when they have the usual elliptical cross section. The magnetite and the organic substance are both in comparatively large-sized grains. The former have badly defined crystallographic outlines, while those of the latter are irregular and ragged. If a small

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[1] Principles of North American Pre-Cambrian Geology, by C. R. Van Hise: Sixteenth Ann. Rept. U. S. Geol. Survey, Part I, pp. 633-668. See also Deformation of Rocks, Part III, Cleavage and Fissility: Jour. Geol., Vol. IV, 1896, pp. 449-483.

portion of the section is heated for some time on a piece of platinum before the blowpipe the organic particles are burned out, while the magnetite remains unchanged. This is about the only method of distinguishing between the two substances when present in such small particles. It is impossible to determine, except by careful chemical tests, whether the organic material is carbon or a compound of this element. Besides these opaque constituents there are in the muscovite shreds, between the lamellæ, numerous little black particles, most of which are in tiny short needles, though a few are in larger round or irregularly shaped masses. The latter have a brownish color, but their dimensions are so small that the nature of the material composing them can not be determined. From analogy, however, we may conclude that they are tiny grains of rutile. This mineral in small needles is so characteristic of slates that they were long known by the German petrographers under the indefinite name of thonschiefernadeln, until in 1881 Cathrein[1] proved them to consist of rutile.

No other components are important enough to merit mention as essential to the rock, though perhaps in an occasional section a single grain of pyrite or of some other widely occurring mineral may be detected.

From the microscopic examination of the slate we easily discover why it splits so readily in one direction only and in such very thin plates. The different constituents, with the exception of the biotite, are arranged in layers composed of flat pieces lying in parallel positions and overlapping and dovetailing into one another. Across the laminæ fracture is difficult, and the fracture surface is rough, for the breaks, following the paths of least resistance, refuse to pass across the grains in their courses when they can so easily turn aside and pass around them. The crystalline structure noticed on the cross-fracture surface is caused by the projection of the grains. The cleavage surface, on the contrary, is smooth, because so few grains extend from one layer into the other that the easiest path for the fracture is between successive layers.

In the following table the composition of the rock, as determined by L. M. Norton, is given in column I; in column II is given the composition of a specimen of the Peach Bottom slates, Pennsylvania.

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[1] Neues Jahrb. f. Min., etc., 1881, I, p. 169.

Analyses of slates.

	I.	II.
	Per cent.	*Per cent.*
SiO_2	56.42	55.880
TiO_2	....	1.270
SO_3	....	.022
Al_2O_3	24.14	21.849
FeO	4.46	9.034
MnO	....	.586
CaO	.52	.155
MgO	2.28	1.495
K_2O	5.53	3.640
Na_2O	3.15	.460
H_2O	3.88	.051
Organic matter		1.974
Pyrite	....	.051
Total	100.38	99.800

The specific gravity of the Monson slate is 2.851.

The analysis accords well with the results of the microscopic study of the thin section. The small amount of magnesia indicates a small proportion of biotite. The absence of plagioclase is revealed by the small percentage of lime. The large proportion of potash points to an abundance of muscovite, while the water and ferrous iron show the presence of chlorite. The percentage of silica is so low that there can not be much quartz in the rock, and the alumina is just about sufficient to combine with the potash, magnesia, and iron protoxide to form muscovite, biotite, and chlorite. The soda may indicate the presence of a very alkaline feldspar, or it may be present in the light-colored mica, some of which may be paragonite instead of muscovite.[1]

No. 123. INDURATED JOINTED SHALE.

(FROM SOMERVILLE, MIDDLESEX COUNTY, MASSACHUSETTS. DESCRIBED BY C. R. VAN HISE.)

Various causes have been assigned for joints, of which the more important are tension, torsion, and compression. It is believed that joints may be classified into tension joints and compression joints, torsion joints being but a variety of tension joints. The first are ordinarily in the normal planes, or at right angles to the stretching force; the second are in shearing planes, or are inclined to the crushing force.[2]

Joints may be produced in rocks in the outer zone of the crust of the earth, where fracturing results from deformation. Rocks which are buried to a great depth are under such a load that it is impossible that crevices and cracks can exist; therefore jointing does not occur.

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[1] For other descriptions of slates see Irving and Van Hise, Tenth Ann. Rept. U. S. Geol. Survey, pp. 372, 428; Geology of Wisconsin, Vol. III; and for general account of slate regions, etc., Report on Building Stones of the United States, Census of 1880, Washington, 1884.

[2] For a fuller discussion of joints, see Principles of North American pre-Cambrian Geology, by C. R. Van Hise: Sixteenth Ann. Rept. U. S. Geol. Survey, Part I, pp. 668-672.

Jointing is almost certainly confined to the outer 10,000 meters of the crust of the earth, and is perhaps confined to the outer 5,000 meters.

Tension joints.—Tension is often due to the contraction caused by cooling or by desiccation. It is well known that the peculiar columnar jointing of igneous rocks is due to the contraction and consequent tension caused by cooling, and the mud cracks of sedimentary rocks are due to the contraction and consequent tension caused by desiccation. However, it is probable that neither cooling nor desiccation is important in the production of systematic parallel sets of joints.

When rocks are simply folded in the outer zone of fracture, the convex halves of the folds may be subjected to simple tension, and if this goes beyond the ultimate tensile strength of the rocks, radial cracks will form, which extend through the strata and strike parallel with the rocks. In rocks which are complexly folded or cross folded, there may be two sets of tensile joints which intersect each other nearly at right angles. Tensile joints in homogeneous rocks are exactly or nearly at right angles to the stretching force.

Daubrée[1] has shown that if a brittle plate breaks when it is subjected to torsion, a double set of parallel fractures nearly at right angles to each other are produced. The forces which produce complex folding stretch the convex parts of the strata, where not too deeply buried, in two rectangular directions; or, in other words, they are subject to torsion. It therefore appears that Daubrée's explanation of joints by torsion is but another statement of the production of joints by complex folding in the two principal planes of tensile stress.

Compression joints.—Daubrée[2] and Becker[3] have shown that joints may be produced by compression. Then there may be jointing in two sets of shearing planes when the rocks are subjected to a single stress, and, according to Becker, there may be joints in three or four planes when they are subjected to unequal stresses in different directions, in the latter case one of these sets of joints being normal to tensile stress and the other in shearing planes. In all cases in which jointing occurs in shearing planes the joints are inclined to the pressure. In a simple ideal case the joints should be at an angle of 45° to the pressure, but this rarely occurs in nature. Fracturing along shearing planes is illustrated when stones are crushed in a testing machine. The fractures do not form in the lines of pressure, but in general at any place in a homogeneous rock in two intersecting directions at angles somewhat less than 90° to each other. The direction of pressure bisects the acute angle.

Becker has explained that minor faulting is a common phenomenon of compression joints.

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[1] Géologie Expérimentale, by A. Daubrée, pp. 306-314, Paris, 1879.

[2] Ibid., pp. 315-322, Paris, 1879.

[3] George F. Becker: Finite homogeneous strain, flow, and rupture of rocks: Bull. Geol. Soc. America, Vol. IV, 1893, pp. 41-75. The torsional theory of joints: Trans. Am. Inst. Min. Engineers, Vol. XXIV, 1894, pp. 130-138.

In many cases when the rocks are jointed in more than one direction the different sets of joints may have been produced by successive orogenic movements, rather than at a single period of deformation.

The specimen (No. 121) from Somerville, Massachusetts, belongs to the so-called "Cambridge slates" whose geologic age is not yet positively known. Crosby has referred them to the Carboniferous, but others have considered them to be Cambrian.

The specimen is bounded by three sets of joints. One set is parallel to the bedding; the other two sets intersect the bedding at acute angles and are at acute angles to each other. As a result of the three sets of joints, the rock is broken into rhomboidal blocks (or more accurately oblique parallelopipeds) bounded by the three sets of joint planes, each piece having as boundaries two parallel fractures along each of the three sets of joints. Probably each of the sets of joints is produced by compression rather than by tension, and therefore is formed along shearing planes. The joints parallel to the bedding are undoubtedly controlled in direction by planes of weakness along the bedding. As shown by the smoothed surfaces, there has been slipping along many of these joints during the folding process. In some cases the evidence of readjustment in slickensided faces is also seen along the sets of joints intersecting the bedding.

NO. 124. CRUMPLED SHALE.

(FROM HOT SPRINGS, MADISON COUNTY, NORTH CAROLINA. DESCRIBED BY BAILEY WILLIS.)

The specimen of crumpled calcareous shale illustrates the folding of laminated rocks. When this shale was deposited as a sediment its successive layers of red and buff mud were level and parallel. In that position they hardened into firm rock. The shale was gradually buried beneath later sediments and sank into the earth's mass. At a depth of a few thousand feet the superincumbent pressure was such as to hold this shale in a condition in which it could not break apart. When compressed edgewise by a sufficient lateral force the layers were obliged to bend like paper. In thus bending, they slid one over another, they were squeezed thinner in certain parts of the fold, on the limbs, and they thickened where the combined pressure of load and edgewise thrust were less intense.

Folds of rock masses are not limited to small crumples such as can be shown in a specimen. The beds of strata folded may be 5,000 feet, or five times 5,000 feet thick; then the folds are large. For example, in central Pennsylvania there is a fold, known as the Nittany Arch, which is 25 miles across and about 150 miles long. Examples of still larger folds might be cited.

The accompanying illustrations[1] show two forms of single folds. One of these (Fig. *A*, Pl. XLI), which is open upward like a trough, is

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[1] Plate XLVIII, Thirteenth Ann. Rept., U. S. Geol. Survey.

called a *syncline*. The other (Fig. *B*, Pl. XLI), which is arched upward, is called an *anticline*.

Synclines and anticlines usually occur in association, side by side and overlapping end on end. They then form systems of folds, which may be of great extent. The Appalachian system of folds extends from Nova Scotia to Alabama, about 1,600 miles, and varies from 50 to 125 miles in width. Along the eastern base of the Rocky Mountains there is a similar system of folds.

Folds develop many different forms, both in cross section and in longitudinal section. They are usually classified according to the degree of compression, which varies from gentle undulations to structures in which the strata are pressed closely in vertical positions, or to those in which the beds are even overturned and squeezed out thin. Folds are also classified according to magnitude and complexity. Any large fold includes smaller folds, each such smaller fold includes still smaller folds, and so on down to microscopic crinkles.

Strictly speaking, in folds the relative order of strata is not changed; beds *a*, *b*, *c*, *d*, *e*, *f*, etc., after folding succeed one another in their original order. But there is another class of structures resulting from compression, called *faults*, *overthrusts*, or *thrusts*, which are characterized by a change in the order of strata. When rocks break, the separate parts may be pushed one over another. When folding, rocks are so intensely compressed that some strata, softer than others, are squeezed out, then that portion of the fold above the squeeze may be pushed over the portion beneath. When rocks flow under tremendous pressure the movement of flow may be concentrated in a plane or in a number of planes in a narrow zone. Then the rock is divided at each plane, and the parts may be moved past one another. In all these cases the changes of form in the rock mass may result in placing a lower formation *a*, over a higher stratum *f*. Such a structure is an overthrust, and the rock is said to be faulted.[1]

Overthrusts vary in magnitude from those which may be visible in the specimens of crumpled shale to those of the southern Appalachians, which exceed 300 miles in length and traverse strata 10,000 feet thick.

The deformation of rock masses is more fully illustrated and discussed by the writer in the Thirteenth Annual Report of the United States Geological Survey, pp. 211 to 281, and by C. R. Van Hise in the Sixteenth Annual Report of the United States Geological Survey, pp. 581 to 872; also in the Journal of Geology, Vol. IV, 1896, pp. 195 to 213 and 313 to 353.

NO. 125. FAULTED PEBBLE OF CRETACEOUS CONGLOMERATE.

(FROM SISKIYOU MOUNTAIN, CALIFORNIA. DESCRIBED BY BAILEY WILLIS.)

There is movement in the solid rock masses of the earth. Earthquakes are a violent but temporary effect of forces which act constantly to modify at least the surface of the globe. The nature of these forces

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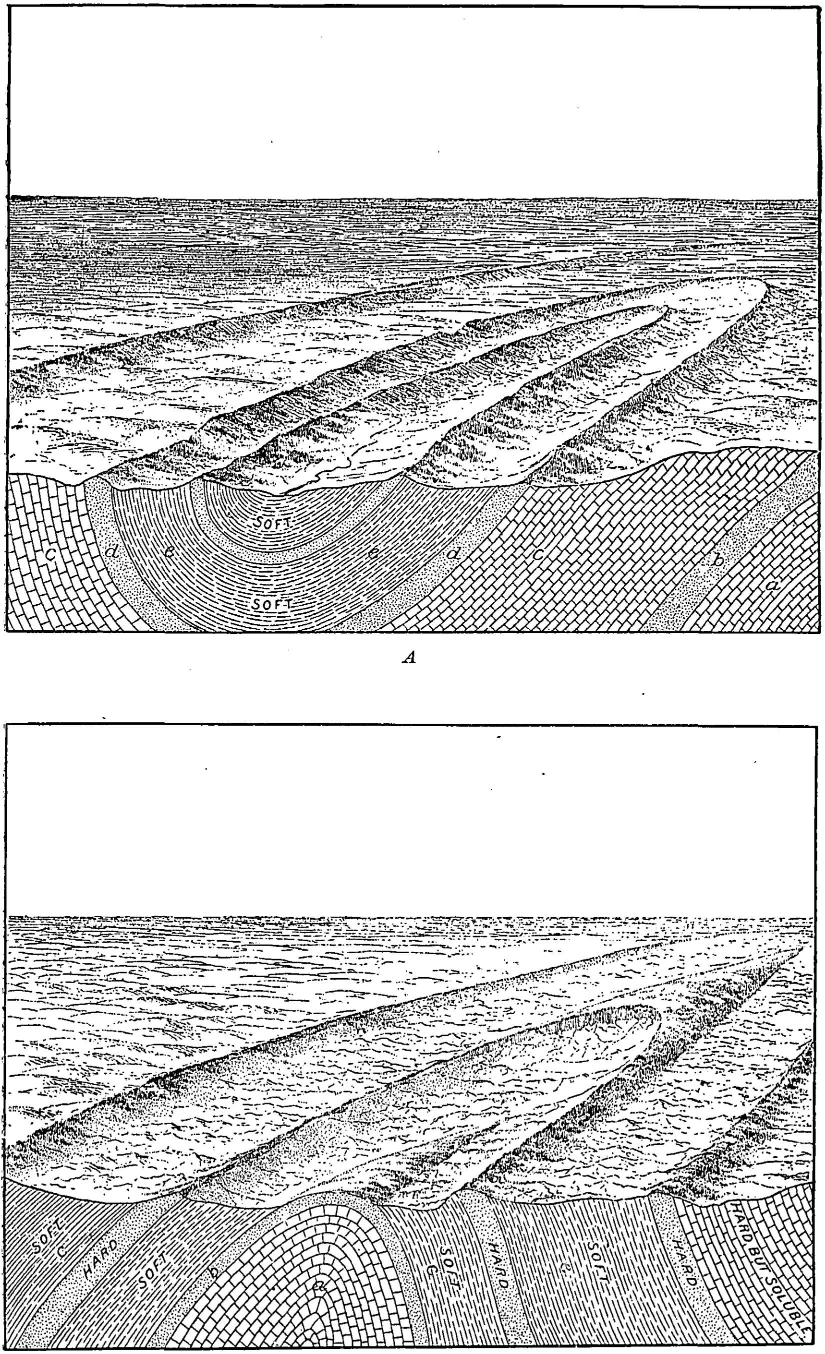
[1] Plate LII, Fig. 1, Thirteenth Ann. Rept., U. S. Geol. Survey.



A

B

SYNCLINE AND ANTICLINE.

A. Syncline. *B*. Anticline.

is but vaguely understood. They originate in gravity, in the earth's internal heat, and in physical and chemical reactions at temperatures and pressures which far within the earth greatly exceed human experience.

To these forces are due the differences of elevation of sea bottoms and continents; they raise mountain ranges, from which the atmospheric agents, heat, frost, wind and rain, carve individual mountains; they are active now, and have been active throughout all the earth's past.

These forces act upon rock masses whose size may be measured by cubic miles, and whose weight may be expressed in millions of tons. The power of these forces is beyond comprehension.

Against such forces the resistance of firm rocks is but as the plasticity of wax. In the movements within the earth's mass rocks break, bend, or even flow. Whether they break, or bend, or flow depends upon the amount of superincumbent load under which they are forced to change form. The softening effect of heat is for rocks of the outer crust insignificant as compared with the influence of pressure.

Consider any horizontal layer of the earth's crust. It rests with all its weight on the next layer below. The weight of the two layers is borne by a third below them; and so on into the depths. The pressure due to this weight of the rocks increases rapidly downward. At 5 miles below the surface it is sufficient to crush most rocks; at 10 miles below the surface the pressure of load exceeds the strength of the hardest rocks at the surface.

Rock masses which are lightly loaded as compared with their strength, that is, rocks near the surface, break when forced to move. Rock masses which are more heavily loaded as compared with their strength, that is, rocks lying deeper in the earth, bend when obliged to change form. Rock masses which are loaded in excess of their strength, that is, rocks at depths of 6 to 10 miles below the surface, flow from regions of overwhelming force to regions of less resistance.

The specimen of a faulted pebble, No. 125, from a Cretaceous conglomerate in northern California, illustrates the breaking of rock masses. The pebble is composed of the very hard and brittle mineral, quartz. It has not been cracked by a blow, it was not suddenly shattered, but it has been broken across by pressure. Afterwards the separated parts have been cemented by the deposition of silica from solution. Many pebbles over a large area in this particular conglomerate are thus broken, showing that the effect of the force was distributed throughout the mass of the rock.

No. 126. PHYLLITE (SERICITE-SCHIST).

(FROM LADIESBURG, FREDERICK COUNTY, MARYLAND. DESCRIBED BY W. S. BAYLEY.)

The western portion of the Piedmont Plateau in Maryland is underlain by rocks that are less thoroughly crystalline than are those of the eastern portion.[1] While they have been subjected to a certain amount of metamorphism and alteration, they still plainly show that they were once sediments of an ordinary type, such as limestones, shales, etc. The line of demarcation between these rocks and the more crystalline schists to the east is sharp. Where occasionally the less crystalline rocks are infolded with the more crystalline ones, the former appear to be much younger than the latter. Moreover, they are interbedded in places with a lower Silurian limestone, and are always much less folded and distorted than are the eastern schists. The eastern schists are regarded by Williams[2] as Algonkian in age, and the western ones as Cambrian and Lower Silurian.

The principal rock of the western area is a phyllite[3] of which several types occur. That represented by the specimen is the most characteristic. All the phyllites were originally argillaceous sediments. Since their deposition they have been subjected to dynamic and chemical metamorphism.

Dr. Williams describes these phyllites as constituted principally of a silky white mica (kaolin or sericite), whose individual scales vary greatly in size in different specimens. This is sometimes wholly or in part replaced by chlorite, forming a chlorite-schist. Quartz grains of varying size and outline are generally present, while feldspar is extremely rare. It is probably the alteration of this mineral in the process of weathering that has yielded the micaceous component. Iron oxide is also present in very small grains. Tourmaline in small crystals is very common, as are also microscopic needles of rutile (thonschiefernadeln). The phyllites have always a perfect cleavage and a satiny luster which increases with the crystallization of new mica. Their color ranges from black through every shade of purple, blue, and green to a pale gray. The darker varieties are largely worked as roofing slates.[4] Evidences of clastic structure are not infrequently preserved in the shape of rounded grains and small pebbles of varying appearance and composition. Where least disturbed these slates are jointed and cut by cross seams of chlorite or quartz. When they are more disturbed they become greatly puckered and filled with eyes of quartz.[5]

The specimen in the collection represents one of the lightest colored of the phyllites. It came from near the town of Ladiesburg, in Frederick County, on the western side of the area occupied by these rocks, near the contact of the phyllites with the overlying Newark sandstones.[6] The rock is so closely folded and so perfectly cleaved that its

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[1] Cf. description of No. 119.

[2] G. H. Williams, Guide to Baltimore; prepared for Am. Inst. Min. Engineers, Baltimore, 1892, p. 80-87.

[3] G. H. Williams, The petrography and structure of the Piedmont Plateau in Maryland: Bull. Geol. Soc. America, vol. 2, 1891, pp. 305-307.

[4] The value of the slate quarried from these rocks in the State of Maryland amounted to $153,068 in the year 1894.

[5] Op. cit., p. 306.

[6] See Preliminary Geological Map of Maryland, G. H. Williams, editor, 1893: Maryland, its Resources, Industries, and Institutions; prepared for the Board of World's Fair Managers of Maryland, Baltimore, 1893. Ladiesburg is at about latitude 39° 35′ and longitude 77° 15′.

bedding has been much obscured. From the differences in the geological structure of the regions in which the phyllites and the mica-schists (No. 119) occur, it is argued that the former rocks have been squeezed in one direction only, by a single earth throe, while the latter have been subjected to different squeezings at different times.

The specimens are soft, argillaceous, slaty rocks of a light-green color when fresh and a pinkish-yellow color when weathered. Along the cleavage surfaces and along the sides of joint cracks the material is yellow. All specimens are very fissile, their cleavage planes being very numerous and very close together, and nearly all are crossed either by joint planes perpendicular to the cleavage or by little puckerings, which appear in cleavage surfaces as series of tiny waves. These are little contortions that serve as evidence that the rock has been at some time subjected to great pressure. When breathed upon the specimens emit the argillaceous odor so characteristic of clays and slates.

When viewed under low powers of the microscope the thin sections occasionally reveal the presence of rounded areas that appear to be cross sections of sand grains. Between crossed nicols they often break up into matted fibrous aggregates of a strongly refracting mineral colored by yellow ocher.

Under high powers in natural light the rounded and irregularly shaped colorless areas are seen to be embedded in a brownish-yellow or light-green cloudy mass, through which are scattered fibers of a light-green mineral, tiny grains of a very highly refractive one—probably zircon—small plates of red hematite, and little opaque particles of magnetite. Between crossed nicols the nature of the various components is not difficult to determine. The most prominent ones are quartz, sericite, chlorite, and masses of a finely fibrous substance, believed to be kaolin.

In most sections quartz and chlorite are the most abundant. Some of the former is in little rounded or irregular grains. To these as a nucleus has been added new quartz material, which often extends in the form of long, narrow spicules into the surrounding mass of quartz and chlorite. In this the quartz forms a groundmass that is so thickly strewn with chlorite fibers and with opaque grains of different kinds that its polarization can scarcely be distinguished. It is evidently a secondary product which has resulted from the decomposition of some of the rock's original components or is a substance that has been introduced from without. The chlorite, which is a ferruginous variety, is mainly in bunches of light-green fibers, with a very weak double refraction. In many instances where the chlorite is thick it appears like an isotropic substance. Occasionally the chlorite is intergrown with a brightly polarizing, light-colored sericite. The two minerals together occupy areas that resemble the shapes of sharp-edged fragments. Through this quartz-chlorite groundmass are scattered large plates of sericite, crystals of zircon, opaque reddish-brown grains of some iron oxide that has been superficially changed to limonite, small, irregular masses of ocher, innumerable particles of various opaque bodies that may collectively be denominated dust, and thousands of very small, slender, apparently opaque needles. These are the rutile needles characteristic of slates. They are most abundant in those portions of the slides in which chlorite predominates, being especially numerous around the opaque granules of limonite.

The yellow tint of most of the specimens is due to the presence of ocher. This occurs not only in the grains and irregular masses already referred to, but it also occurs as a very finely divided pigment which saturates the chlorite fibers and colors them.

The structure of the rock is that of fine-grained slates which have suffered a large amount of alteration and which have been made fissile by movement under pressure. All of its present constituents are secondary, except the larger grains of quartz, which probably represent original sand grains. Its composition (I) as determined by George Steiger, of the United States Geological Survey, shows that however much it may differ from its original condition, it still possesses the composition of a clay slate. The analysis (II) of a typical clay slate from near Clausthal[1] in the Harz is given for comparison.

Analyses of phyllite and clay slate.

	I.	II.
	Per cent.	*Per cent.*
SiO_2	57.24	57.99
TiO_2	.08	.32
Al_2O_3	23.48	23.42
Fe_2O_3	3.19	.49
FeO	4.87	5.06
MnO	none	....
CaO	.09	1.65
BaO	none	....
MgO	.93	1.20
K_2O	3.55	3.50
Na_2O	1.18	1.32
Water at 100°	.33	3.39
Water above 100°	4.65	
S	none	.17
C	....	.74
P_2O_5	.09	....
CO_2	none	1.12
Total	99.68	100.37

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[1] J. Roth: Allgemeine und Chemische Geologie, II, p. 588.

NO. 127. PHYLLITE (CHLORITE-PHYLLITE).

(FROM LISBON, GRAFTON COUNTY, NEW HAMPSHIRE. DESCRIBED BY W. S. BAYLEY.)

Specimen No. 127 is from a characteristic member of the Lisbon group of green schists, which C. H. Hitchcock[1] places in the lower division of the Huronian. The group embraces greenish schists, conglomerates, quartzites, jaspers, and dolomites. Van Hise[2] doubts the advisability of continuing to call these rocks Huronian, in view of the fact that so many of the New England crystalline schists are being found to be Cambrian or later in age. The term as used by Hitchcock seems to have been chosen largely on lithological grounds. Whatever the age of the rocks, they have been squeezed and altered until the evidence of their origin has been more or less obscured.

The hand specimen shows a uniformly fine-grained, crystalline rock of a grayish-green color. It has a typical though not very distinct schistose structure. A study of the hand specimen reveals little respecting its composition. On surfaces at right angles to the schistosity the rock has the appearance of a fine-grained graywacke; surfaces that are parallel to the schistosity have a more or less silky luster which is due to the presence of numerous small flakes of a green micaceous mineral with the appearance of chlorite. Here and there streaks of denser green occur. In these the green mineral is plainly chlorite.

If the thin sections of the rock are examined under a hand lens the cause of the rock's schistosity is seen to be the elongation of its constituents in a common direction. The elongation is, however, not very strongly marked, and so the schistosity is not very prominent.

The constituents of the sections, as seen under the microscope, are quartz, calcite, chlorite, epidote, feldspar, magnetite, pyrite, and hematite, in the order of their abundance, and in a few sections, in addition, a little biotite.

The quartz is in irregular grains aggregated in long, lenticular areas, and in very small grains that, together with a little feldspar, make up the matrix by which all the other components are surrounded. The larger, lens-like areas resemble large, flattened sand grains that have been squeezed until they were shattered internally, and the fine grains appear to be portions of the finer matrix of a sandstone in which the larger grains lay. Under high powers quartz is also seen forming a cementing mass uniting the small quartz grains and all the other components of the matrix. This form of the mineral may be a secondary product resulting from the decomposition of some original constituent

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[1] C. H. Hitchcock, Geology of the Connecticut Valley District: Geol. of New Hampshire, Vol. II, Chap. IV, pp. 277-293, Concord, 1877.

[2] Cf. C. R. Van Hise, Correlation Papers—Archean and Algonkian: Bull. U. S. Geol. Survey No. 86, p. 382.

of the rock. All of the quartz, except the larger grains, contains numerous inclusions of chlorite and epidote.

The calcite occurs in two forms. It is present as large, irregular grains, including within its mass grains of all the other constituents, and as the filling of little veins and nests that were at once tiny crevices and cavities in the rock mass. A third form exists in some sections, where it appears to replace an original component whose nature can not be determined. The calcite is easily recognized by its silvery white color in certain positions between crossed nicols, by the Newton's rings of color around the edges of many of its grains, by the two series of cleavage lines present in most grains, and by the parallel twinning bars in the larger ones. The mineral is probably in all cases secondary.

Chlorite is present as flakes of a light-green color and with a faint pleochroism. Its double refraction is so weak that many flakes behave almost like isotropic substances. In a few instances portions of some of the plates have a strong pleochroism in green and brown tints. These portions resemble biotite in some of their characteristics, and they suggest the thought that some of the chlorite is an alteration product of this mineral.

The epidote is in small, prismatic crystals, small, rounded grains, and larger, irregular masses that appear to be aggregates of grains, imbedded in the quartz and chlorite. The color of the mineral is light greenish yellow, the tint being deeper in the large masses than in the smaller grains and crystals. Pleochroism is noticeable in all but the smallest particles. It is always slight, the mineral appearing in different tints of the same color in different directions. The epidote is easily distinguished from the other components by its color, its high refractive index, and its strong double refraction, producing bright interference colors. Although the mineral is scattered everywhere throughout the rock, it is accumulated more thickly in some areas than in others. Together with chlorite and quartz, it forms aggregates whose outlines suggest that they once belonged to sand grains that have been replaced by the aggregate.

Feldspar is rare. It is present as small, irregular grains scattered among the quartz. In all cases it is altered, and in most cases so much so that the traces of its twinning bars are very obscure. Like the other components, it is filled with inclusions of epidote and chlorite, and in addition it contains included grains of quartz. As a rule, the more altered the feldspar, the more abundant the inclusions; hence it would appear probable that this mineral has in many cases given rise by its alteration to the aggregates of chlorite, quartz, and epidote mentioned above as possessing the outlines of sand grains. Whether all of the epidote, chlorite, and secondary quartz has resulted in this manner or not is unknown, but it is probable that much of it was thus formed.

Biotite is rare. It occurs in only a few sections, where it appears as large, reddish-brown flakes and plates, with a distinct cleavage, and a strong pleochroism in reddish-brown and yellow tints.

The magnetite and pyrite are both opaque. The former is in very irregular masses with a blue-black luster, and the latter usually in well-defined crystals with an octahedral habit and a brassy yellow luster. The magnetite is more abundant than the pyrite. In some sections it is very plentiful. Like many of the other constituents, by its very irregular outlines it presents the appearance of a secondary substance.

Hematite is only occasionally met with. It occurs as small blood-red plates included in quartz, chlorite, and feldspar, more particularly around the borders of magnetite grains.

From the general appearance and the composition of the rock, it is apparent that it is a product of the alteration of some preexisting rock of an entirely different character. At present it is completely crystalline. The structure, however, suggests that it was originally fragmental. The shattered quartz grains and some of the feldspars may represent original sand grains, but all the other components are probably secondary. The rock as it now exists is a chloritic phyllite (Cf. No. 126) or a chlorite-schist. It possesses hardly sufficient chlorite to be typical of the chlorite-schists, consequently it seems preferable to call it a chlorite-phyllite. Were its grains fine and its cleavage surfaces even, it would be a chloritic slate.

No. 128. Metamorphic Conglomerate.

(From Hoosac Mountain (Tunnel), Massachusetts. Described by J. E. Wolff.)

In the hand specimen the rock varies in character according to the distinctness of the pebbles. These are of three kinds: First, quartz, either white or of a beautiful opaline blue; second, feldspar; third, a fine-grained quartz-feldspar rock, either granite or gneiss. These pebbles are separated from each other by the cement, a crystalline aggregate of mica, quartz, and little glistening glassy feldspars (albite). The cement winds about the pebbles, sometimes cutting across them along little fault lines; at other times, little tongues of the cement, parallel to the general foliation or structure, cuts off thin strips from the pebbles, giving them a sharpened, ragged look. In this case the cement appears to have followed planes of break and slipping. Thus a quite banded phase of the rock is produced, in which the dark mica bands, by their obliquity to each other, may simulate cross-bedding. However, in the large blocks at the dumps, bands filled with pebbles (original conglomerate bands) are plainly to be seen alternating with fine-grained bands (original sandstone bands) in which little fragments of the same blue quartz found in the larger pebbles can still be recognized.

In the thin sections the quartz pebbles are distinguished by the same properties as those of the original quartz masses of the granitoid gneiss from which the former were evidently in part derived. The core of blue quartz, which can be recognized by its iridescence on holding the section up to the light, is stained and cracked, passing at the edges into a mosaic of fine quartz, evidently separated from the parent mass by pressure and motion. As soon as we pass from the core to the separate grains we find that the blue color disappears, so that we might imagine this color was due to some peculiar effect on the light produced by the strained but not granulated quartz. This granulated quartz becomes gradually mingled with mica and metamorphic feldspar, and so merges into the cement.

The feldspar pebbles are also generally much strained and invaded by secondary quartz, mica, epidote, etc., producing sometimes the appearance of an aggregate of individual grains of feldspar separated from each other by grains of quartz, but such aggregates are really a sort of feldspar breccia belonging originally to one piece, as is evident by the fact that the cleavage cracks run about parallel through all the grains which have been but slightly moved. The feldspar of the pebbles is microcline, orthoclase, or plagioclase. It is often difficult to distinguish such aggregates, or those formed by the metamorphic feldspar of the cement, from pebbles of original quartz-feldspar rock. The latter contain the feldspar and quartz in grains of more uniform size, with sometimes a tendency to imperfect crystal form on the part of the feldspars (a characteristic of eruptive granites); moreover, the feldspar may be of several kinds in the same pebble, in different crystallographic positions, and free from the inclusions which abound in the metamorphic feldspar.

The cement is composed of occasional small pieces of clastic quartz and feldspar, but principally of metamorphic mica, feldspar, quartz, etc. The mica, both muscovite and biotite, and sometimes green chlorite, occurs in plates, sometimes in clumps or stringers. The muscovite and biotite are often intergrown parallel to the base. The quartz is in isolated grains or interlocking aggregates. The metamorphic feldspar is in grains, often elongated, but without crystal outline; the grains are either simple, or in simple twins (albite law). These feldspars are similar to those developed on a larger scale in the albite schist, and are probably albite.[1] They contain as inclusions grains of quartz, round flakes of biotite and muscovite, dark grains of magnetite, reddish-brown hexagonal plates of ilmenite (?), fluid inclusions, and dark aggregates of iron ore and graphite (?), among which occasional prisms of rutile may be recognized. Grains of calcite are found among the biotite or in the feldspar, and occasional large prisms of zircon, with high double refraction and positive character. Aggregates of dirty-white titanite grains are found near masses of black iron ore. Some of the little grains of microcline found in the cement are probably formed in place, i. e., metamorphic. The contemporaneous crystallization of these minerals of the cement is shown by their

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[1] Compare The metamorphism of clastic feldspar in conglomerate schist, by J. E. Wolff: Bull. Mus. Comp. Zoology Harvard Coll., Vol. XVI, No. 10.

intimate association, and the honeycombing of the feldspars by the quartz, mica, etc.

For further information concerning this rock, the student is referred to Monograph XXIII, United States Geological Survey, pages 49–59.

No. 129. ALBITE-SCHIST.

(FROM HOOSAC MOUNTAIN (TUNNEL), MASSACHUSETTS. DESCRIBED BY J. E. WOLFF.)

In the hand specimen the rock has a perfect schistose structure, with the mica in continuous layers separated by flat lenticular masses of quartz, while the crystals of albite are scattered irregularly through the rock. There is a dark, almost metallic luster on the foliation plane, due to the greenish color of the muscovite and its mixture with biotite and chlorite.

The crystals of albite are of about the same size and generally rounded or subangular, their longer dimension not necessarily parallel to the schistosity of the rock. Sometimes the basal cleavage sections (P) are seen to be bounded by crystallographic planes corresponding to the second cleavage (M) and the prisms T and *l*.

The following analysis of this feldspar was made by R. B. Riggs for Monograph XXIII, before cited:

Analysis of feldspar of albite-schist from Hoosac Mountain, Massachusetts.

	Per cent.
SiO_2	69.69
Al_2O_3	18.60
CaO	trace
MgO	.20
NaO	10.28
K_2O	.40
Ignition	.42
Total	99.59
CO_2 (combustion) 0.77 = 0.44 C. (graphitic material).	

It is common to find the basal cleavage of a crystal reflecting the light in two parts, and this is due to the fact that the crystal is a simple twin parallel to (M)—albite law.

Basal cleavage pieces, showing a simple twin, give an extinction 4° oblique to the twinning plane and second cleavage (M). Twins measured on the goniometer give angles of 172° 46′ to 172° 50′ between the basal cleavages of the two twins. The chemical and physical properties are therefore those of albite.

In the thin section the albite grains are recognized by their large size, by the development of cleavage when the slide is thin, and by the characteristic inclusions. The latter consist of quartz in droplets or lenticular grains, muscovite or biotite in round or long flakes, crystals of zircon, round grains of apatite, magnetite in crystals or masses, rhombs of carbonate (calcite), grains of titanite, fluid inclusions, and irregular black masses or specks of iron oxides and graphitic substances, among which little six-sided brown plates of ilmenite (?) can be observed with a high power. These inclusions may be few, or so abundant as to honeycomb the crystal, and are characteristic of many pseudoporphyritic crystals of the schists in general, such as ottrelite, staurolite, mica, etc., differing from true porphyritic crystals (phenocrysts) of eruptive rocks by the fact that they are of contemporaneous or even later origin than the constituents of the rock which lie outside them, but which they inclose so abundantly.

It is a peculiarity of the dynamic metamorphism of both sediments and eruptive rocks that the new feldspar is sometimes a pure albite or a soda-lime feldspar near to albite in the series, and that the habitus is unlike that of similar feldspars in eruptive rocks, inasmuch as the crystal form is imperfect and the crystals untwinned, even under the microscope, or in simple twins, unlike the multiple-twinned albite of eruptive rocks. An exception should, perhaps, be noted for the alkaline eruptive rocks (e. g., theralite).

The mica, muscovite, biotite, and chlorite occurs outside the albite in thick plates or irregular aggregates of plates, or clumps. The muscovite and biotite may be intergrown parallel to the base. The quartz grains are generally in the interlocking aggregates, which are crossed by fluid inclusions arranged in lines (really in planes). The quartz is otherwise generally free from inclusions near the center of the lenses, but at their edges, where individual grains lie in the meshes of the mica, they may contain flakes of mica.

Magnetite, calcite, titanite, apatite, and zircon are found in the masses of mica. The clumps of mica and quartz have sometimes a rough concentric arrangement. The muscovite has a distinctly greenish color, even in the thin section, and in part the fibrous appearance due to the interweaving of irregular plates of the mineral, which is characteristic of the variety called sericite.

Neither in the hand specimen nor in the thin sections of the schist has any clastic material been observed, although such a derivation is certain both from the field relations and from the rocks of this class observed elsewhere in this field which are transitional to clastic rocks. Neither can we state from what source were derived the elements which produced the large amount of albite (soda-alumina silicate) in this and in (probably) the two other rocks. The granitoid gneiss may have been originally an eruptive granite;[1] the metamorphic conglomerate was originally a mass of granitic débris at the base, becoming a feldspathic sandstone or arkose in succeeding stages until succeeded by the schist,

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[1] Its similarity should be noted to the coarse eruptive granite called "Rapakiwi," which covers extensive areas in Finland.

which must have been a shale or slate, perhaps at the base an impure limestone. Metamorphism has given all three rocks certain characters in common (regardless of diversity in origin and composition), such as schistosity, albitic feldspars, mica, etc., while the differences seem due to the remnants of the original material or the influence this exerted on the process of the new crystallization.

No. 130. MICA-SCHIST (TOURMALINE-BIOTITE-SCHIST).

(FROM BLACK HILLS, SOUTH DAKOTA. DESCRIBED BY W. S. BAYLEY.)

This specimen is particularly interesting because it has every characteristic of a typical mica-schist, while at the same time its mode of origin is well understood. The rock of which it is a sample occurs in the Black Hills, South Dakota. In the southern part of the district is a large core of pre-Cambrian eruptive granite, forming Harney Peak.[1] Immediately surrounding this on all sides are crystalline schists, striking everywhere parallel to the boundary between the granite and themselves and dipping away from the eruptive mass. Close to the granite the schists are completely crystalline; at some little distance from it they are less so. A few miles away from the contact they become very much less crystalline, and possess, in addition to their foliation parallel to the granite boundary, a slaty cleavage which is parallel to the cleavage of slates, existing at a greater distance from the granite mass, and into which the schists pass gradually. Since no unconformity exists between the schists and the slates, and since the microscopical examination of both shows that the mineralogical gradation between them is as complete as the gradation noticed in the field, it is concluded that the schists are derived from the slates, and consequently belong to the same geologic horizon as do these, which are Algonkian, and probably Huronian.[2]

The position of the schists with respect to the granite, their more complete crystallization as this is approached, and their passage into true fragmental slates at a distance from the eruptive are all indications that not only is their crystallization due to the proximity of the granite, but their schistosity as well, since this structure disappears as the distance from the intrusive increases.

The action by which an eruptive mass produces crystallization in clastic rocks through which it breaks is known as contact action, and the change effected in the fragmentals is known as contact-metamorphism. This kind of metamorphism, while it may obliterate the proofs of the original fragmental nature of the material acted upon, never of itself produces in the resulting rock a schistose structure. This is always a result of movement of the rock particles, a consequence, in turn, of mechanical action, hence known as dynamical metamorphism.

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[1] The specimen came from a point north of Harney Peak, about 1 or 1½ miles west of the Etta Mine.

[2] For further information concerning the relations existing between the slates and schists, see C. R. Van Hise, Bull. Geol. Soc. America, vol. I, p. 203.

The force producing the schistosity in the case under discussion was that generated by the intrusion of the granitic mass, as is plainly shown by the strike of the foliation of the schists and its dip away from the core of granite. The mica-schist represented by the specimen may therefore be regarded as a dynamically metamorphosed contact-rock, whose original character was fragmental. Its present condition is due entirely to the recrystallization of its originally clastic grains through processes carefully described by Professor Van Hise in the article referred to in the footnote. It is now a typical crystalline schist.

It may be described macroscopically as a light gray, fine-grained rock with a well-marked schistose structure which is best seen on the two long sides of the specimen. Here thin parallel bands of light and dark colors alternate. The grains comprising them are so small that the nature of the minerals forming the lighter bands can not be determined without the aid of the microscope. The dark color of the other bands is plainly seen to be due to what look like fine black needles. On the upper and lower flat surfaces of the specimen the needles are observed to have more the appearance of narrow plates, with a brilliant luster. With a sharp knife thin flakes may be sprung from them. The mineral therefore is very easily cleavable, and may be regarded presumably as mica. The only other features of the hand specimen worthy of notice are the little black flakes or bunches that dot the planes of cleavage and the small rusty spots scattered throughout the rock. The latter are garnets, and the former are accumulations of mica flakes, as may be determined under a hand lens. They resemble very strongly the "knoten" described by Rosenbusch[1] and other German petrographers as characteristic of sedimentary rocks that have been made crystalline by the intrusion of eruptives through them. On some specimens there are also little circular areas with diameters of about 6^{mm}, glistening brilliantly from many tiny facets. These consist of aggregates of a light-colored mica, probably muscovite. The rock is quite soft, and is apparently much decomposed. The softness is due to the slight amount of coherence existing between the component grains, in consequence of which they fall apart very easily when rubbed.

The microscopic investigation shows the rock to be remarkably fresh. Its specific gravity is 2.806. Under the microscope the predominant light-colored mineral is discovered to be quartz, while some of the black plates and needles are biotite and others are tourmaline. Garnets and muscovite are also observed, but in very small quantity. The schistose structure is the result of the arrangement of the constituents with their longer axes approximately in the same plane, which is the plane of schistosity. (See Pl. XLII.)

The lenticular forms of the light-colored quartz grains are so apparent in the photograph that they need merely be referred to. Between these grains is a matrix composed principally of large flakes of biotite

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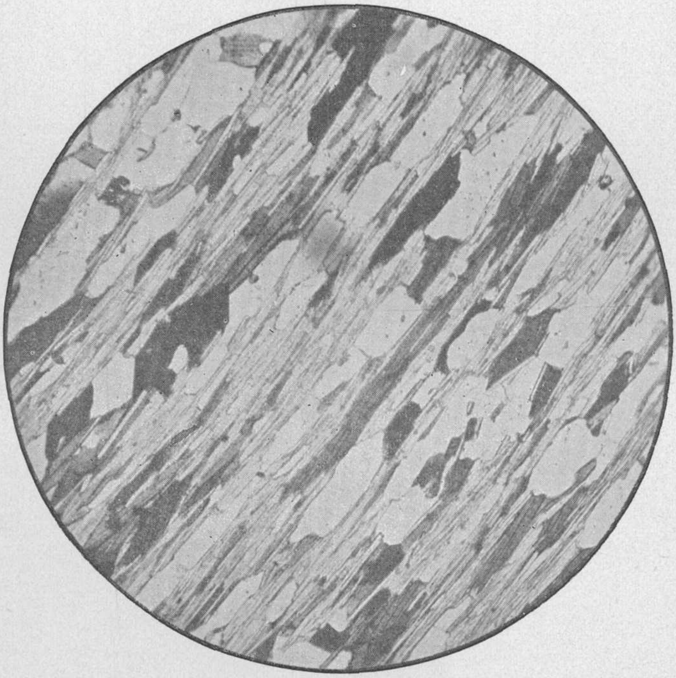
[1] Rosenbusch: Mikroskopische Physiographie der Massigen Gesteine, Stuttgart, 1887, p. 47.



THIN SECTION OF TOURMALINE-BIOTITE-SCHIST FROM BLACK HILLS, SOUTH DAKOTA, AS IT APPEARS UNDER A MICROSCOPE IN POLARIZED LIGHT.

that appear dark in the picture, and slender needles of tourmaline that have a light color. Not all of the lighter colored portions between the larger quartz grains are composed of tourmaline exclusively. Small grains of quartz, tiny flakes of biotite, some muscovite, and little masses of limonite are all found in it, but they are too minute to be distinguishable in the photograph.

The quartz is in transparent, colorless grains with lenticular cross sections, measuring from 0.15 to 0.35^{mm} in length and about 0.1 to 0.15^{mm} in width. It holds as inclusions many little liquid-filled cavities, and some filled with glass and devitrification products. Tiny specks of magnetite and other iron compounds and small crystals of apatite, besides many tourmaline crystals, are also inclosed by it.

The dark constituents, as has been stated, are biotite and tourmaline. In sections cut parallel to the plane of schistosity the biotite appears in irregularly outlined plates, most of which are basal sections of the mineral. These are dark brown in color and show no pleochroism. In other sections the mica is cut at some inclination to the vertical axis, so that its pieces are marked by parallel cleavage lines running in the direction of the long axes of the flakes, which are, in the main, parallel to the long axes of the quartz lenses. The biotite in these sections extinguishes parallel to the cleavage. It is very dark brown, almost opaque, when the cleavages and the longitudinal axes are parallel to the vibration plane of the nicol, and is light yellow in directions at right angles to this. It includes tourmaline and contains round dark areas (halos) that are more or less pleochroic.

The tourmaline is in small, well-developed crystals of a dark-brown color, and with nearly the same pleochroism as the biotite. These measure 0.2 to 0.5^{mm} in length and from 0.05 to 0.1^{mm} in thickness. They are often doubly terminated in such a way as to show clearly their hemimorphism. They may be distinguished from the biotite by the fact that their absorption is much less in the direction of their long axes than at right angles thereto; consequently, they appear dark when in that position in which the biotite appears light, i. e., when their long axes are perpendicular to the vibration plane of the lower nicol. They may also be recognized by their basal parting running across the crystals at right angles to their long axes. The tourmaline extinguishes parallel. Its double refraction is negative. It is commonly arranged parallel to the schistosity of the rock, though many exceptions to this general rule are noted.

The only other component that need be mentioned at any length is the garnet. This is present in almost colorless isotropic grains, with diameters of about 0.5 to 0.8^{mm}, except in rare instances, when they reach as much as 2^{mm}. The mineral is not very abundant, and consequently is not present in all sections. From the fact that the mica plates are sometimes bent around the garnets, it follows that the latter mineral existed at the time when movement of the rock particles was in progress. Around the borders of the grains is often a yellowish-green stain, resulting from the decomposition of magnetite or other iron compounds. It is this that causes the rusty color around the garnets in the hand specimen.

Another yellowish-green substance sometimes stains the constituents over small areas, and in some places forms little lenticular masses between the components. This substance possesses no definite structure and shows no double refraction, hence its true nature is difficult to determine. It is, however, neither essential to the rock nor characteristic of it, and therefore is of little importance for purposes of classification.

Muscovite flakes are very rare. Occasionally a tiny one may be seen lying between the quartz grains when the section is examined under crossed nicols. In ordinary light they are invisible. When the thin section includes one of the little groups of plates noticed in the hand specimen, the number of the flakes seen naturally becomes quite large, though the area covered by them is limited entirely by the outline of the group.

Though all the mineral components of the schist have been described, there remain a few structural features to be noted. The schistosity has already been stated to be the result of the arrangement of the minerals with their long axes approximately parallel, and the difference in color of alternate bands has been ascribed to the varying proportions of biotite and tourmaline in them. In some sections the difference in color is found to depend largely upon the accumulation of black iron compounds between the quartz grains in certain bands and its absence from others, in which case it is probable that there were variations in the composition of successive laminæ in the original sedimentary beds.

Another structural feature of interest is the occurrence here and there of lenticular areas in which the quartz grains are larger than elsewhere in the rock, and the amounts of biotite and tourmaline are much less. These areas may represent pebbles that were originally scattered through the slates and were afterwards flattened by the pressure that produced the schistosity,[1] while at the same time chemical changes set up in them gave rise to the quartz, mica, and tourmaline that now usurp their places.

The biotite, quartz, magnetite, and muscovite in the schist may all be looked upon as resulting from the decomposition of the original materials of the slate under the influence of contact action. The garnets may likewise be ascribed to this action. The tourmaline, on the contrary, contains a large amount of boron—a substance not occurring in any large quantity in slates. Its formation is probably due to a reaction beteen the constituents of the slate and the boron gases given off by the granite before it finally solidified.[2]

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[1] Cf. Geol. Soc. of America, Vol. I, pl. 4.

[2] For account of gases exhaled from eruptive masses see Geikie, Text Book of Geology, 1885, pp. 180-184.

The composition of the schist, which should be called a tourmaline-biotite-schist on account of the large amount of tourmaline in it, has been found by H. N. Stokes to be as follows:

Analysis of schist from the Black Hills.

	Per cent.
SiO_2	66.77
Al_2O_3	17.65
Fe_2O_3	1.55
FeO	3.29
CaO	.56
MgO	2.13
K_2O	4.49
Na_2O	.99
Ign	1.89
Total	99.32

The boron was not determined, but it is evident that it is present in considerable quantity in the rock, since very little of the loss of weight upon ignition is due to the escape of water.[1]

NO. 131. HORNBLENDE-SCHIST.

(FROM MANHATTAN ISLAND, NEW YORK. DESCRIBED BY J. P. IDDINGS.)

Rather massive crystalline schist, greenish black, with tendency to cleave in parallel plates. It occurs with mica-schist and gneiss, exposed in the northwestern portion of Manhattan Island, in the neighborhood of Riverside drive and One hundred and twenty-fifth street, New York city.[2]

In thin section it consists of dark-green hornblende, with subordinate amounts of feldspar, quartz, magnetite, biotite, apatite, and a little zircon and pyrite, besides some secondary minerals in places—muscovite, epidote, or zoisite.

The lamination of the rock is produced by a somewhat parallel arrangement of the stout crystals of hornblende and by streaks of the other constituents in smaller grains. It is most pronounced in sections cut across the lamination, but also appears in those cut parallel to the schistosity.

The hornblende is strongly green in thin section, with tinge of brown and with pronounced pleochroism, the variation being from green through brownish green to light brown. Owing to the fact of easy cleavage of the rock due to the parallel arrangement of the hornblende, thin sections are mostly prepared parallel to the prismatic axis of the crystals; consequently cross sections are scarce. Many

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[1] For other descriptions of mica-schists see R. D. Irving, Geology of Wisconsin, Vol. III, 1880, pp. 145, 148. Plate XV, Fig. 1 and 3; A. A. Julien: Ib. p. 232. A. Wichmann, Ib. p. 634.

[2] Compare J. F. Kemp, The Geology of Manhattan Island: Trans. New York Acad. Sci., Vol. VII, pp. 49-65

individuals of hornblende exhibit no cleavage. The extinction angle is low. Twinning is seldom observed. The substance of the hornblende is very pure. There are inclusions of occasional rounded crystals of zircon surrounded by brown halos, slightly pleochroic, considerable magnetite in places, besides feldspar, quartz, and biotite.

Feldspar occurs in irregular grains without crystallographic boundaries, and of much smaller size than the crystals of hornblende. It is mostly plagioclase with polysynthetic twinning according to albite and pericline laws. Some of the extinction angles suggest andesine-labradorite. The lamellæ are in places curved and may have been produced by dynamic processes. There is some undulatory extinction in places, but not much. Orthoclase may be present in small amounts, as there are a few unstriated feldspars.

Quartz occurs in irregular grains which are sometimes rounded, especially when inclosed in hornblende. The substance is very pure, with almost no undulatory extinction. Biotite is brown, with strong absorption, and occurs in irregularly shaped pieces, generally inclosed in the hornblende. Magnetite occurs in clusters and streaks of irregular grains, and is relatively abundant. Apatite forms colorless grains or stout crystals with irregular or rounded outline.

The rock in places is traversed by microscopic veins. When these cross crystals of hornblende they consist of aggregations of quartz and other minerals; or quartz may exist alone, having the same crystallographic orientation as that of adjacent grains of quartz; but where the minute vein should appear crossing quartz crystals, it is represented only by rows of dots included in otherwise very pure quartz. The hornblende sometimes exhibits a slight fibration on both sides of the vein, the direction of the fibers being parallel to that of the *c* axis of the hornblende.

NO. 132. SCHISTOSE BIOTITE-GNEISS.

(FROM MANHATTAN ISLAND, NEW YORK. DESCRIBED BY J. P. IDDINGS.)

Schistose, fine-grained, dark-colored rock associated with amphibolite-schist and gneiss at the same locality as that of the hornblende-schist on Manhattan Island, near Riverside drive and One hundred and twenty-fifth street, New York City. It consists of biotite, feldspar, and quartz, with a small amount of muscovite, apatite, and zircon. The thin sections are most easily made parallel to the schistosity of the rock and the foliæ of the mica; hence they seldom show cross sections of the mica plates. There is somewhat of a flaser-structure, caused by flakes of mica grouped in lines curving about larger crystals of feldspar and quartz.

In thin section the biotite is dark brown, with strong absorption. Its form is irregular and seldom exhibits crystal boundaries. It includes grains of quartz and feldspar and other minerals, and in turn occurs as microscopic crystals included in quartz and feldspar.

Muscovite occurs sparingly as relatively large colorless plates, sometimes surrounded by biotite.

Quartz appears to be more abundant than feldspar. Its outline is quite irregular, the smaller grains often rounded. It exhibits slight undulatory extinction and in places minute rutile needles, and some inclusions of the other mineral constituents of the rock. Fluid inclusions are quite scarce.

Feldspar forms allotriomorphic grains like those of quartz, but often attains larger dimensions. It is mostly plagioclase, with polysynthetic twinning, in places curved, accompanied by undulatory extinction. The extinction angles are low, indicating oligoclase. Orthoclase appears to be present in smaller amounts. No microcline was noted.

Apatite forms comparatively large, irregular grains, colorless and quite pure. Some grains are surrounded by a shell of brown, doubly refracting mineral. A similar mineral, with paler color and low double refraction, occurs in spots through the rock. Its character has not been determined. Zircon occurs in rounded microscopic crystals. Magnetite is almost entirely absent.

As the proportion of feldspar grows less the rock approaches a gneissic mica-schist.

No. 133. STAUROLITIC MICA-SCHIST.

(FROM CHARLESTOWN, SULLIVAN COUNTY, NEW HAMPSHIRE. DESCRIBED BY W. S. BAYLEY.)

The rock stratum from which specimen No: 133 was obtained constitutes one of the members of C. H. Hitchcock's Coos group,[1] which comprises (1) a quartzite, (2) a staurolitic mica-schist, and (3) a staurolitic and garnetiferous clay slate. In the Connecticut Valley the mica-schists gradually lose their micaceous character and become argillitic; hence there can be no question that the schists are rocks of sedimentary origin. In the New Hampshire reports the "Coos group" is included in the Paleozoic system. In a later paper[2] it is more definitely assigned to some horizon above the Cambrian, possibly the Devonian.

As represented in the hand specimen, the rock is dark gray in color and crystalline in texture. In structure it is typically schistose, but the schistosity is not developed in parallel directions. In all specimens it is more or less contorted in short waves, which show themselves on cleavage surfaces as a series of approximately parallel crumplings. The luster of these surfaces is silky, suggesting the presence in the rock of some micaceous mineral with its broader faces parallel to the cleavage surfaces. On cross fractures the specimens are characterized by the presence of rods of a very glistening, easily cleavable mineral in a dull, light-gray matrix, resembling in appearance a very

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[1] C. H. Hitchcock: Geology of New Hampshire, Vol. II, Chap. IV, pp. 316-323.

[2] C. H. Hitchcock: Jour. Geol., Vol. IV, 1896, p. 59.

fine-grained gneiss or graywacke. The rods are all elongated in the direction of the rock's schistosity. Cleavage plates of this mineral are of a reddish-brown color. They are not pleochroic to the slightest degree. Between crossed nicols they remain dark through an entire revolution, and in converged light they exhibit the uniaxial figure. These characteristics belong to biotite.

The most noticeable feature of the specimens is the presence in them of irregular lumps whose cross sections are oval in outline. Their longer directions are approximately parallel to the schistosity of the rock. An inspection of a freshly fractured cross section of one of these rounded crystals—for such they are—reveals the presence of a core of a garnet-colored substance surrounded by a mass of lusterless greenish-gray material. The nucleus consists of fresh staurolite and the surrounding material of an aggregate of alteration products of this mineral. Hawes[1] describes these crystals as consisting of a core surrounded by a zone, the core and zone being separated from each other by a line of impurities. Sections made from some of the largest crystals in the specimens collected for this series leave no doubt that these crystals are staurolite. The appearance of a cross section of one of the best crystals is shown in the accompanying figure (fig. 17). The nucleus is an oval area of fresh staurolite, which is pleochroic in light-yellow and orange-yellow tints. Absorption $c > a$. Plane of its optical axes is $\infty P \bar{\infty}$. The surrounding material is a fine-grained aggregate of a white micaceous mineral. This is divided into distinct areas, as indicated, by lines composed largely of chlorite flakes and small grains of an opaque substance that may be some carbonaceous material. The same opaque substance borders the periphery of the section, which in outline is a rhomb with rounded corners. The micaceous aggregate is evidently the product of the decomposition of a staurolite crystal, the nucleus which it surrounds being a remnant of the original substance which has not yet suffered decomposition. The chlorite lines were in all probability produced from inclusions that so commonly exist in both andalusite and staurolite crystals.[2] A close inspection of the hand specimen will show that the micaceous minerals in the groundmass wrap around the staurolite crystals in a manner suggesting the existence of the latter in their present positions at the time when the rock was attaining its schistose structure.

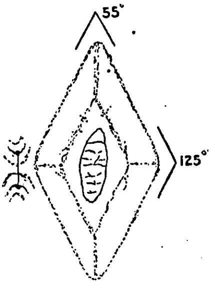

FIG. 17.—Cross section of staurolite in staurolitic mica-schist.

Under low powers of the microscope the groundmass in which the staurolite crystals lie is seen to be composed of large plates of brown biotite or of green chlorite and comparatively large masses of a light-

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[1] G. W. Hawes: Geol. New Hampshire, Vol. III, Pt. 4, pp. 109-111.

[2] Cf. J. D. Dana: System of Mineralogy, 6th Ed., pp. 497, 560; also G. W. Hawes: Geol. New Hampshire, Vol. III, Pl. II, figs. 8 and 8*a*.

green fibrous aggregate with crystal contours, embedded in a foliated matrix consisting of quartz, sericite or muscovite, chlorite, an occasional grain of zircon, rutile, and tourmaline, and innumerable small, black particles scattered everywhere throughout the slide, except through the light-green fibrous masses.

Biotite is the most noticeable constituent. It is in large plates, usually elongated in the direction of the *c* axis, and hence possessing a cleavage transverse to their longer directions. Its color is dark reddish-brown parallel to the cleavage and a light greenish-yellow perpendicular thereto. On the edges of many plates the mica has been changed to chlorite, and often the alteration has proceeded from the edge inward, so that lamellæ of the green chlorite are intergrown with lamellæ of brown biotite. In the smaller grains all the mica has often been replaced by the chlorite, and in sections cut from weathered portions of the rock not a trace of biotite remains in even the largest grains. Both the biotite and the chlorite developed from it contain many inclusions of quartz, magnetite, rutile, zircon, and tiny opaque grains that may be some form of carbon or of a carbonaceous substance. A few of the inclusions, more particularly those of zircon, are surrounded by dark circles that are more or less pleochroic. These are known as "pleochroic halos." The biotite flakes were evidently formed in the rock after the constituents of the matrix, but probably before the cessation of the motion that rendered this schistose.

The light-green masses with crystal outlines are composed of an intermixture of little bundles of a green fibrous chlorite and spicules of a colorless micaceous mineral. The chlorite is recognized by its slight pleochroism and its dull interference colors. The colorless mineral is brilliantly doubly refracting. Its extinction is parallel to a well-defined cleavage that may be seen under high powers. It is probably muscovite or talc. From the shapes and composition of these masses it is clear that they are pseudomorphs after some mineral that originally was present in well-defined crystals. In all probability this mineral was garnet. The alteration of garnet into chlorite is not uncommon. Perfect pseudomorphs of this nature have been described by Pumpelly[1] from the Spurr mine in Michigan.

The relation of the garnets to the matrix is the same as that of the biotite and of the large staurolite crystals. Evidently they were already present in the rock prior to the final production of its schistosity. They appear to be the oldest of its present constituents, since they only are devoid of the black particles so thickly strewn through all the other components.

The matrix surrounding the biotite and garnet pseudomorphs appears, in ordinary light, as a colorless aggregate of fibers and grains besprinkled more or less thickly with numberless small black or brown particles, and containing here and there an irregular flake of green

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[1] Am. Jour. Sci., 3d series, Vol. X, 1875, p. 17.

chlorite, a rod or a rounded grain of magnetite, a ragged grain of ilmenite or of titaniferous magnetite, a minute crystal of brownish-yellow rutile, and occasionally a small plate of greenish-brown tourmaline. The tourmaline is recognized by its pleochroism and its absorption $\omega > \varepsilon$, the titaniferous magnetite by its gray decomposition products, and the rutile by its color, its lack of distinct pleochroism and its high refractive index. Between crossed nicols the colorless or very light-green component of this matrix is the platy variety of muscovite known as sericite. It is identified by its lack of color, its lack of pleochroism, its brilliant polarization colors, and by the fact that its extinction is parallel to its cleavage. The sericite occurs in long, acicular and columnar crystals or scales, often grouped in little bundles. Between them are colorless grains of quartz, usually elongated in a direction parallel to the long axes of the sericite individuals. No pressure effects are noted in the quartz grains. Their elongation appears to be an original condition. Both the quartz and the sericite have the aspect of minerals that have crystallized in situ, and the entire rock seems to have undergone a complete recrystallization from its original state as a sediment.

The structure of the matrix is plainly schistose, the schistosity being due to the elongation of the quartz grains, and the arrangement of the sericite flakes parallel to this elongation. The foliation, however, is not evenly parallel, as it is in specimens of some of the other rocks in the collection, but is contorted, little folds being crowded closely together in some portions of the sections and opening out into very gently curved folds in others. The quartz grains on the limbs of the folds are always much more elongated than those in their crests and along their axes, thus causing these microscopic folds in the thinning of their sides to resemble the larger folds noted in disturbed rock strata.

Nothing in the microscopic structure of this rock suggests its original fragmental character. As at present constituted, it is a thoroughly crystalline rock. No indications of a fragmental grain may be detected in it. Since, however, it has been traced into slates, there can be no question as to its derivation from a sediment composed of the same constituents as those composing an ordinary shale. The rock is a typical crystalline schist that has been derived from a sedimentary fragmental rock. In composition it is a mica-schist containing altered staurolite and garnet crystals.

The rock's foliation is unquestionably the result of pressure. The elongation of the quartz grains and the bending of the mica flakes point to this origin. There is, however, no fracturing of grains and no distortion in their optical properties, as in the case of schists derived by dynamic metamorphism from igneous rocks (see No. 140). The foliation of the rock under discussion was not produced by the flattening of grains of minerals already existing in it, nor by their rotation into positions of least resistance. It was caused by crystallization of its components while under pressure, attended by motion in the plastic crystallizing mass.

The rock affords a good example of a schist formed from a fragmental rock through metasomatic agencies accompanying dynamic action. In dynamically formed schists like No. 140 the present constituents are practically the same as those existing in the original rocks; in metasomatic schists the present components have been formed de novo.[1]

NO. 134. HORNFELS.

(FROM GENESEE VALLEY, PLUMAS COUNTY, CALIFORNIA. DESCRIBED BY H. W. TURNER.)

By contact metamorphism is meant those alterations in a rock mass which take place along the border of an intrusive mass in consequence of the heat and mineralizing solutions whose origin is due to the intrusive igneous rock.

In the Educational Series collection this phenomenon is illustrated by two specimens from California—one a hornfels from Plumas County and the other a chiastolite-schist from Mariposa County.

At both these localities areas of granitoid rocks are in contact with sedimentary masses, and along the border of the granite there is a zone of metamorphic rock which grades almost imperceptibly into less altered sediments at about the same distance from the granite contact at all points.

In the metamorphic zone new minerals have been formed, chiefly by the recrystallization of the material of the sediments. This phenomenon has been noted in many parts of the world, and careful investigations have shown beyond all reasonable doubt that the formation of these minerals took place after the intrusion of the igneous magma and as a result of it.

The investigations of Hawes[2] have, indeed, made certain that in one instance there has been an addition of boric acid to the schists from the mineralizing solutions, resulting in the formation of abundant tourmaline in the zone nearest the granite. Rosenbusch,[3] in a very thorough investigation of contact phenomena, however, found that, at the locality which he studied, the new minerals formed were almost wholly due to the recrystallization of the material of the sediments which had been metamorphosed.

Hornfels is the term applied by Rosenbusch to contact metamorphic rocks which are massive and not schistose. Such rocks usually break with a conchoidal fracture, especially when fine grained. Often, as in the specimens in the Educational Series collection, the hornfels is a

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[1] For a discussion of the processes concerned in the metamorphism of sedimentary rocks see C. R. Van Hise, The principles of North American pre-Cambrian geology: Sixteenth Ann. Rept. U. S. Geol. Survey, pp. 680-694, 705. For a discussion of metamorphism in general see Harker's Petrology for Students, University Press, Cambridge, 1895, pp. 257-290.

[2] Am. Jour. Sci., 3d series, 1881, Vol. XXI, p. 21.

[3] Die Steigerschiefer. Strassburg, 1877.

fine-grained flinty rock, but the name may also be applied to coarser varieties which were originally argillaceous sandstones. The hornfels zone from which specimen No. 134 was obtained varies in width, according to Mr. Diller, who collected the specimens, from 160 to 1,300 feet. This great variation in width is thought by Mr. Diller to be due to the fact that the contact of the granite and the sedimentary mass is probably not a vertical one; that is to say, he supposes the granite to pitch in under the hornfels, so that when the zone is wide the distance of the metamorphic rock from the underlying granite surface may not in reality be any greater than when the zone is narrow. The igneous rock which has caused the original shale to be metamorphosed into a hornfels has been called above a "granite." In reality it should be called a quartz-gabbro or a quartz-pyroxene-diorite, for it contains little or no alkali feldspar. The intrusive rock is a gray, medium- to rather coarse-grained granitoid rock, of granitic or hypidiomorphic structure, and is composed of plagioclase, hornblende, monoclinic pyroxene, quartz, iron oxide, biotite, and hypersthene, the relative abundance of the components being roughly indicated by the order in which they are named, plagioclase being the most abundant. Apatite is present in some specimens, and in one thin section no pyroxene was noted. The plagioclase is chiefly labradorite, and if the kind of feldspar be taken as the basis of classification, following Brögger and others, then the above rock must be called a quartz-gabbro.

Microscopically the rock is dark, very fine- and even-grained, with conchoidal fracture. None of the individual constituents are recognizable with the unaided eye.

Microscopically the rock presents, without the analyzer, a minutely mottled appearance, due to the presence of very abundant spots, lighter in color than the intervening spaces. These spots are often close together. With the analyzer they are seen to be made up of aggregates of translucent grains, with low, gray, interference colors. The grains of these aggregates often extinguish together; that is to say, they show aggregate polarization, indicating a like optical orientation of all of the grains of any one aggregate. No interference figure could be obtained in convergent light. There are very minute polarizing fibers scattered through these aggregates, which are presumably biotite. The aggregates appear to represent the incipient formation of some mineral.

The spaces between the aggregates are dark colored and contain very abundant minute foils of a reddish-brown biotite and dull black grains, which are probably carbonaceous.

Scattered through the section, both in the aggregates and in the intervening spaces, are clear grains of clastic (?) quartz and large foils of biotite, some of them 0.4^{mm} long.

No. 135. CHIASTOLITE-SCHIST.

(FROM NEAR MARIPOSA, MARIPOSA COUNTY, CALIFORNIA. DESCRIBED BY H. W. TURNER.)

The locality from which specimen No. 135 was obtained is in a zone of contact metamorphic rocks at the south end of a long belt of the Mariposa slates which extends from Colfax, in Placer County, to the point at which the specimens were collected, a distance, following the curvature of the slate belt, of about 130 miles. To the west of Placerville this belt of Mariposa slates is in contact with an area of granite-porphyry and does not seem to be greatly altered, but the contact was only cursorily examined. Only at its south end is this slate belt in contact with any large body of a coarsely granular rock of a granitoid nature, and at no other point in its entire extent does it show great alteration. The granitoid rock, which has caused the metamorphism of the slates in Yaqui Gulch, extends at least as far south as the San Joaquin River, a distance of 35 miles, with an average width of 12 or more miles. This granitic rock is not near the contact with the schists a true granite, but a subsiliceous quartz-mica-diorite, as may be seen from the analysis in the table below, and indeed this is probably true of most of the area.

A fine-grained granite, No. 372 in the table below, from Raymond, near the center of the area, is nearly a normal granite in composition, but analyses Nos. 369 and 851, from near the edge of the area, show the rock there to be much less siliceous. It has not, however, been determined whether or not No. 372 represents the average rock of the center of the area, or whether it is not a portion of an older or younger granite mass.

Analyses of granite from the Raymond granitoid area.

	No. 369, Chowchilla River.	No. 851, Yaqui Gulch.	No. 372, Raymond Quarry.
	Per cent.	*Per cent.*	*Per cent.*
Silica	62.62	58.09	73.54
Lime	5.49	6.24	2.55
Potassa	1.76	2.02	1.89
Soda	3.49	2.94	4.66

In Yaqui Gulch, near the intrusive rock, the Mariposa schists have been irregularly displaced and their relation to the quartz-diorite is not a perfectly simple one, so that the study of the details of the metamorphism is not so satisfactory as it would otherwise be. The rocks near the granitoid rock (a quartz-diorite) are much obscured by soil.

The specimen collected nearest the quartz-diorite is a rather medium-grained andalusite-hornfels, and was obtained at a point about 2,500 feet north of the main diorite contact. This hornfels is presumed to have been originally a sandstone. The expression "main diorite contact" is used for the reason that a small mass of quartz-diorite, doubtless an apophysis of the main area, occurs near the andalusite-hornfels noted above. After crossing the zone of andalusite-hornfels, the exact extent of which was not determined, we find in going away (or north) from the main diorite mass a considerable zone of knotted mica-schists and of chiastolite-schist.

In Yaqui Gulch, about 3,800 feet from the main diorite contact, these schists are well exposed in the bed of the stream. The normal strike of the main belt of Mariposa slates is about N. 30° W., with a dip of from 50° to 90° to the east. In the vicinity of the diorite these slates are much displaced and to some extent contorted. Along that portion of Yaqui Gulch, where the specimens were collected, the beds strike approximately north and south, and dip both east and west at an angle of 60° or more. The schists thus lie nearly at right angles to the course of the main diorite contact, which is nearly east and west.

The specimens of chiastolite-schist were not obtained all at one point, but at various points along the gulch within a distance of about 1,200 feet, or in a zone of from 3,800 to 5,000 feet from the main diorite area. The chiastolite-schist occurs in layers interbedded with mica-schists and knotted schists. Often these layers are but 2 to 6 inches in thickness. It is evident that their formation depends largely upon the original composition of the individual layers. Those containing a large percentage of argillaceous matter appear to develop into chiastolite-schists, and the more sandy layers into micaceous schists without chiastolite, or with only imperfectly developed crystals. This is to be expected from the composition of chiastolite, which is a silicate of alumina, the latter being a prominent constituent of all argillaceous rocks.

Some of the specimens of chiastolite-schist collected in Yaqui Gulch contain distinct impressions of *Aucella errington*i, or one of its closely allied varieties described by Professor Hyatt. This fossil is said by Professor Hyatt, Professor Smith, of Stanford University, and others, to be of Jurassic age. It is thus evident that the granitoid rocks which have affected the metamorphism of the clay-slates are of late Jurassic or post-Jurassic age.

More than 5,000 feet away from the diorite the Mariposa beds are not greatly metamorphosed. They are no longer schists, but clay-slates. However, they still show some effects of the metamorphic action of the diorite in the presence of very abundant minute prisms, the distribution of which appears to be somewhat capricious, as some layers of the clay-slate show them and some do not, at exactly the same locality. At a distance of about 6,500 feet from the main diorite contact the metamorphic action of the igneous mass appears to have ceased entirely, but the contact of the diorite and the schists is perhaps not a vertical one, and the distance of the schists from the underlying diorite mass in a vertical or inclined direction may be much less than the distances here given. Moreover, it should be stated that these distances are all approximate. Some of them were measured by pacing, others only estimated. A contour map has not as yet been made of this region, which lies directly south of the Sonora quadrangle.

The specimen is from Yaqui Gulch, 2 miles southwest of the town of Mariposa.

Megascopically, when fresh, it is a hard, black, fine-grained schistose rock, with very abundant minute points with a silvery reflection and slender prisms which are square in cross section. These prisms are sometimes an inch in length, but usually shorter. In weathered specimens a dark center can be seen in some of the cross sections of the prisms.

Microscopically, when seen without the analyzer, it shows a fine-grained, dark groundmass, composed of minute, clear grains, many of them rounded; abundant minute, black particles, and reddish brown biotite scales, arranged in more or less nearly parallel lines, giving the schistose structure to the rock. In this groundmass are long, clear prisms which are square in cross section, and minute, clear prisms which are nearly of a size, having a width of 0.02^{mm} and a length of about 0.2^{mm}. Many of these lie at an angle to the plane of schistosity, suggesting their formation after the rock had been rendered schistose. The large prisms with square cross sections are chiastolite, and are from 1 to 2^{mm} in diameter. The dark cross which distinguishes chiastolite from andalusite is feebly developed in many of the prisms, and consists in lines of minute granules extending from the center to the prism edges, bisecting the prism angles. The minute, black particles show on some surfaces a metallic luster by reflected light. Some of the rock was powdered and washed. A fine, black dust, which collected on the surface of the water and which presumably represents the black particles seen under the microscope, was consumed when placed on a platinum spatula in a flame at high temperature. This powder is therefore assumed to be carbon, and the metallic luster indicates that it may be in the form of graphite. The minute, clear prisms seen in natural light probably represent the silvery points observed megascopically. They are muscovite. With the analyzer these prisms extinguish parallel to the direction of elongation and show bright interference colors.

The clear cross sections of the chiastolite crystals show the two prismatic cleavages intersecting nearly at right angles. In the cross sections the extinction is diagonal, bisecting the prism angles and the intersections of the cleavage lines. In longitudinal sections the two cleavages are indicated by parallel lines, and the extinction is parallel to the cleavage. In favorable light a slight pleochroism may be detected in some of the chiastolite prisms, $\mathfrak{c}$ being faintly reddish. The outer edge of even the freshest chiastolite crystals is altered to a fibrous, colorless aggregate, which, according to Rosenbusch, may be a mixture of sericite and kaolin, and occasionally irregular cracks extending into the crystals are filled with this same decomposition product. The fibers of the decomposition rim usually stand approximately normal to the prism planes. The particles of the groundmass, to a certain extent, exhibit a tendency to flow around the chiastolite crystals—that is to say, they are arranged in lines roughly parallel to the sides of the prism. This is best seen in the cross sections, and may be taken to indicate that the schists were in a plastic condition after the crystals were formed. A few minute veinlets cut the section, filled with a clear mineral in little grains, which is apparently quartz. The powdered rock was tested for magnetite, but merely a few grains were found.

Analyses of contact-metamorphic rocks.

[Analyst, Steiger.]

	No. 851.	No. 432.	No. 431A.	No. 855.
SiO_2	58.09	65.10	62.15	60.35
TiO_2	.95	.72	.89	.75
Al_2O_3	17.46	17.77	19.34	17.62
Fe_2O_3	1.12	1.95	4.23	5.64
FeO	5.08	3.29	2.25	2.20
MnO	none	none	trace	none
CaO	6.24	1.38	1.50	.45
SrO	.04	none	none	none
BaO	.07	none	.04	.12
MgO	4.06	1.43	1.88	1.14
K_2O	2.02	2.45	3.07	3.16
Na_2O	2.94	2.25	1.60	1.
Li_2O	none	none	none	none
Water below 100° C	.29	.47	.19	1.02
Water above 100° C	1.45	2.49	1.79	4.36
P_2O_5	.17	.14	.15	.17
SO_3	.05	.03	.13	.05
CO_2	.21	none	none	none
Cl	.02	{strong trace.}	none	.01
F	trace	.12	.22	trace
B_2O_3	none	none	none	none
Carbon	.11	1.21	1.12	1.72
Total	100.37	100.80	100.55	99.76
Less O	.01	.06	.10	.01
Total	100.36	100.74	100.45	99.75

No. 851 is a basic quartz-mica-diorite, collected near Yaqui Creek, about 300 feet from the border of the zone of contact-metamorphic rocks. It is the igneous rock which has caused the formation of the contact minerals.

No. 432 is a knotted mica-schist collected in Yaqui Gulch, about 3,800 feet from the main diorite contact.

No. 431A (Educational Series Collection, No. 135), is a chiastolite-schist collected in Yaqui Gulch, a few feet to the north of No. 432, or about 3,800 feet from the main diorite contact.

No. 855 is a clay slate collected near the head of Yaqui Gulch, somewhat more than a mile from the main diorite contact.

The above analyses were made with the object of showing, as nearly as practicable, whether the new minerals in the zone of contact metamorphism had formed as a result of certain elements being added to the schists from the quartz-diorite magma or from the mineralizing solutions and gases accompanying its intrusion, or had resulted merely from the recrystallization of the material of the clay slates. The specimens Nos. 432, 431A, and 855 may be regarded as having been all originally clay slates. Rosenbusch found that the amount of the water of crystallization in a contact metamorphic schist varied inversely with the distance from the igneous rock that caused the metamorphism. This same law appears to apply to the above series. In Nos. 432 and 431A the amount of this water is 1.79 per cent and 2.79 per cent, respectively, while in No. 855, which is farthest from the igneous mass, the water of crystallization (100° C.+) is 4.36 per cent. It will be noted that the amount of fluorine is greater in those schists nearest the diorite. This element probably exists in the authigenic micas, and may be regarded as having been added to the schists from gases that ascended along the contact at the time of the intrusion of the diorite. The carbon content (0.11 per cent) in the quartz-diorite may have been derived from carbonates of lime and magnesia formed by the action of surface waters containing carbon dioxide. This is more than probable, since carbonates were noted in small amount in the thin sections of the rock. It should be borne in mind, however, that carbon dioxide occurs in a liquid form in minute cavities in the quartzes of diorite and granite, and when great masses of granitic rocks have undergone crushing the amount of carbon dioxide liberated would be considerable. The quartz-diorite No. 851, however, shows no evidence of crushing. The large majority of the newly formed minerals in the contact schists probably represents merely a molecular rearrangement of the original components.

METAMORPHIC IGNEOUS ROCKS.

No. 136. Aporhyolite.

(From South Mountain, Adams County, Pennsylvania. Described by Miss F. Bascom.)

The term aporhyolite, which has been recently introduced into petrographical nomenclature,[1] is designed to cover those acid volcanic rocks which are similar in chemical and mineralogical composition and in

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[1] Bull. U. S. Geol. Survey, No. 136. The structure, origin, and nomenclature of the acid volcanic rocks of South Mountain: Jour. Geol., Vol. I, No. 8, pp. 813-832.

structure to the rhyolite, but differ from that rock type in possessing a holocrystalline groundmass, presumably secondary.

The presence of those microscopic structures peculiar to glassy rocks, associated with evidence of the secondary character of the crystallization of the groundmass, is considered indicative of the original glassy character of the rock, and hence of a former identity with the rhyolite. It is maintained that the present difference is due to changes which have taken place subsequent to the solidification of the rock, chief among which has been devitrification.

By devitrification (entglasung) is meant the conversion of a glassy or partially glassy groundmass into a holocrystalline groundmass. That molecular motion does not cease with the solidification of a rock mass is an acknowledged fact. Daubrée[1] has shown experimentally that crystallization may take place in glass just as in a molten magma. The action differs only in the amount of time required. In the former case it is exceedingly sluggish. Heat and moisture, which are not likely to have been altogether absent in the history of metamorphic rocks of any age, might be important factors in initiating and accelerating the process.

Such then are the facts—the original character of the rock and the subsequent alteration—indicated by the name aporhyolite.[2]

The structures pointing to a glassy origin and the secondary character of the crystallization of the groundmass will be indicated in the description of the specimen included in this collection.

The aporhyolite of the collection comes from a spur of South Mountain, about 2 miles west of the old Maria Furnace, in Adams County, Pennsylvania, and about 3½ miles northeast of Monterey Station, in Franklin County, Pennsylvania. The best specimens are found north of the junction of Toms Creek and Copper Run, upon the mountain side. They are of pre-Cambrian age, and have been subjected to pressure, rendering them more or less schistose.

In color the aporhyolites of this locality show considerable range; a blue-gray, bluish purple, and a reddish purple are the predominating colors. Both shades of purple are frequently present in a single hand specimen, when there is a tendency to alternating bands of these colors. Some specimens show a yellowish-green tone due to the presence in some abundance of a secondary micaceous mineral which will be characterized later. Phenocrysts are absent or inconspicuous. An amygdaloidal structure, so characteristic of aporhyolites from other localities in the South Mountain, is not observable in these specimens.

The conspicuous feature of the specimens is the globular or ellipsoidal spherulites which crowd the rock so thickly as almost to exclude the matrix in which they are embedded. These spherulites are from 3^{mm} to 5^{mm} in diameter. On the weathered surface of the rock they stand

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[1] Daubrée: Géologie Expérimentale. 1879, p. 158.

[2] The prefix *apo* may be used to indicate the derivation of one type from another by some specific alteration.

out in relief, giving it a superficial resemblance to a conglomerate. They are irregularly distributed or are arranged in bands, and are often elongated by the movement of the magma during their formation. When seen in cross section the spherulites show a threefold zonal banding of the blue and purple pigment. There is a dark center surrounded by light and dark zones, or this arrangement of zones is reversed.

A flow structure, while not conspicuous as in many aporhyolites, is obscurely indicated by the banding of the purple and blue shades, by the elongation of the spherulites, and by their arrangement in chains.

The bright cleavage surfaces of minute feldspar crystals occasionally reflect the light. These feldspars, magnetite, and the secondary micaceous mineral before alluded to are the only constituents readily determined with the naked eye.

Both the matrix and the spherulites are cryptocrystalline.

The hardness of the rock is between 6 and 7. Its specific gravity is 2.678. The specific gravity of specimens of spherulitic glass ranges from 2.385 to 2.394. These figures show the increase in density which accompanies devitrification. The presence of manganese oxide is denoted in a brown stain on the weathered surface of the rock.

Under the microscope in ordinary light the spherulites appear as circular, elliptical, or irregularly oval areas outlined by minute particles of red iron oxide (hematite) and dusted by the same pigment. Successive zones are faintly indicated and arise from the crowding in bands of innumerable particles of black and red iron oxide. Sometimes these circular areas merge one into the other, forming a chain of spherulites suggestive of those described by Professor Iddings[1] as characteristic of the Yellowstone National Park volcanics.

The groundmass in which the spherulites lie, and which constitutes only a small portion of the field, is distinguished in ordinary light from the spherulitic areas by its comparative freedom from the iron oxide particles. Pl. XLIII shows the altered spherulites of an aporhyolite from the type locality in the South Mountain, Pennsylvania.

With the analyser in place the field has a much more homogeneous aspect. The spherulites unexpectedly disappear. Instead of the radiating fibers of quartz and feldspar, which constitute the well-known spherulitic structure, there is a finely granular quartz-feldspar mosaic, quite similar to the quartz-feldspar mosaic of the groundmass.

A cloudiness due to the abundant iron oxide particles in the spherulitic areas, the presence of brightly polarizing scales of a secondary mineral, or the finer grain of the quartz-feldspar crystallization alone serve to distinguish the spherulites from the groundmass.

Rarely the aporhyolites of this locality show traces of a radial growth of quartz and feldspar, not yet entirely obliterated by alteration to a granular crystallization, while sometimes the groundmass still preserves

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[1] Obsidian Cliff: Seventh Ann. Rept. U. S. Geol. Survey, 1888, p. 277, Pl. XVII.

faint indications of perlitic parting. This is a structure peculiar to a glass and consists in a concentric cracking due to the contraction on cooling. Subsequent crystallization might readily obliterate such a structure. In this case iron oxide particles are so arranged as to preserve the outline of the cracks. This structure is illustrated in Fig. *A*, Pl. XLIV, prepared from a thin section[1] of aporhyolite from the Lower Keweenawan of the Lake Superior region.

Aporhyolites from Raccoon Creek in the South Mountain, about 10 miles west of Copper Run, show spherulitic and perlitic structures still perfectly preserved, associated with lithophysal flow and rhyolitic structures in great perfection. Fig. *B*, Pl. XLIV, is aporhyolite from Raccoon Creek, showing spherulitic and perlitic structures.

The association of any two of these structures is considered sufficient proof that the rock which they characterize consolidated as a glass. Such is the nature of the evidence that the finely granular crystallization of the groundmass and the spherulites alike is secondary.

The rock first consolidated as a glass (or in large part a glass), crowded with spherulites possessing the true radiating structure characteristic of spherulites. Subsequent to this consolidation, devitrification, the nature of which has already been explained, has brought about the uniform granular holocrystalline character which the rock now possesses.

The mineral constituents of these rocks are few in number. Chief among the crystals of the first consolidation is a clear, well-preserved feldspar. Crystals of this mineral are inconsiderable in size. They are frequently grouped, and are distributed without reference to the spherulites. They may be twinned by the Carlsbad or Manebacher law and often show microperthic structure as result of pressure. They may contain inclusions of an original glassy magma. That they belong to the alkali end of the series of feldspars is indicated by the chemical analysis of the rock, while their specific gravity (2.6) and the emergence on the M face of a positive bisectrix very slightly inclined, as may be observed in converging light on the Manebacher twins, suggest anorthoclase.

Occasional clear oval areas of granular quartz may sometimes represent granulated quartz crystals of the first consolidation, or the secondary replacement of spherulitic centers, or they are, in many places, the filling of minute vesicles elongated by the movement of the magma. In the last case there are frequently forms along the walls of the vesicles, outlined by the iron oxide, which suggest minute tridymite crystals or spherulites, such as are found lining the walls of vesicles in modern lavas. They disappear in polarized light. Fig. *B*, Pl. XLIV, prepared from an aporhyolite from Raccoon Creek, shows quartz-filled vesicles bearing tridymite spherulites on their walls. Rarely transparent colorless crystals of zircon, characterized by high index of

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[1] Thin section furnished by N. H. Winchell.

THIN SECTION OF APORHYOLITE FROM SOUTH MOUNTAIN, PENNSYLVANIA, SHOWING ALTERED SPHERULITES, AS SEEN UNDER A MICROSCOPE.

refraction and brilliant polarization colors, may be recognized, also minute grains of pleochroic hornblende. The only other original constituents are the iron oxides, magnetite, and hematite. They are both in part secondary. The latter is recognized by its nonmetallic luster and reddish color in incident light, the former by its rough metallic black surface. Neither show crystalline form. The former is magnetic in the powder. Hematite is a characteristic pigment for rhyolites.

The conspicuous secondary constituent is the micaceous mineral of which mention has already been made and to whose presence the rock owes a light greenish tinge. Under the microscope, in ordinary light, it appears as transparent pale greenish yellow, irregular plates showing lines of cleavage, with a low index of refraction and an oily luster. In parallel polarized light these plates show brilliant interference colors, and in converging polarized light a small axial angle. These plates are developed most abundantly around the feldspar crystals, filling the cracks in the feldspars that have suffered crushing, and around and in the spherulitic areas.

It is undoubtedly an alteration product of feldspar under pressure and that species of mica known as sericite. This mineral can be formed from the acid feldspars by the replacement by hydrogen of a portion of the alkali constituent and the setting free of silica. This kind of metamorphism is of common occurrence in the development of schistose rocks from the massive acid eruptives, and has been carried so far in some of the acid volcanics of South Mountain as to form a sericite-schist.

Another secondary constituent of these aporhyolites is epidote. This mineral is of a deeper yellowish green than the sericite, and is easily distinguished from the latter by its high index of refraction. It occurs in irregular granular aggregates. Its high relief and bright interference colors serve to distinguish it. It is a product of the weathering of the feldspars in the presence of solutions carrying alumina.

That the magnetite of these rocks is titaniferous is plainly shown by its alteration products, of which there are two. The most abundant one is a cloudy, white (in incident light), or yellowish substance called leucoxene. Associated with this mineral there are, rarely, brown semitransparent grains of titanite, showing a higher relief than epidote, and without brilliant interference colors.

The evidence that these rocks have undergone pressure and some shearing lies in the development of a sericite and the resulting foliation, the cracking and pulling apart of the feldspars, the development of the perthitic structure, and the granulation of the quartzes.

An analysis of aporhyolite from Monterey, Franklin County, Pennsylvania, as reported by H. N. Stokes, is as follows:

Analysis of aporhyolite.

	Per cent.
SiO_2	76.34
TiO_2	.26
P_2O_5	trace
Al_2O_3	11.60
Fe_2O_3	2.41
FeO	.30
MnO	trace
BaO	.09
SrO	none
CaO	.55
MgO	.06
K_2O	2.75
Na_2O	5.50
Li_2O	none
Co_2	trace
H_2O below 110° C	.10
H_2O above 110° C	.39
Total	100.35

The analysis is essentially that of a typical rhyolite. The relation of soda percentage to the potash accords, in its indication of the character of the feldspar, with the optical determinations. The lime may be referred to the epidote, which doubtless also explains the trace of manganese oxide. A manganese epidote has been found very abundantly in some of the aporhyolite near Monterey. The presence of titanium in the magnetite is also substantiated by the analysis.

Beside the locality from which these specimens were obtained typical aporhyolites also occur in the South Mountain along Raccoon Creek, south of Caledonia Furnace, Franklin County, Pennsylvania. Elsewhere similar acid volcanics have recently been recognized, forming, with the South Mountain volcanics, a belt extending along the eastern border of the United States and Canada.[1]

In Newfoundland, Nova Scotia, New Brunswick, and on the Gaspé peninsula old volcanic rocks, both acid and basic, are extensively developed and have been described by the Canadian surveys. Hitchcock and Shaler report their presence in Maine about Eastport and Mount Desert, along the coast,[2] and on Moosehead Lake, in the interior.[3]

Dr. Wadsworth[4] and Mr. Diller[5] have made the felsites (aporhyolites) of the Boston basin famous.

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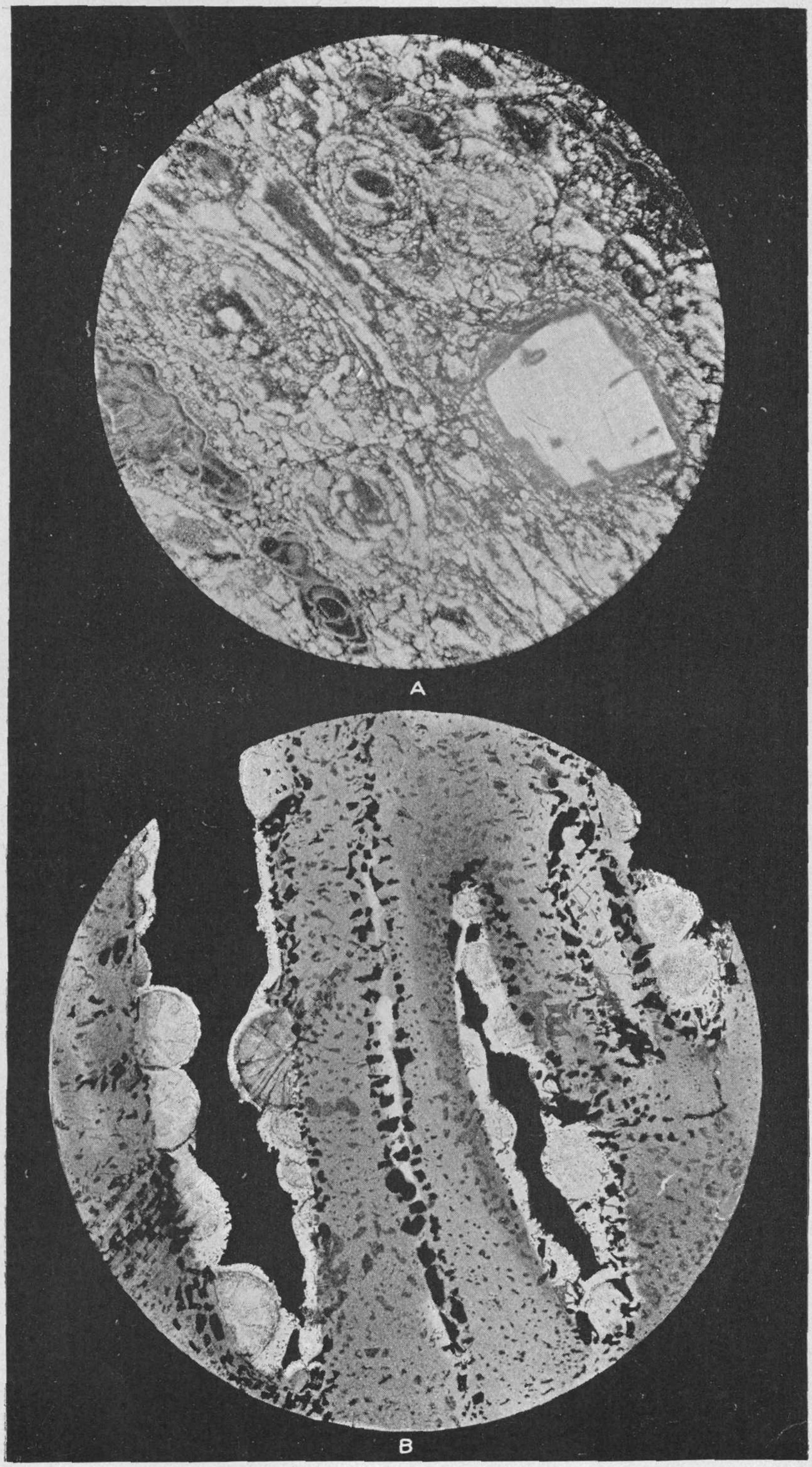
[1] For a full account of these localities see a paper by G. H. Williams, The distribution of ancient volcanic rocks along the eastern border of North America: Jour. Geol., Vol. II, No. 1, pp. 1-31, pl. 1, 1894.

[2] Am. Jour. Sci., 3d series, Vol. XXXII, pp. 40-43, 1886.

[3] Geol. Maine, 1861, p. 190 and 432; also id. 1863, p. 330.

[4] The classification of rocks: Bull. Mus. Com. Zool. Harvard College, Vol. V, p. 282, 1879.

[5] The felsites and their associated rocks north of Boston: Bull. Mus. Comp. Zool., Vol. VII, p. 165, 1881.



THIN SECTIONS OF APORHYOLITE.

A. From Lake Superior, Minnesota, showing perlitic structure

B. From South Mountain, Pennsylvania, showing perlitic, spherulitic, and lithophysal structures.

In Chatham and Orange counties, North Carolina, ancient acid volcanics showing spherulitic and flow structures have been collected by Dr. G. H. Williams, and at Lancaster, South Carolina, devitrified glasses have been found by Prof. S. L. Powell. With continued petrographic study of the pre-Cambrian rocks of America aporhyolites may be recognized at many other points. The similarity of the pre-Cambrian volcanics of the Lake Superior region to their modern equivalents was long ago remarked by Dr. Irving.[1]

In the Kewatin (Lower Huronian) of Minnesota holocrystalline volcanics, showing perlitic parting, spherulitic, and other structures common to aporhyolites, have lately been described by Dr. Grant.[2]

While aporhyolites have only recently been recognized in America, in England such writers as Allport, Cole, Bonney, Rutley, and Harker have long investigated similar rocks as they occur in Scotland, the Lake District, and northern Wales. In Sweden and Belgium they have been recognized and described by Nordenskjold[3] and De La Vallée Poussin.[4]

For a list of English, French, and German papers on this class of rocks see Bulletin 136, United States Geological Survey, pp. 87-91.

No. 137. Granitoid Gneiss.

(From Hoosac Mountain (Tunnel), Massachusetts. Described by J. E. Wolff.)

The three rocks, granitoid gneiss (137), metamorphic conglomerate (128), and albite-schist (129), form an ascending series, with the granitoid gneiss at the base, and in their geologic relations give the key to the structure of the main axis of the Green Mountains in northwestern Massachusetts.[5]

The granitoid gneiss occurs in two areas. The first (from which the specimens are taken) is on Hoosac Mountain, where the rock occupies a long oval area on top of the mountain south of the tunnel line, and is again cut by the tunnel for a distance of several thousand feet at a considerable depth below the surface of the mountain. The second area lies a few miles northwest from the first, forming the crest and slopes of Stamford Mountain, in Vermont, and a part of its southern continuation in Massachusetts, called Clarksburg Mountain. The rock has hence been called the "Stamford granite,"[6] and occupies

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[1] R. D. Irving, Copper-bearing Rocks of the Lake Superior Region: Mon. U. S. Geol. Survey, pp. 312, 313, note 5, p. 436.

[2] U. S. Grant, Volcanic Rocks in the Kewatin of Minnesota: Science, Vol. XXIII, Jan. 12, 1894, p. 17.

[3] Otto Nordenskjold, Ueber archaeische Ergussgesteine aus Smaland: Bull. Geol. Instit. Upsala, No. 2, Vol. I, 1893.

[4] De La Vallée Poussin, Les anciennes rhyolites dites eurites de Grand Manil: Bull. Acad. R. de Belg., 3d series, Tome 10, 1885.

[5] Consult Mon. XXIII, U. S. Geol. Survey, Part II, The Geology of Hoosac Mountain and Adjacent Territory, by J. E. Wolff.

[6] Geology of Vermont, p. 601.

a rounded area several miles in diameter, within which the rock displays considerable lithologic variation. On the outside of the core of this Stamford granitoid gneiss there is a mantle of younger sedimentary rocks, composed principally of quartzite and schist, in which, on the west side, near the summit of Clarksburg Mountain, in Massachusetts, Mr. C. D. Walcott found the remains of Lower Cambrian trilobites.[1] This quartzite mantles around the southern end of the granite and is found again on the east side, where it is partly quartzite, partly mica-schist, so that the mass as a whole has a dome structure, with the granitoid gneiss as a central core. On the east side of this dome, west of the village of Stamford, Vermont, a remarkable contact between the two rocks is found. The quartzite is conglomeratic, and in the granitoid gneiss there is a curious cleft due to the weathering of what was originally a trap dike, some of the material from which is found in the overlying sandstone, whose layers thicken over the cleft and sag down into it, the whole showing plainly the unconformable deposition of the quartzite and the pre-Cambrian age of the granitoid gneiss. The latter rock is finely banded, almost schistose at the contact, but away from this it becomes more and more massive and coarse, with the development of large phenocrysts of feldspar in places. The schistose structure is evidently an effect of crushing (stretching), combined with mineralogical change, which decreases toward the solid core of massive rock, but this change was probably assisted by the previous disintegration of the granitic rock on the old pre-Cambrian land surface.[2]

On Hoosac Mountain the rock occurs in smaller mass and is somewhat more metamorphosed than the rock of the Stamford area. It occurs, however, in the same relation, forming the original Cambrian shore line and overlain by the representative of the Lower Cambrian, here a conglomerate, itself extremely metamorphosed (the metamorphic conglomerate of the collection). It is noticeable here, too, that the gneissic structure is often better developed near the contact, and is then roughly parallel to the banding of the conglomerate.

The second rock, the metamorphic conglomerate (No. 128), typically developed, is found resting on the granitoid gneiss of Hoosac Mountain at the place where the latter rock leaves the surface of the mountain and plunges downward to the tunnel level. The rock forms a bed 600 to 700 feet in actual thickness, very coarse at the base and becoming gradually finer-grained toward the top, where it is succeeded by the albite-schist. The conglomerate outcrops run east and west from the central point in the mountain crest, curving around on each side from an east-and-west trend to a north-and-south one, so that they bound the granitoid gneiss area, and, in fact, completely encircle it. While the conglomerate dips *from* the granitoid gneiss on the north and east sides, it dips *toward* or under it on the west and

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[1] Am. Jour. Sci., 3d series, Vol. XXXV, 1888, p. 236.

[2] R. Pumpelly, The relation of secular rock disintegration to certain transitional crystalline schists: Bull. Geol. Soc. America, Vol. II, pp. 209-224.

southwest sides, so that the structure is that of an anticlinal fold or dome overturned to the west, the axis of which inclines or pitches north, and therefore the formations successively leave the surface along the crest of the mountain and plunge northward and downward to the tunnel level. The conglomerate, therefore, having been folded over the granitoid gneiss with overturning on the west side, we find that the rock has lost nearly all traces of its original character on the sides of the fold where the motion or stretching action was greatest, but that this is better preserved on the axis or center of the arch, where the northerly pitch of the axis gives us the series in normal position.

The conglomerate specimens are also taken from the dumps of the central shaft of the tunnel, which cuts the rock 1,000 feet below the surface. They show conglomeratic character plainly, while the same rock found at the surface on the sides of the fold loses its character as a conglomerate and becomes a gneiss.

The third rock, the albite-schist (No. 129), overlies the conglomerate conformably on the crest of the mountain, exposing a thickness of at least 1,000 feet, and mantles over the conglomerate on the east and west sides, as the upper layer of the fold. The basal layer, 50 feet or more thick, is very rich in garnet crystals, suggesting an original calcareous rock, and as the conglomerate represents the Cambrian quartzite, this overlying schist must represent the Stockbridge limestone and associated schists (Cambro-Silurian) which lie in the Hoosac valley and mountain mass of Greylock to the west of Hoosac Mountain, so that there is some basis for this explanation of the presence of the lime-silicate (garnet) in such abundance.

The albite-schist is cut by the tunnel on both sides of the anticlinal axis, and the specimens are therefore taken from the dumps of the central shaft, which is a great storehouse for specimens of the various modifications of the three rocks, in an ideally fresh condition.

With this brief description of the geological occurrence of these specimens, we may proceed to their individual description.

In the hand specimen the granitoid-gneiss contains large elongated masses of pale-reddish feldpar, separated by thinner bands of white or bluish granular quartz, in the middle of which there are often larger grains of homogeneous blue quartz. Thin, dark-green, branching bands of mica and epidote traverse the specimen in rough parallelism to the quartz-feldspar bands, while within the quartz or feldspar masses little patches of the same green color are found. A broad, flat cleavage face of feldspar is often distinctly curved, or may be broken up into several pieces which do not reflect the light simultaneously, and have therefore been moved from their original position in one plane. When we remember that the more massive rock, as found in the center of the great Stamford core, has the same large feldspars in well-formed crystals, the blue quartz in large grains, and but little banding or development of thin mica bands, we can understand that the present structure is due to pressure, which strained and broke up the minerals, the granulated minerals moving a little over each other, and in the interstices thus formed, or along the larger planes of motion, the mica, epidote, etc., developing to form the little secondary bands. In this way, by dynamic metamorphism, a coarse banded rock has been produced from a coarse massive rock.

In the thin section these mechanical and mineralogical changes can be studied more in detail. Many of the large feldspar areas are recognized as microcline by the fine double twinning (albite and pericline laws), while others which show no twinning are partly orthoclase, partly microcline, which the section cuts parallel to the second cleavage ($\infty P \breve{\infty}$). In some cases the large feldspars contain narrow, spindle-shaped masses of another feldspar, in parallel growth (microperthite). Other feldspar areas with but a single polysynthetic twinning are probably albite (primary). These large crystals are crossed by little vein-like aggregates composed of rounded grains of quartz, little irregular grains of fresh, clean microcline, other grains of feldspar with a clear, even, polarizing tint, with often two straight parallel sides and a twinning line parallel to them which divides the crystal into two halves, all these properties being identical with those of the albites of the conglomerate and schist, so that it is probably the same feldspar in the case of the granitoid gneiss. In addition to these, the veinlets contain little grains of epidote and plates of biotite and muscovite. They may run irregularly or be roughly parallel in direction to the general banding of the rock. It often happens that the large feldspar is broken into several minor pieces, which are separated along the lines of break, or of micro-faulting by an aggregate of these minerals, whose later origin, after pressure and motion had acted, is thus evident.

In the same way the larger masses of original quartz are identified by their large size and by the fact that they are surrounded by a zone of aggregate quartz broken off from the parent mass, which, in polarized light, is seen to be itself strained or cracked. This original quartz is moreover free from inclusions of any of the secondary minerals, unless in cracks, while the metamorphic quartz of the little veinlets which penetrate the feldspar, and of the banded aggregates between the feldspar, frequently inclose biotite, showing the contemporaneous origin of the two minerals, and that the larger masses of original quartz existed before the period of the biotite formation.

The rest of the slide is composed of an aggregate of the following minerals:

(1) Feldspar, in little imperfect crystals, which are often simple twins according to the albite law and are probably albite.[1] These are either clear or are filled with little plates of mica, grains of epidote, and droplets of quartz. There are also irregular grains of microcline, in part

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[1] Their refractive index is usually lower than that of the balsam of the section, or barely equal to it. Obliquity of extinction in the zone of the twinning axis is too high for oligoclase, i. e., albite.

broken off from the large primary crystals, in part probably metamorphic. (2) Quartz in interlocking aggregates or isolated grains. (3) Biotite and greenish muscovite in irregular stringers, inclosing in their meshes little prisms or grains of yellow epidote with high polarizing colors, occasional grains of black opaque magnetite, white grains or aggregate masses of titanite, and some areas of white calcite, recognized by its rhombohedral cleavage and white polarization. There are occasional small prisms of zircon with terminal planes and with distinct uniaxial positive character.

This aggregate of minerals often invades the large original masses of feldspar, but it will be noticed that none of these minerals show signs of straining or breaking, and that the little albitic feldspars inclose epidote, quartz, and mica. Reasoning from this, we infer that they formed after or during the action of the forces which strained and broke the original feldspars and quartz, and under conditions of contemporaneous crystallization, unlike those of eruptive rocks, where there is generally a certain succession in the formation of the different minerals—some earlier, some later.

The original rock was a coarse, massive, granitic rock, perhaps of eruptive origin, and resembling the coarse granite of Finland, called rapakiwi, while dynamic metamorphism has produced the present gneissic condition, the mineralogical change consisting essentially in the production of new feldspar, mica, quartz, and epidote.

NO. 138. EPIDOTE-MICA-GNEISS.

(FROM LEBANON, GRAFTON COUNTY, NEW HAMPSHIRE. DESCRIBED BY J. P. IDDINGS.)

This gneiss from Lebanon, New Hampshire, was supposed to be so-called protogene-gneiss, the characteristic minerals of which are "chlorite, talc, rotten mica, or other decomposition products," according to Hawes.[1]

It is in fact an epidote-mica-gneiss, according to present classification. It consists of relatively large, irregular crystals of microcline, with small grains of quartz in aggregates equaling the feldspar in bulk, besides brown biotite in aggregates of small plates, variable amounts of colorless muscovite, and much epidote in aggregations of microscopic crystals. Subordinate minerals, occurring in relatively small amounts, are apatite, tourmaline, allanite, zircon, possibly sphene, and occasionally green mica or chlorite and, rarely, calcite. The rock is quite fresh and undecomposed, judging from the condition of the brown biotite. The epidote is grouped in aggregations with quartz and sometimes with muscovite, or is scattered in various-sized crystals and grains through the microcline, but there are no remains or other evidence

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[1] G. W. Hawes: Mineralogy and Lithology of New Hampshire, Part IV, of Geology of New Hampshire. Concord, 1878, p. 201.

of any ferromagnesian mineral, more or less altered, from which it could have been in part derived. It appears as a primary constituent.

The microcline exhibits microscopic multiple twinning with grating structure, and the fibration due to an intergrowth of plagioclase, or microperthite structure. In certain sections the microcline twinning is scarcely recognizable. There is, besides, a simple Carlsbad twinning. Smaller feldspars occur mixed with the quartz. The feldspars are clouded to a greater or less extent by minute crystals of epidote, and sometimes of muscovite. The minerals are in some cases arranged in several directions in a feldspar, the substance of the feldspar being otherwise quite pure. Micropegmatitic intergrowth of quartz and feldspar is occasionally noticed. In some feldspars there are innumerable minute rectangular inclusions with a bubble of gas in each, presumably fluid inclusions of secondary origin. Microscopic grains of quartz with rounded outline are abundant in certain feldspars, the quartz being more numerous in the marginal part of the feldspar.

Quartz forms irregular grains, somewhat rounded in outline, often very free from inclusions or impurities, sometimes bearing numerous minute crystals of epidote, and less often those of biotite and muscovite. Fluid inclusions are not common.

Biotite forms small stout plates, set at all angles, without approach to parallelism. Its color is dark brown with a tinge of green. The absorption is strong, and the substance of the mineral quite pure. In a few cases it is altered to a green mica, and in some cases chlorite. Muscovite is almost absolutely colorless in thin section, with slight absorption of light for rays vibrating parallel to the cleavage of the mica. It is sometimes inclosed by biotite. Both micas are in places intergrown, or include one another, together with grains of quartz and epidote. Inclusions of apatite and zircon are scarce.

Epidote forms yellowish crystals or grains with faint pleochroism. Its high index of refraction and strong double refraction are characteristic. Occasionally the center of a crystal is chestnut-brown and pleochroic, and is probably allanite. It is closely associated with muscovite in some places, in others is independent of it. Its size sinks to the minutest microscopic dimensions. It might be assumed to be an alteration product, as it often is, were it not for the fact that no partially decomposed calcium-iron mineral is to be found in the rock.

Apatite is scarce, in colorless, irregular grains. Zircon is also scarce, and forms very small grains.

Tourmaline occurs sparingly in short prisms, with a purplish-brown color in thin section, and exhibits complete absorption of the ordinary ray. Several grains of calcite were noted in one section, and in another an irregular grain supposed to be sphene. Chlorite is present in only a few instances, when it exhibits a strong green color and marked pleochroism. It is evidently an alteration product derived directly from biotite. Magnetite is entirely absent.

It is possible that this rock may be the same as, or similar to, that mentioned by Hawes, in the report already referred to, as occurring at Walling's quarry, which contains epidote.

NO. 139. DIABASE AMYGDALOID.

(FROM GRAND MARAIS, COOK COUNTY, MINNESOTA. DESCRIBED BY W. S. BAYLEY.)

This rock forms one of the many flat-lying sheets that, together with conglomerates and other fragmental layers, make up the Keweenawan[1] or copper-bearing series of the Lake Superior region. On the north shore of the lake the eruptive beds of the series come down to the water's edge, forming cliffs, in whose sides several distinct layers may often be seen. Some of the beds are dense throughout; others, and among them the bed from which the specimen was taken, are completely crystalline and moderately coarse grained toward their centers, and finer grained and vesicular at both the upper and the lower contacts.

The vesicles in modern lavas are known to be due to the expansion of water contained in the molten rock magma. As long as this remains in the interior of the earth the pressure there existing retains the water in a liquid condition. When the magma escapes to the surface, where the pressure is much less, the superheated water flashes into steam, which in attempting to escape produces bubbles in the liquid mass, just as bubbles are produced in boiling water. If the rock solidifies quickly at top and bottom some of the bubbles are caught, the steam escapes from them, and a vacuole results. If the vacuole is afterwards filled by material deposited from waters circulating through the rock, amygdules are formed, and the rock becomes an amygdaloid. The vesicles in old lavas are undoubtedly due to the same causes as give rise to the vacuoles of modern volcanic rocks. Hence, when a sheet of eruptive material is found with vesicles near its upper surface, and especially when these are found near its lower surface as well, we conclude that the sheet was a surface flow, like the lava sheets of modern volcanoes.

The specimen was taken from near the upper surface of a flow or sheet that reaches the water's edge 1½ miles east of Grand Marais, on the north shore of Lake Superior.

An inspection of the hand specimen shows it to be a very fine-grained purple rock, without any evidences of stratification or foliation. In it are a large number of vacuoles. In a few of the specimens these are arranged with their long axes approximately parallel, but in most no such regular arrangement is apparent. In the former case the regularity is due to the fact that movement continued in the pasty rock magma even after it had become viscous enough to prevent the escape of the bubbles. These were consequently drawn out in the direction of the motion.

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[1] For characterization of the Keweenawan, see Irving and Chamberlin; Bull. U. S. Geol. Survey No. 23, and R. D. Irving, Copper-bearing Rocks of Lake Superior, Mon. U. S. Geol. Survey, Vol. V.

Some of the vacuoles are entirely empty. Others have their walls covered with a thin coating of a fibrous pink mineral, while others again are almost filled with larger needles of the same substance. A few are lined with a pistachio-green material resembling epidote, while still others have their sides lined with a layer of the green mineral under a coating of the pink substance. It is evident that the green mineral is older than the pink one, since the latter could not have been deposited upon the former until this had already existed. In a few of the vesicles a third substance may be seen. It is a soft, colorless, or white, easily cleavable material that effervesces strongly when moistened with cold hydrochloric acid. This mineral, which is evidently calcite, is younger than the pink mineral, since it occupies the central portions of the vesicles and is surrounded by the latter, which is present in little bundles of radiating needles, whose hardness is low. The needles easily dissolve in hydrochloric acid, yielding gelatinous silica, and give up water in the closed tube. Though no complete chemical analysis of them has been made, there is but little doubt that they are laumontite.

When placed under the microscope the mass of the rock is found to consist largely of small microlites of a twinned feldspar and a dark-brown interstitial substance or groundmass. The feldspar is often clouded with decomposition products and is reddened by stains of iron salts. It occurs usually in skeleton crystals with forked ends in place of crystal terminations, and in cross section it frequently appears as a hollow shell including portions of the brown groundmass. The microlites extinguish at low angles as measured against their long axes, and consequently are composed of a substance near oligoclase in composition. The highest extinction to be noted is about 16°, while many of the tiny crystals extinguish nearly parallel. The microlites are scattered irregularly through the section, except in those parts near the vacuoles, where they are absent.

The interstitial substance or groundmass is opaque in most parts of the section and particularly so immediately around the vesicles. On the edges of the section, where it is thinnest, it is seen to be composed of many very slender feldspar needles aggregated into little radiating bunches or into sheaf-like forms. Between these is a dark matrix consisting of a nonpolarizing substance—originally glass—darkened by little round grains and irregular masses of magnetite, hematite, or brown iron oxides. In other places this matrix is comparatively clear, when it exerts a feeble influence on polarized light, as if the glass of which it was composed had begun to differentiate into mineral species, whose nature, however, can not be determined because of the abundance of the iron compounds mingled with them. In the vicinity of the walls of the amygdaloidal cavities there is an absence of the larger feldspar microlites, as has already been stated. Under the higher powers small feldspathic microlites may be detected in these portions of the groundmass, but otherwise no special features are to be noticed in it.

The general characteristics of the amygdaloid are those of a much decomposed glassy rock with feldspathic microlites. Its structure resembles that of a glassy diabase or basalt. Upon comparison with sections made from various portions of similar vesicular flows from other horizons in the Keweenawan, it is found that the rock under investigation resembles very strikingly the fine-grained portions of those beds which in their interior have the composition and structure of typical diabase. Its fine grain and the microlitic character of its feldspars are due to the rapid cooling of the rock mass. The lack of the larger microlites in the neighborhood of the vacuoles is due to the fact that in those places comparatively large surfaces of the rock mass were exposed to cooling which there went on more rapidly than elsewhere, so that the time before the final solidification of the rock was not sufficiently long to enable the crystals to grow to the size reached by those in other portions of its mass.

Not much can be learned from the section regarding the filling of the cavities. In most cases the softer materials contained in them are removed in the grinding. Along the walls may sometimes be seen adhering a small amount of a colorless mineral with a low double refraction. It occurs in little aggregates resembling very closely the quartz mosaics of certain quartz porphyries.

Other smaller cavities may be distinguished from the true vesicles by the fact that their sides are ragged and not smooth. The filling, a dirty green substance having very little effect on polarized light, extends far back between the microlites of the rock; and that portion of the rock mass immediately contiguous to them is not more compact than the portions away from them. These two facts taken together indicate that the cavities have an origin different from that of the larger vesicles. The irregular penetration of the filling mass into the rock material indicates that the boundary between the two has encroached on the material of the rock. Since the feldspar microlites project into the greenish substance filling the cavities, it is evident that the interstitial groundmass yielded more rapidly than the feldspathic material. These cavities are consequently not true amygdaloidal ones, but they resemble these in that both are often filled with the same minerals. They are supposed to be secondary in origin, i. e., to have been formed by the decomposition of the groundmass of the rock containing them, and are distinguished from true amygdules by the designation pseudamygdules.

No analysis of the rock is given, because it is so much decomposed and so full of secondary products that very little regarding its original composition would be learned from it.[1]

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[1] For descriptions of similar amygdaloids from the Lake Superior region see R. Pumpelly: Proc. Am. Acad. Adv. Sci., 1878, XII, p. 282; and R. D. Irving, Copper-bearing rocks of Lake Superior, Mon. U. S. Geological Survey, Vol, V, Washington, 1884, pp. 87-91.

No. 140. QUARTZ-NORITE-GNEISS.

(FROM ODESSA, BIGSTONE COUNTY, MINNESOTA. DESCRIBED BY W. S. BAYLEY.)

In the valley of the Minnesota River, in Minnesota, there exists an area of crystalline schistose rocks a few miles wide and extending with very many interruptions from New Ulm in a northwesterly direction to the southeastern end of Big Stone Lake. Among the rocks occurring in this area are interbedded gneisses, crystalline schists, and other foliated rocks that may be regarded as squeezed eruptives. They are all thought to be pre-Algonkian in age, though so far as known no proofs of the correctness of this view have as yet been recorded.

The specimen described in this article was taken from a small outcrop 1,200 paces north and 1,500 west of southeast corner, sec. 9, T. 120 N., R. 45 W., near Odessa, Minnesota.[1]

In the field the rock appears to be quite schistose, with a strike about northeast and a dip of about 45° to the northwest. According to Prof. C. W. Hall, of the University of Minnesota, who collected the specimen, the outcrop is isolated, being separated from all others by a distance of some two or three hundred paces. Consequently its relations to the other rocks in the vicinity can not be made out.

Very little can be learned from an inspection of the hand specimen. From the ease with which thin slabs may be broken from it we are justified in supposing it to be schistose, and this supposition is rendered certain by an examination of the specimen with a lens, especially on slightly weathered surfaces, where black acicular particles may be seen with their long axes lying in the plane along which the rock breaks most easily.

We may, then, describe the rock as a very dark-gray crystalline aggregate with an obscure schistose structure and a sugary texture. Its grain is so fine that but one of its constituents may be recognized with any degree of certainty. This is a black mineral with a tinge of brown. It is easily cleavable, and it glistens brilliantly from its cleavage surfaces. A flake of this mineral sprung from the specimen with the point of a penknife and placed under the microscope is found to have a nearly uniaxial interference figure, which, with the other properties above mentioned, indicates a biotite. In addition to this there can also be detected a granular white mineral, whose particles are so small that their nature can not be determined. The specific gravity of the rock is 2.770.

In thin section, the character of the rock becomes very apparent. It consists essentially of quartz, plagioclase, and a pyroxene, with biotite, garnet, pyrite, and magnetite as accessory constituents.

In natural light there appears an apparently homogeneous colorless groundmass, in which lie large, irregular grains of a very highly refractive, almost colorless, mineral with well-marked cleavages, smaller dark-

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[1] See Map, Pl. 29, in The Geology of Minnesota, Vol. I of final report, Minneapolis, 1884, p. 614.

brown flakes, small irregular or rounded grains of an opaque substance, and occasionally isolated highly refractive grains of a very light pinkish tinge, or aggregates of these. When examined with a low power, a certain parallelism may be detected in the arrangement of the various minerals (see Pl. XLV, *A*), though this is not so well marked as in the case of the mica-schist from the Black Hills (Pl. XLII). The schistosity of this rock is beautifully shown in the photograph, where the pyroxene and biotite grains, and to a less marked degree the plagioclase grains as well, have their long axes running in the same direction. The light-colored substance without cleavage cracks is quartz, that containing dark inclusions is plagioclase, and the dark inclusions are its decomposition products; the dark-gray grains with heavy cleavage lines are pyroxene, and the darker fibrous masses on the edges of these are biotite. In the upper right-hand corner is a large flake of the last-named mineral, and on the right-hand side of the center of the picture is a grain of magnetite. The supposition grounded upon the macroscopic examination of the hand specimen, viz, that the rock is schistose, is found to be correct, as is also the implied conclusion that the schistosity is not well marked.

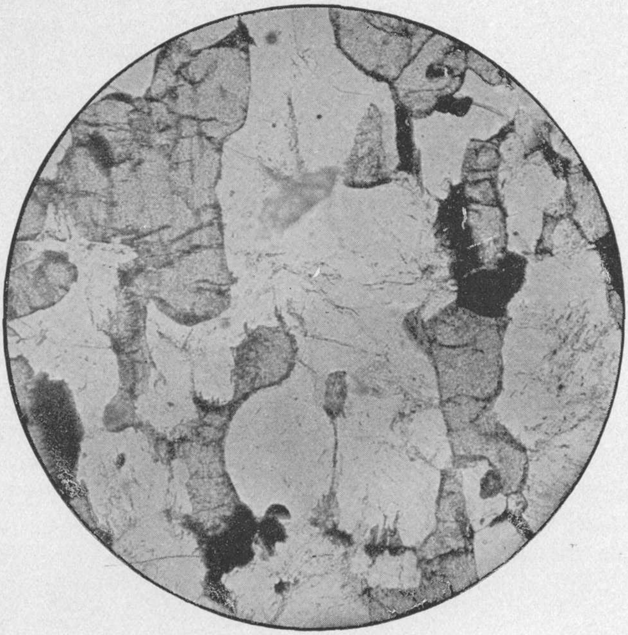
When examined under crossed nicols the apparently homogeneous groundmass breaks up into an aggregate composed of very irregularly shaped interlocking grains of quartz and feldspar. Both are perfectly pellucid in natural light and both contain the same kinds of inclusions. They may be distinguished from each other by the brighter polarization colors of the quartz and the twinning striations of the feldspar. From the intricate manner in which they interlock it is impossible to determine which is the older. Both include small particles of all the other components, and therefore they must be younger than these. They contain, also, tiny liquid inclusions, a few with movable bubbles, large quantities of black, red, and green dust, and irregularly outlined green and reddish inclosures that appear to be either decomposition products of some substance whose nature can no longer be determined or secondary infiltration products. The latter supposition seems to be more plausible, since the character of the inclusions is so varied, while at the same time they are undoubtedly such as are produced by secondary agencies.

The twinning bars of the plagioclase are usually parallel, but sometimes they appear in two series, crossing each other at nearly right angles. The maximum symmetrical extinction of two contiguous lamellæ, measured against their line of contact, is about 26°, indicating a plagioclase somewhere in the labradorite series. The specific gravity of the mineral is 2.673. In any given position of the section between the nicols in most grains only one portion of the lamellæ of any series is dark, the other ends of the same lamellæ remaining bright. As the section is revolved the dark portions become bright, the dark zone gradually moving toward what were the bright ends in the first position. This gradual movement of the dark portion of the field from one part of a mineral to another is known as undulatory extinction. It is supposed in most cases to be due to a strain under which the mineral exhibiting it exists. Its occurrence in the present instance is probably evidence that the rock was produced by pressure from some previously existing rock of a somewhat similar character.

The irregular, highly refractive grains have a slight pleochroism in pale greenish and pinkish tints, the latter, when the most prominent of the two cleavages, being perpendicular to the vibration plane of the lower nicol. The extinction is parallel to the cleavage where only one set of cleavage lines is observed, and on sections on which two cleavages are seen it bisects the angle between these. The axis of elasticity parallel to the single cleavage is smaller than the one at right angles to this, and the double refraction is not great. The polarization colors are consequently not brilliant. Since the long axes of nearly all the grains run in about the same direction, which is parallel to the plane of schistosity of the rock, and the sections are made parallel to this plane, it is not surprising that so few basal sections of the mineral can be found. In the one or two that may be discovered in each section there are two series of cleavage lines, which make with each other angles of about 88° and 92°. No inclined extinctions are to be seen in any sections where only one set of cleavage lines appears.

The mineral, which is an orthorhombic pyroxene, is usually quite fresh and free from inclusions. In sections cut from weathered portions of the rock, however, an interesting alteration is observed to be in progress. The cleavage cracks of the pyroxene are filled with a brown, pleochroic substance without definite morphological characteristics. This brown substance gradually spreads into the surrounding augite, replacing it in part, so that often what at one end is a perfectly fresh, almost colorless, pyroxene is at the other end a mass of brown, pleochroic substance. As the amount of the brown substance increases, its characteristics become more pronounced, until finally it takes the form of biotite. This biotite often lies embedded in augite, often it borders large grains of this mineral, and sometimes it occurs in the spaces between neighboring grains. There can be no doubt that this biotite is an alteration product of the pyroxene.

The greater portion of the biotite in the section is in isolated grains between the colorless constituents, quartz and plagioclase. The long axes of its grains are nearly always approximately parallel to the long axes of the pyroxene. The mineral is dark brown, almost opaque, in the direction of its single cleavage, and is a brownish yellow at right angles to this. The pleochroic halos observed in the micas of other rocks are found also in these, but their pleochroism is not very marked. It is, of course, impossible to state positively that this biotite has the same origin as that found in and near the pyroxene, but since it has



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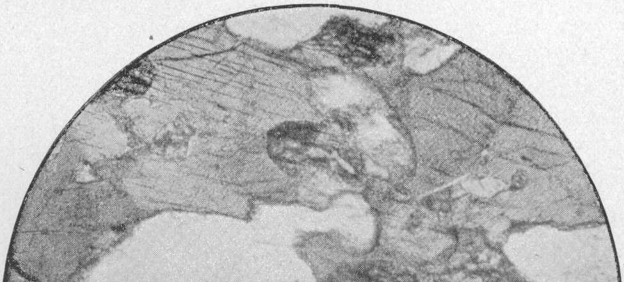

B

THIN SECTIONS.

A. Quartz-norite-gneiss from Odessa, Minnesota.
B. Hornblende-gabbro-gneiss from Minnesota Falls, Minnesota.

exactly the same properties as the secondary mica, we may infer that it is probably of the same origin.[1]

The only constituents remaining to be described are the garnets, pyrite, and magnetite. The first mentioned are in almost colorless, very highly refractive grains, without cleavage and without inclusions. They are irregular in cross section, but approximate more or less closely to circles. They may be easily distinguished from all other constituents, since they are perfectly isotropic between crossed nicols. The large grains are traversed by irregular fracture lines, distinguishable from cleavage cracks by their lack of parallelism. The garnets are found frequently as inclusions in quartz and feldspar, or in the interstices between these. They are evidently among the earliest formed of the rock's components, as the contours of all the others, except pyroxene, where they touch the peripheries of the garnet are molded by them. The pyroxene is regarded as older than the garnet, for the reason that the contours of the garnet depend somewhat upon those of the pyroxene for their shape.

The pyrite and magnetite are both irregular, opaque grains that may be distinguished from one another by the brassy luster of the former in reflected light and the bluish-black luster of the latter.

In an attempt to name the rock we are met with the difficulty always experienced in discussing the classification of schistose rocks. No systematic scheme for their classification has yet been proposed. It would seem best to confine the term schists to foliated aggregates of quartz and some bisilicate without feldspar, and the term gneisses to schistose aggregates of feldspar and some bisilicate with or without quartz. According to this distinction our rock is a gneiss, since it consists essentially of plagioclase and pyroxene; i. e., it is a schistose rock with the composition of quartz-norite. Roth[2] calls such rocks "zobtenites," while Dathe calls them "flaser-gabbros."[3] Gordon[4] suggests that when the origin of a gneiss is known it receive a compound name, the first term of which shall designate the original rock from which the gneiss was derived, so that as much knowledge as possible concerning the rock may be comprehended in its name. If we accept this suggestion the name of our rock should be quartz-norite-gneiss. Professor Hall, who has made a careful study of the rock in the field, thinks there can be no doubt that it was once a typical member of the gabbro family. The microscopic examination confirms his opinion. It shows the rock to be a very slightly altered quartz-norite that has undergone pressure sufficient to render it schistose.

Norite-gneisses are exceedingly rare, as are also gabbro-gneisses in

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[1] Cf. M. E. Wadsworth, Bull. No. 2, Geol. Survey Minn., p. 65. For literature on alteration of augite to biotite, see W. S. Bayley, Bull. U. S. Geol. Survey, No. 109, p. 41.

[2] Allgemeine und Chemische Geologie, Bd. II, p. 484.

[3] Zeits d. deutsch geol. Gesell, 1877, p. 327.

[4] Bull. Geol. Soc. America, vol. 7, 1895, p. 122.

which the pyroxene and plagioclase are perfectly fresh,[1] for the pressure that so squeezes a massive rock as to flatten its constituent grains produces a condition of affairs very favorable to the alteration of pyroxene into hornblende. In the present case alteration has been effected in the rock, but the change has been from pyroxene into biotite.[2] Schistose gabbros in which hornblende exists in large quantities have been described in a number of foreign publications, and in several published in this country.[3]

An analysis of the rock, as reported by H. N. Stokes, is here given:

Analysis of quartz-norite-gneiss from Odessa, Minnesota.

	Per cent.
SiO_2	61.04
Al_2O_3	16.97
Fe_2O_3	5.58
FeO	....
CaO	5.99
MgO	3.62
K_2O	.55
Na_2O	1.96
Ign	.43
FeS_2	3.73
Total	99.87

The 1.96 per cent of Na_2O corresponds to about 34 per cent of labradorite among the rock's constituents. After making allowance for the amount of SiO_2 required by the pyroxene, biotite, and garnet, there remains over about 20 per cent of the oxide, which must be regarded as existing in the rock as quartz.[4]

No. 141. GARNETIFEROUS HORNBLENDE SCHIST.

(FROM HANOVER, GRAFTON COUNTY, NEW HAMPSHIRE. DESCRIBED BY W. S. BAYLEY.)

The specimens of this rock were collected at Hanover, Grafton County, New Hampshire, where it was originally thought by Professor Hitchcock[5] to belong with the Lisbon group of schists. In a later paper, however, the same author is inclined to regard it as igneous,

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[1] For descriptions of hornblende free gabbroitic gneisses, see accounts of augite-schists, by Wichmann, Geology of Wisconsin, Vol. III, 1880, p. 645; and R. D. Irving, ib., Vol. IV, pp. 669 and 694–696; and Fifth Annual Report U. S. Geol. Survey, 1885, p. 211.

[2] See G. H. Williams, Bull. U. S. Geol. Survey No. 62, for discussion of effect of pressure upon the minerals of the massive rocks.

[3] Cf. G. H. Williams, Bull. U. S. Geol. Survey No. 28, and description of specimens Nos. 109 and 143 in this bulletin.

[4] This rock will be further described in a paper now in preparation by C. W. Hall, designed for publication as a bulletin of the United States Geological Survey.

[5] C. H. Hitchcock, Geology of the Connecticut Valley District: Geol. of New Hampshire, Vol. II, p. 363. Concord, 1877.

since it occurs in "bunches, varying in size from a peck measure to a mass 10 miles long. . . . On the northwest side of the principal range, the schist comes successively in contact with mica-schist, hydromica-schist, argillite, and chlorite-schist, all of which have been altered through heat into vitrified and indurated rocks, usually richer in silica than when unaltered. On the southeast side the adjacent rock is invariably mica-schist, somewhat indurated. . . . The present attitude of the igneous hornblende is like that of the modern laccolite where the cap has been worn away."[1]

All specimens of the rock are schistose, and some are banded with alternating, narrow, dark and light bands. The rock as a whole has a dark greenish-gray color, which is produced by large numbers of slender black needles of hornblende embedded in a fine-grained white or gray matrix. The bands of the banded specimens are portions of the rock in which these two substances alternately predominate. In the thicker of the lighter layers the white material is quartz, that seems to have been introduced along joint cracks in the rock.[2]

Besides hornblende and quartz, two other minerals are observable in the hand specimens—garnet and biotite. The former appears as little dark-red dodecahedral crystals, and the latter as dark bronzy plates with a very brilliant luster. The mica plates and the hornblende needles are arranged with their longer axes approximately parallel to the banding of the rock, thus accounting for the schistosity in this direction.

Under the microscope the rock is discovered to be composed of numerous green hornblende prisms and large plates of brown biotite, crystals of garnet, and grains of magnetite, in a colorless matrix which between crossed nicols is resolved into an aggregate of quartz and plagioclase.

The hornblende is usually elongated parallel to the c axis. Occasionally a cross section with the characteristic prismatic cleavage is observed, but not frequently. While the majority of the prisms are arranged with their longer directions approximately parallel, many of the larger crystals lie in a direction inclined to this, thus interfering with the perfection of the rock's schistosity. The hornblende is strongly pleochroic, as follows: $\mathfrak{c}$, bluish green; $\mathfrak{b}$, yellowish green; $\mathfrak{a}$, yellow. Its cleavage is fairly well marked parallel to the longer axes of the prisms. In addition to this there is a parting, nearly at right angles to the cleavage.

The biotite is not found in all sections, though it occurs in greater or less quantity in most of them. It is in large flakes with a distinct cleavage and a reddish-brown and yellow pleochroism. The extinction is nearly zero. The biotite is evidently one of the latest formed of the rock's components. It not only incloses needles of hornblende and

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[1] Bull. Geol. Soc. America, Vol. VII, p. 511.

[2] Cf. C. R. Van Hise. Principles of North American Pre-Cambrian Geology: Sixteenth Ann. Rept. U. S. Geol. Survey, pp. 662–664, 666, 667.

grains of plagioclase and quartz, but its plates occur mainly in the spaces between neighboring hornblendes.

The garnets appear in thin section as light pink, perfectly isotropic bodies, that include a few grains of quartz and some magnetite. Though completely idiomorphic, they were plainly formed after the hornblende and the biotite, as may be seen by the examination of their contacts with these minerals.

The magnetite occurs as small irregular masses and grains scattered through the colorless groundmass and as comparatively large crystals with an octahedral habit. A noticeable feature in connection with the crystals is the presence around them of a zone free from hornblende and biotite. The iron that is necessary to the production of these latter minerals appears to have been appropriated by the magnetite in the manufacture of its crystals.

The matrix in which these constituents lie is a hypidiomorphic granular aggregate of triclinic feldspar and quartz. The latter mineral is the more abundant. It occurs in irregular grains of a larger size than the feldspar grains. The quartz grains are usually simple Occasionally they are complex, a single one sometimes breaking up between crossed nicols into a number of differently oriented parts. Very rarely a grain exhibits the undulatory extinction. Usually the quartz is water clear and is free from inclusions. In some sections, however, a few grains include small groups of colorless prismatic crystals that resemble a zeolite. The strong polarization of the quartz in which they are embedded has prevented the accurate determination of their nature.

The feldspar of the matrix is mainly plagioclase; a few grains resemble microcline. The feldspars, like the quartz, are in irregular grains which show little or no effects of pressure. The majority of the grains are crossed by parallel twinning bars with a symmetrical extinction of from 18° to 22° against their line of junction. These are probably andesine or labradorite. In the darker bands, where hornblende is abundant, the plagioclase contains few if any inclusions; but in some portions of the lighter bands, where the plagioclase is most abundant, the grains are full of inclusions of hornblende, biotite, and magnetite. The microcline is represented by a few grains only. They are distinguished from the plagioclase grains by the two series of twinning bars crossing each other at nearly right angles.

The study of the thin sections throws but little light on the problem of the origin of the schist. The garnets, the biotite, and the hornblende are probably secondary, i. e., they are not original secretions from a molten magma. Whether the components of the matrix are also secondary or not can not be told. It is impossible to discover, therefore, from a study of the specimens in the collection, whether the rock from which the schist was derived was originally a quartz-diorite a diabase or a gabbro. From its mineralogical composition it may quite safely be inferred that it was originally one of these three types. A chemical analysis of a series of carefully selected specimens of the rock would probably show that it was originally igneous, and it might determine the type of igneous rock to which it belonged, for Adams[1] has shown that in all probability sedimentary and igneous schists may by this means be distinguished from each other, and Rosenbusch[2] has proved that a massive rock in its change to a schist suffers little chemical change. Whatever may have been the original nature of the rock it is now a hornblende-schist, since it consists largely of hornblende and quartz. The structure of the rock from which it was derived has been completely lost in the changes which it has suffered in passing to its present condition.

NO. 142. STEATITE, OR SOAPSTONE.

(FROM FRANCESTOWN, HILLSBORO COUNTY, NEW HAMPSHIRE. DESCRIBED BY W. S. BAYLEY.)

Specimens No. 142 is from the quarries of the Francestown Soapstone Company, at Francestown, New Hampshire. The rock has been quarried at this place since 1802. It is used largely for the manufacture of stoves, the refuse and waste being sold for packing material. The soapstone is said to occur as a bed in ferruginous and micaceous schists belonging to the Merrimac group of sediments, which is placed by Hitchcock[3] in the Paleozoic.

"The peculiarity of the stone," writes Hitchcock,[4] "consists in the uniform distribution through it of spherical radiated aggregations of crystalline plates of talc. These make the stone uniformly strong in all directions." The rock in thin sections appears to be a fibrous mass, and where the fibers do not overlie one another so as to interfere they are dark when parallel to the plane of vibration of the light.[5]

The specimens in the collection are sawn slabs, consequently their surfaces do not present the characteristic appearance of the rock as seen in nature. On a fresh fracture, such as may be obtained by breaking off an edge of the block, the rock exhibits an irregular aggregate of silvery gray plates, which here and there are grouped into the little spherical masses referred to by Hitchcock. Occasionally a small grain of a dark metallic mineral, pyrrhotite, may be detected among the talc plates, but no other constituents are observable. So far as can be seen the rock is massive. There is no evidence of foliation in it.

In thin sections the following components are noticed in addition to those mentioned above: chlorite, calcite, biotite, magnetite, quartz,

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[1] F. D. Adams: Am. Jour. Sci., 3d series, Vol. L, 1895, pp. 58-69.

[2] H. Rosenbusch: Zur Auffasung der chemischen Natur des Grundgebirges, Tschermak's Min. und Petrog. Mitth., XII, p. 49.

[3] C. H. Hitchcock, Geology of the Merrimac District, East Part: Geology of New Hampshire, Vol. II, Chap. VI, pp. 588-591, Concord, 1877.

[4] C. H. Hitchcock, Economic Geology, Pt. V: Geology of New Hampshire, Vol. III, p. 87.

[5] G. W. Hawes, Mineralogy and Lithology, Pt. IV: Geology of New Hampshire, Vol. III, p. 113. Concord, 1878.

limonite, and rutile. The rutile and limonite are present in very small quantity, the former as tiny irregular grains and the latter as little crystals disseminated throughout the chlorite and talc. The magnetite is also in irregular grains, but they are not evenly scattered over the section. They are much more abundant in the vicinity of calcite, some grains of this mineral being well filled with them. This fact suggests that the iron and the calcite are secondary substances derived from some original component by alteration. The quartz is not found in all sections. When it is present it occurs as hypidiomorphic grains associated usually with chlorite. From its general appearance and the shape of its grains, it appears to be a secondary infiltration. Biotite is more abundant than any of the other accessories. Under low powers its little plates look like brown stains on the almost colorless talc and chlorite fibers. When examined under high powers the "stains" are discovered to be very thin scales of a reddish-brown biotite, with the usual properties of this mineral.

The calcite, chlorite, and talc are the essential components. All are practically colorless. The calcite is granular and the other two minerals are fibrous. The former appears often as large irregular granules, with a higher refractive index than any other of the colorless minerals in the rock. It is distinguished by its strongly emphasized rhombohedral cleavage and by its brilliant polarization colors. The most usual occurrence of the mineral, however, is in the form of little veins interposed between the folia of the micaceous components and as nests filling the spaces between neighboring grains of talc and chlorite.

The two micaceous constituents, talc and chlorite, constitute the greater portion of the rock, and the talc is the more abundant. Both minerals are found in plates, fibers, and folia. They are both colorless, or nearly so, both possess a parallel series of well-marked cleavage lines, and both extinguish parallel to these cleavages. The chlorite is slightly pleochroic in very light-green tints, and has a very low double refraction. Its interference colors between crossed nicols are gray, blue, or white. The talc is nonpleochroic. Its double refraction is strong, and its interference colors are in brilliant red and green tints. There is no difficulty in distinguishing between the two minerals.

In structure the rock is radially fibrous. The folia of talc and chlorite are rarely straight. They are usually curved and bent to such an extent that every plate shows the undulatory extinction. Large bent and crumpled folia lie in a felted mass of smaller fibers, which in turn are curved and crumpled in the same manner. It is this interlacing of fibers rather than the occurrence of spherical aggregates of talc that gives strength to the rock.

Nothing can be learned from thin sections of the rock concerning its origin, except that, since its components are all secondary, the rock itself is probably secondary. There is nothing in the nature of these components, however, and nothing in the structure of the rock that suggests the nature of the original. Professor Hitchcock[1] in a recent paper regards steatite as an alteration product of material originally igneous, and Roth[2] declares that generally steatite is a secondary substance produced from minerals that contain but little alumina, especially from augite, hornblende, and olivine. The chlorite associated with the talc originated from aluminous hornblende and augites. If the original rock contained olivine this may have yielded magnetite in its decomposition. If Roth's statement expresses a fact the soapstone of Francestown may be an altered diabase or diorite, containing some olivine. The only phenomenon observed in the thin section that may shed some light on the question is the accumulation of magnetite and biotite in certain areas, which may possibly have once been occupied by olivine.

No. 143. Hornblende-gabbro-gneiss (Gabbro-diorite).

(From Franklin, Baltimore County, Maryland. Abstract by J. P. Iddings from the description by George H. Williams.)

This rock has been described by George H. Williams[3] as a product of alteration of gabbros by processes of dynamic metamorphism. The rock varies in character from place to place, grading from massive gabbro into massive hornblendic rock in some places. In other places the hornblendic rock possesses a well-marked schistose structure.

> When thus foliated the rock cleaves with greater or less readiness along one plane, which, so far as observed, appears to be parallel to the foliation of the adjacent gneisses. Where this structure is most eminently developed, all traces of the gabbro disappear, and the diorite has much more the appearance of one of the so-called crystalline schists than of a massive rock.[4]

The specimens in the Educational Series represent the more schistose phase of the gabbro-diorite, and might be described as a somewhat feldspathic amphibolite. The rock is greenish black and distinctly crystalline, and consists of hornblende and a subordinate amount of feldspar. These are arranged in parallel layers not clearly distinguished except in thin section.

The hornblende is the usual green variety common in massive diorite and crystalline schists. It almost never occurs in well-defined crystals, but in confused aggregates of imperfectly developed individuals. In the rock from Franklin, the hornblende is in compact crystals which are perfectly idiomorphic. The extinction angle, measured on splinters parallel to the prismatic cleavage plane, gave an average value of about 13°. The pleochroism is very pronounced and of the character usual in hornblende, i. e., the $\mathfrak{a}$ ray, nearly parallel to the clinodiagonal axis, is light yellow; the $\mathfrak{b}$ ray, coincident with the orthodiagonal, yellowish green; and the $\mathfrak{c}$ ray, dark bluish green. The absorption is here, as in all hornblende, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

The ordinary hornblende of the diorite is quite free from inclusions, but in certain specimens crystals much larger and more compact than the average occur, in which

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[1] Jour. Geol. Vol. III, p. 58.

[2] J. Roth: Allgemeine und Chemische Geologie, Vol. II, p. 541.

[3] George H. Williams, The gabbros and associated hornblende rocks occurring in the neighborhood of Baltimore, Maryland: Bull. U. S. Geol. Survey No. 28, Washington, 1886, p. 27 et seq.

[4] Loc. cit., p. 32.

minute black needles are so abundant as to render the mineral quite opaque, no matter how thin the section may be. These needles are short and stout, being often so rounded as to present an elliptical outline. They vary considerably in size, but even the largest are not more than .04 mm in length and .002 mm in width. In prismatic sections of the hornblende, they are seen to be arranged parallel to the vertical axis, and also in two directions, making an angle of about 45° with this. In basal sections they appear to follow, for the most part, the prismatic cleavage lines, though they are also less frequently disposed in other directions, especially in that parallel to the clinodiagonal.

These inclusions furthermore are always central in their arrangement, the periphery of the hornblende crystal being free from them. When particularly abundant the smaller needles appear to run together, forming irregular, opaque masses, much resembling magnetite. That these inclusions are in reality magnetite is indicated by the fact that such crystals of hornblende as contain them most abundantly are attracted by the magnet, while others are not.

The feldspar of this rock is anorthite, yielding extinction angles on the basal plane (001) as high as 22° to 28°, and on the brachypinacoid (010) as high as 36°. The chemical composition of the feldspar, as determined by W. S. Bayley, in the variety of this rock from Pikesville, is as follows:

Analysis of feldspar from hornblende-gabbro-gneiss of Pikesville, Maryland.

	Per cent.
SiO_2	45.06
Al_2O_3	35.69
CaO	18.30
Na_2O	.95[a]
Total	100.00
Specific gravity, 2.74.	

[a] By difference.

This corresponds closely to the composition of a feldspar composed of eight molecules of anorthite to one of albite, $An_8 Ab_1$. The crystals exhibit polysynthetic twinning, and occasionally dust-like inclusions, similar to those found in the feldspars in the gabbro from this region and elsewhere. The amount of feldspar in this rock is very small, more so than in the gabbro specimens.

The subordinate or accessory minerals are very few in number and of very small amount. They are colorless apatite, pyrite, sphene, and minute crystals of epidote, and larger ones of irregularly shaped zoisite.

The chemical composition of the gabbro-diorite from near Pikesville, Maryland, as determined by Leroy McCay, is given in the following analysis:

Analysis of gabbro-diorite from Pikesville, Maryland.

	Per cent.
SiO_2	46.85
TiO_2	.30
Al_2O_3	20.02
Fe_2O_3	2.30
FeO	4.60
MnO	trace
MgO	10.16
CaO	13.84
Na_2O	1.32
K_2O	trace
P_2O_5	trace
H_2O	.88
Total	100.27
Sp. gr., 2.996.	

Its similarity to those of the gabbro of the region has been pointed out by Williams.

NO. 144. HORNBLENDIC GABBRO-GNEISS (GABBRO-DIORITE).

(FROM MINNESOTA FALLS, YELLOW MEDICINE COUNTY, MINNESOTA. DESCRIBED BY W. S. BAYLEY.)

Specimen No. 144, like No. 140, was found among the crystalline schists of the Minnesota Valley. It occurs at Minnesota Falls of the Minnesota River, 600 paces north and 100 west of southeast corner, sec. 11, T. 115 N., R. 39 W., Minnesota.[1] In the field it appears as a distinctly foliated rock, striking about east and west and dipping north at 30°.

The rock is a medium-grained, distinctly crystalline aggregate of a white striated plagioclase and a lustrous black mineral with a quite perfect cleavage. The cleavage surface is less even than that of mica and the cleavage plates that can be sprung from the mineral are less thin. The microscope investigation of thin sections shows it to be hornblende. In the hand specimen but little evidence of schistosity is at first sight apparent; but upon close examination it may be seen that the long axes of a majority of the grains lie approximately in the same plane, though not necessarily in the same direction in this plane.

A single glance at the thin section reveals a general parallelism in the arrangement of the rock's darker constituents (see Pl. XLV, *B*). When placed under the microscope most sections show only a coarse-grained aggregate of plagioclase and light green hornblende. A few show in addition a very light-colored, highly refractive augite.

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[1] See pl. 28, Geology of Minnesota, vol. 1 of Final Report, 1884, p. 589.

The plagioclase is in very irregular grains that are clear and colorless except for certain tiny dust-like inclusions scattered through them. In addition to these the plagioclase contains also tiny specks of magnetite and small flakes of green hornblende. Under crossed nicols it is seen to be crossed by series of twinning lamellæ. The majority of these form a single series of parallel lines; others form two series, cutting each other at angles of about 78°. Some of the lamellæ run entirely across the grains; others spring from their edges and wedge out toward their centers, while still others spring from the sides of cleavage cracks and extend only a short distance into the feldspathic substance. In many grains the lamellæ have an undulous extinction, different portions of the same lamellæ extinguishing in different positions of the stage as it is revolved. All these phenomena indicate that the feldspars have been subjected to pressure. The maximum symmetrical extinction of contiguous lamellæ is somewhere in the neighborhood of 33°, and the density of the mineral is 2.731. It is thus a basic bytownite. Though the main mass of the feldspar is fresh, as has been said, the corners of grains and the small areas between neighboring ones are often filled with a micaceous, brightly polarizing substance in tiny flakes, forming by their accumulation little cloudy masses in and between the fresh plagioclase grains. This substance has the peculiarities of kaolin, a common alteration of all feldspars, and is undoubtedly this material.

The hornblende is in large masses with a green color and a moderately strong pleochroism. Many of the grains have but one set of cleavage lines. The extinction against these varies between parallelism and an inclination of 38°, according as the section is parallel to the orthopinacoid or to the clinopinacoid, and the pleochroism is in clear-green and yellowish-green tints, the former when the cleavage is nearly parallel to the vibration plane of the nicol. Other grains of the mineral have two series of cleavage lines making angles with each other that the extinction bisects. Where the series are most distinct and most sharply cut the angles made by the two sets are 124° and 56°. The pleochroism in these sections is dark green and light greenish yellow, the latter when the shorter diagonals of the rhombs made by the cleavage are parallel to the principal plane of the nicol. The pleochroism is thus $\mathfrak{a} =$ greenish yellow, $\mathfrak{b}$ and $\mathfrak{c} =$ green. Absorption $\mathfrak{b} = \mathfrak{c} > \mathfrak{a}$. The different individuals of the mineral are very irregular in shape and usually four or five aggregate into groups. Most of these are simple individuals, but others have two or more different parts in the twinned relation to each other, as may be attested by examining the section between crossed nicols, when the different parts of the same grain extinguish in opposite directions, and the polarization colors are different. The only inclusions noted in the hornblende are little grains of magnetite, small dust particles, and in certain sections masses of a light-colored, highly refractive mineral.

The latter substance is found only in the interior of hornblende masses, surrounded on all sides by the green hornblendic material. It has a very high index of refraction and is not pleochroic. It is either colorless or some very light shade of green. Under favorable conditions it may be seen to be crossed by two series of cleavage cracks making angles of nearly 90° with each other. The extinction bisects these angles, and the polarization colors are very brilliant. This augite, for such the mineral is, is not always sharply separated from the surrounding hornblende. It gradually assumes a greenish tinge on its edges. This color deepens as the distance from the interior of the augite increases, and the substance acquires more or less pleochroism, until it finally becomes indistinguishable from the surrounding hornblende. This relation of the two minerals indicates that the hornblende has been derived in some way from the augite. This change of augite to green hornblende is known as uralitization, and the variety of green hornblende so produced is called uralite. Uralitization is especially characteristic of rocks that have undergone dynamic metamorphism.[1]

Occasionally on the edges of hornblende grains, and especially where these are in contact with feldspar, may be found small reddish brown flakes of strongly pleochroic biotite, sometimes extending with frayed ends far into the hornblende. It is present in small quantity, either between plagioclase and hornblende, as described, or between neighboring hornblende grains. Its origin is probably secondary, and its cause a reaction between the hornblendic and plagioclastic materials.[2]

The essential components of the rock as it at present exists are plagioclase and hornblende. The latter is evidently an alteration product of augite, and the plagioclase is bytownite. Both minerals are allotriomorphically developed, but the rock has been given a gneissoid structure by pressure. If we reconstruct the predecessor of the gneiss from the material at hand, remembering that the hornblende represents an original augite, we shall have a granular aggregate of plagioclase and augite, i. e., a gabbro. Since the rock is a gneiss which has been derived from a gabbro, we must call it a gabbro-gneiss, if we adopt the nomenclature suggested by Dr. Gordon.[3] Moreover, since its characteristic ferromagnesian component is hornblende, its more distinctive name is hornblendic gabbro-gneiss.[4] Dr. Williams[5] has called the rocks of this character that occur so widely in the Baltimore region gabbro-diorites, but since these rocks at present are neither gabbros nor diorites the name is open to grave objections.

The hornblendic gabbro-gneiss illustrates the usual form taken

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[1] See G. H. Williams, Bull. U. S. Geol. Survey No. 62, p. 52, for general discussion of uralitization and the literature of subject.

[2] The alteration of hornblende into biotite is not a common phenomenon, though by no means unknown; cf. G. H. Williams: Bull. U. S. Geol. Survey No. 62, p. 182.

[3] See description of No. 140, p. 358.

[4] The name hornblende-gabbro-gneiss describes a gneiss derived from hornblende-gabbro, i. e., a gabbro-gneiss in which the hornblende is original. In the rock under discussion the hornblende is regarded as secondary, hence the use of the adjective hornblendic, which signifies merely that the gneiss contains hornblende.

[5] Bull. U. S. Geol. Survey No. 28, pp. 17, 27-32.

by a gabbro when subjected to dynamical metamorphism, in which case the augite usually changes to hornblende. In the less common case the augite changes to biotite, and since the latter mineral contains but 35 to 40 per cent of SiO_2, while the former contains about 53 to 54 per cent, there is left over a residue of silica, which may crystallize as quartz, yielding a quartz-biotite-augite phase of gabbro-gneiss.[1]

The density of the rock is 2.935, and its composition, as found by Dr. Stokes, is given below in column I. The figures in column II represent the composition of the hypersthene-gabbro of the Baltimore area.[2] Upon comparison it will be found that the schistose rock from Minnesota is almost identical, chemically, with the massive eruptive from Maryland.

Analysis of gabbro-gneiss and hypersthene-gabbro.

	I.	II.
SiO_2	48.29	46.85
Al_2O_3	20.87	19.72
Fe_2O_3	1.13	3.22
FeO	4.93	7.99
CaO	14.32	13.10
MgO	7.54	7.75
K_2O	.38	.09
Na_2O	1.77	1.56
Loss in ignition	.89	.56
Total	100.12	100.84

The hypidiomorphic texture and the schistose structure of the rock are both well brought out in Fig. *B*, Pl. XLV. The plagioclase appears as large white areas, and the hornblende as darker ones, crossed by parallel lines marking the cleavages of the mineral. In the center to the left is a core of augite, whose dark color and broad, irregular cracks are indications of the great amount of alteration suffered by the mineral.

No. 145. SERPENTINE.

(FROM GREENVILLE, PLUMAS COUNTY, CALIFORNIA. DESCRIBED BY J. S. DILLER.)

Serpentine is a green or greenish, hydrous silicate of magnesia. It is of common occurrence, forming large masses, chiefly among more or less altered rocks.

The serpentine of Greenville, California, forms an irregular mass bounded on the one hand by slates and on the other by quartz-porphyry and granite, through which it appears to have erupted. It is a typical, yellowish-green serpentine, and shows well the slickensides due to internal movement of the mass. Adjoining parts are made smooth by rubbing against each other. The slickensides give the serpentine a schistose appearance.

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[1] See description of No. 140 in this bulletin, p. 358.

[2] G. H. Williams: Bull. U. S. Geol. Survey No. 28, p. 39.

Small fragments of the serpentine are readily picked up by a magnet, showing the presence of magnetite. In a thin section under the microscope the serpentine is seen to be irregularly fibrous. The fibers have parallel extinction in conformity to their orthorhombic character. Most of them lie in the same general direction as the slickensiding. In places the fibers are so closely compacted in parallel position as to be optically continuous, giving bright yellow colors between crossed nicols. Generally, however, the interference colors do not rise above yellowish gray. There are no distinct indications of the mesh or grate structures, characterizing respectively serpentine derived from olivine and from hornblende, but rather the structure resembles the bar structure, indicating derivation from pyroxene. The movement of the mass has been so great as to obliterate much of the original secondary structure.

Magnetite is abundant in small grains distributed throughout the mass, but often arranged in streams and elongated patches parallel to the fibrous structure of the serpentine.

Besides magnetite, there are numerous yellowish-brown irregular isotropic grains, without definite crystallographic outlines. They are always less abundant than the magnetite, and although quite generally distributed throughout the section, they are not equally abundant in all portions. Considering the associations, and their optical properties, as well as their chemical reactions observed by Mr. Melville, these particles are regarded as chromite.

This serpentine, where deeply cut by the creek descending from Round Valley reservoir, contains nodular masses ranging from 1½ feet to 8 feet in diameter. They are enveloped by the schistose serpentine. Upon the outside these nodules have a dark border of serpentine and magnetite. The interior of the nodules vary in color; the smaller ones are gray and appear to be composed of pyroxene altered to serpentine and chlorite. The larger nodules have a yellowish, very heavy interior, which appears to be pyroxene, as in the other case, but is much less altered. It has a rather feebly pronounced fibrous structure, with a large angle of extinction. Its outlines are entirely irregular and show no characteristic cleavage. In acid it shows no trace of gelatinization.

These nodules give a clue to the original composition of the rock from which the serpentine was derived, for the serpentine in the nodules, associated with the remnants of pyroxene, from which it was derived, has essentially the same structure as that in the slickensided serpentine, the difference being that in the slickensided serpentine the bars have been made more generally parallel by motion within the mass. This view is corroborated by the fact that upon the borders of the serpentine mass it passes into a rock, which in its outward appearance looks like gabbro with the pyroxene and feldspar distinctly marked. In the thin section, however, it is found that both are highly altered, the feldspar to a saussuritic mass and the pyroxene to serpentine with the bar structure well marked. Considerable of the original fibrous pyroxene is still present.

The analysis of the serpentine (No. 145) was made by W. H. Melville, in the chemical laboratory of the United States Geological Survey, and is as follows:

Analysis of serpentine from Greenville, California.

	Per cent.
Loss	12.70
SiO_2	39.14
Al_2O_3	2 08
Fe_2O_3	4.27
FeO	2.04
CaO	trace
MgO	39.84
K_2O	....
Na_2O	....
Chromite	0.11
Total	100.18

Serpentine when compact may be easily carved and will usually receive a high polish. When of good color it is used for ornaments and interior decorations. This is especially true when the serpentine occurs mixed with limestone, forming verde antique, which is frequently used as a decorative marble.

No. 146. MAGNETITE.

(FROM PORT HENRY, ESSEX COUNTY, NEW YORK. DESCRIBED BY W. S. BAYLEY.)

No. 146 is a specimen of one of the magnetite ores from the Mineville group of mines in Moriah Township, Essex County, New York. The rock is mainly a coarsely granular aggregate of heavy, black, lustrous magnetite, which constitutes the larger portion of the specimen, a smaller proportion of reddish-brown grains of apatite, and a very few grains of a white substance that effervesces with acid. The latter is evidently calcite. When the thin section is viewed against a background of white paper, a fourth component is detected in the shape of irregular grains of a dark green color. These when examined under the microscope are discovered to be pyroxene.

The specimen is a good example of the magnetite ores formerly so extensively worked in New York. According to the Report of the Eleventh Census, the quantity of this ore mined in 1889 was 927,269 tons.[1] Since this time the quantity has materially decreased, in consequence of the increased production of hematite in the Lake Superior region, until in 1894 it amounted to only 196,436 tons.[2] Samples of

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[1] Report on the Mineral Industries of the United States at the Eleventh Census, 1890. Washington, 1892, p. 7. Cf. also plate opp., p. 22.

[2] Sixteenth Ann. Rept., U. S. Geol. Survey, Pt. III, p. 200.

the ore taken from the stock piles at the shipping docks of the Port Henry Ore and Iron Company, at Port Henry, New York, upon analysis yielded: Fe, 61.39 per cent; P, 1.496 per cent; TiO_2, small percentage.[1] The ore is non-Bessemer. According to Kemp[2] it occurs as irregular flattened lenses that are usually associated with gneisses. In general the long axes of the lenses run parallel to the foliation in the gneisses. These latter rocks[3] are aggregates of quartz, orthoclase, microline, pyroxene, biotite, hornblende, and microperthite. Near the ore bodies the rock is darker than elsewhere. It here consists essentially of plagioclase, green hornblende, green augite, and a little magnetite and sphene. Above the gneisses and younger than them is a series of crystalline limestones together with gneissoid and schistose rocks, among which black garnetiferous and hornblendic varieties are most prominent. There is no marked stratigraphic break between the gneisses and the overlying series of limestones and schists, both of which may correspond to the Grenville series of Canada, regarded by Adams[4] and the other Canadian geologists as upper Laurentian and by Van Hise[5] as Algonkian.

Ore occurs in both the gneissic and the limestone series, that represented by the specimen, as already stated, being in the former. The gneisses are so much contorted that no structure has yet been made out for them and their contained ore bodies. As for the origin of the ores, this also is obscure. Kemp[6] states that "no segregative agency, strictly so called, could have occasioned them, and some other method of origin must be invoked." But what this method is he does not state.

Under the microscope the thin sections of the ore show the presence of magnetite, green pyroxene, apatite, calcite, and pyrite. The magnetite and pyrite are both opaque. They may easily be distinguished by the blue-black color of the former and the brassy color of the latter in incident light. The magnetite is in large irregular grains in the spaces between which are triangular areas of pyrite.

The apatite is in large, colorless grains with rounded outlines. It possesses an indistinct cleavage parallel to which is the extinction. The brown color of the mineral as seen in the hand specimen is due to the dissemination through it of thousands of small inclusions, among which are numerous plates of hematite that may be recognized by their red color. Among the other inclusions may be seen grains of magnetite, liquid inclosures, and hundreds of tiny specks whose nature can not be determined. They may be included together as "dust."

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[1] Iron Ores of the United States: Report of the Tenth Census, Vol. XV, p. 112.

[2] J. F. Kemp, Crystalline limestones, ophicalcites and associated schists of the Eastern Adirondacks: Bull. Geol. Soc. America, Vol. VI, 1895, p. 241.

[3] J. F. Kemp, The Geology of Moriah and Westport Townships, Essex County, New York: Bull. N. Y. State Museum, Vol. III, No. 14, September, 1895, p. 325.

[4] F. D. Adams, On the typical Laurentian area of Canada: Jour. Geol., Vol. I, 1893, p. 325.

[5] C. R. Van Hise, Principles of North American Pre-Cambrian Geology: Sixteenth Ann. Rept. U. S. Geol. Survey. Washington, 1894-95, Pt. I, p. 767.

[6] Bull. N. Y. State Museum, Vol. III, No. 4, p. 342.

From their arrangement parallel to the cleavage it may be assumed that some of them are of secondary origin.

The pyroxene is a very compact, green variety, which in thick section is almost opaque. In thin section it exhibits a well-marked pleochroism in emerald-green and grass-green tints. Because of its pleochroism this augite at first sight resembles hornblende. It may, however, easily be distinguished from this mineral by the rectangular cleavage in cross sections and by the high extinction angles (over 40°) observed in longitudinal sections. As a rule, the mineral is in irregular grains, which may surround grains of apatite, but occasionally it is in partially idiomorphic crystals, when it is apparently surrounded by magnetite. The order of crystallization in the rock appears to be apatite, augite, magnetite, pyrite. All the irregular grains of augite are crossed by ramifying veins of white calcite, whose directions appear to be quite independent of the direction of the mineral cleavages. They were probably formed by infiltration after the remainder of the rock had assumed its present condition.

The composition of the ore suggests the possibility of its origin by secretion from some eruptive magma, like the titaniferous ores associated with the gabbros of the Lake Champlain district in New York[1] and those on the periphery of the great gabbro mass in northeastern Minnesota.[2] No positive evidence on this question is yet available. The New York magnetites are similar in many respects to the magnetites that have been so long mined in New Jersey.

RESIDUAL ROCKS.

No. 147. Residual Sand of Granite.

(From District of Columbia, about 3 Miles Northwest of Washington. Described by G. P. Merrill.)

Rock-weathering is a purely superficial phenomenon, brought about through agencies that are in part physical and in part chemical in their nature. The chief physical agencies are expansion and contraction among the mineral particles owing to temperature changes, and the expansion and consequent rending action of absorbed water passing into the condition of ice. The chemical agencies are those comprised in the processes of oxidation, hydration, and solution, though many minor reactions doubtless take place. Hydration without loss of materials involves expansion, and hence an incidental physical agency is brought in play.

Rock-weathering manifests itself in a variety of ways, much depending on the character of the rock masses and the prevailing climatic conditions.

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[1] J. F. Kemp: Bull. N. Y. State Mus., Vol. III, No. 14, p. 351.

[2] W. S. Bayley, The peripheral phases of the great gabbro mass of northeastern Minnesota: Jour. Geol., Vol. II, pp. 816–825.

The ultimate product of extreme weathering of any but purely quartzose rocks is almost invariably a highly ferruginous clay. This for the simple reason that of all substances forming any appreciable portion of rocks, the aluminous silicates, free silica, and iron oxides are the more refractory, and hence are left to accumulate as residuary materials, while the more soluble constituents are removed in solution. The proportional amount of material actually lost by leaching in the reduction of a rock mass to the condition of a soil, or residual clay, is necessarily widely variable. Among calcareous rocks it may amount to even upward of 99 per cent. Among siliceous rocks, however, the amount of soluble matter is vastly less, and the amount lost by purely chemical agencies rarely exceeds 50 per cent.[1]

The series of weathered products here described have been selected with a view of illustrating not merely the characteristic form of weathering, but also the fact that among granular crystalline rocks, as the granite from the District of Columbia and the diabase from Medford, Massachusetts, the beginnings of weathering are more in the nature of disintegration than decomposition. These two cases are also of further interest in that we are apparently enabled to set a time limit to the weathering, the first mentioned being judged as largely post-Cretaceous and the last post-Glacial.

Materials of the nature here described are subject to considerable variation, and the descriptions given must be accepted as descriptive of the general results produced rather than as definitely applicable to any particular sample.

The fresh rock, illustrated by the small fragment in the box with the residual sand, No. 147, is a strongly foliated micaceous granite, the foliation being secondary and due to dynamic causes. In its fresh state, it will be observed, it consists of a finely granular aggregate of quartz and feldspars arranged in imperfect lenticular masses from 2 to 5^{mm} in diameter, about and through which are distributed the abundant folia of black mica. In the thin section the structure is cataclastic; that is to say, the various minerals of which it is composed have, since their formation, been more or less shattered and distorted through dynamic agencies acting upon the rock mass of which they form a part. Quartz and black mica are the most prominent constituents, though there are abundant feldspars of both potash and soda-lime varieties. In addition to these are abundant accessory epidotes, a few small apatites, flakes of white mica (sericite), and widely scattering black tourmalines, with the usual sprinkling of iron ores.

Within a space of 15 vertical feet, as displayed in the road cuttings, this rock passes from its fresh and unchanged condition into that of a sandy soil, upon which trees, shrubs, and a variety of flowering plants are growing. The change is quite gradual, the rock becoming first

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[1] For a more detailed discussion of the subject, see Rocks, Rock-weathering, and Soils, by George P. Merrill, The Macmillan Company, New York, 1897.

browned through the oxidation of the mica and ultimately losing its rock-like character altogether on the immediate surface. The zone of disintegrated material is rarely more than 2 or 3 feet in depth at the point where these samples were collected, though where the material has not been subject to erosion it has accumulated to depths of upward of 50 feet.

The residuary material (No. 147), when submitted to mechanical separation, yielded results as below:

Mechanical analysis of residual sand of granite.

	Per cent.	Diameter of largest grain.
		mm
Silt	4.25	0.10
Fine sand	6.50	.18
Sand	11.25	.25
Sand	3.75	.65
Sand	11.00	1.00
Sand	23.50	1.50
Coarse sand	29.50	2.00
Gravel	10.25	8.00
Total	100.00	

The coarser of these particles, like the gravel and the coarse sand, are of a compound nature, being aggregates of quartz and feldspar, with small amounts of mica and other minerals. In the finer material, on the other hand, the process of disaggregation has gone so far as to largely free each individual from its associates, excepting of course in the case of microscopic inclusions, which could be liberated only by a complete disintegration of the host itself. These particles, as seen under the microscope, are all sharply angular and in many cases quite fresh and undecomposed. The mica shows the greatest amount of alteration, the change consisting mainly in an oxidation of its ferruginous constituent, whereby the folia become stained and reduced to yellowish-brown shreds. The feldspars are in some cases opaque through kaolinization, but in others are still fresh and unchanged even in the smallest particles. The finest silt, when treated with a dilute acid to remove the iron stains, shows the remaining granules of quartz, feldspar, and epidote beautifully fresh, and with sharp angular borders, the mica being, however, almost completely decolorized, and resembling sericite more than biotite.

The chemical changes which have taken place in the process of breaking down, or weathering, are shown in the following table, in which the original analyses have been recalculated on a basis of 100. In columns 3, 4, and 5 are given calculations showing the percentage amounts of the entire rock and of each of the original constituents removed by the leaching action of water during the transformation.

Analyses of fresh and disintegrated granite from the District of Columbia.

Constituents.	Percentage of fresh granite.	Percentage of residual sand.	Percentage loss for entire rock.	Percentage of each constituent saved.	Percentage of each constituent lost.
SiO_2	69.61	65.84	10.50	85.11	14.89
Al_2O_3	14.39	15.26	0.46	96.77	3.23
TiO_2		0.31			
Fe_2O_3		4.40	0.00	100.00	0.00
FeO	3.61				
CaO	3.22	2.64	0.81	74.79	25.21
MgO	2.45	2.65	0.036	98.51	1.49
Na_2O	2.71	2.12	0.77	71.38	28.62
K_2O	2.68	2.00	0.85	68.02	31.98
P_2O_5	0.10	0.06	0.04	60.00	40.00
Ignition	1.23	4.72	[a]0.00	[a]100.00	0.00
Total	100.00	100.00	13.466		

[a] Gain.

Detailed information, together with an illustration showing the locality from which these samples were selected, may be found in Bulletin of the Geological Society of America, Vol. VI, 1895, pp. 321–332, and in Rocks, Rock-weathering and Soils, The Macmillan Co., New York, 1897.

No. 148. Residual Sand of Diabase.

(From Medford, Middlesex County, Massachusetts. Described by G. P. Merrill.)

The fresh rock from which this sand was derived, and which is illustrated by a small fragment in the box, is a coarse, almost granular, dark-gray aggregate of plagioclase feldspar, augite, and black mica, with orthoclase, apatite, magnetite, and ilmenite in smaller proportions, and, as a rule, visible only with the microscope. As secondary products occur hornblende, chlorite, quartz, calcite, leucoxene, pyrite, and a soda-bearing zeolite.

The rock breaks down, giving rise to the brown gravel shown in the box, the change in color being due to the oxidation of the iron of the ferruginous silicates. In the natural outcrops all stages of weathering are to be seen, sound bowlder-like masses with only a slight amount of superficial disintegration lying still in place embedded in the brown residual sand. The material analyzed as fresh rock, and tabulated below, was obtained from the interior of one of these bowlders. The residuary sand when submitted to mechanical analysis yielded results as below:

Mechanical analysis of residual sand of diabase.

	Name.	Diameter of particles.	Per cent.
1	Gravel	Above 2^{mm}	42.3
2	Fine gravel	2 to 1^{mm}	20.66
3	Coarse sand	1 to 0.5^{mm}	12.72
4	Medium sand	0.5 to 0.25^{mm}	9.37
5	Fine sand	0.25 to 0.1^{mm}	4.97
6	Very fine sand	0.1 to 0.05^{mm}	4.18
7	Silt	0.05 to 0.01^{mm}	1.13
8	Fine silt	0.01 to 0.005^{mm}	0.37
9	Clay	0.005 to 0.0001^{mm}	1.67
10	Loss at 110°		0.66
11	Ignition		1.73
	Total		99.76

Concerning these separations, it should be stated, those represented by Nos. 1 and 2 are plainly, even to the unaided eye, of a compound nature, and easily recognizable as diabase derivatives, though somewhat discolored by iron oxides.

No. 3 shows particles of feldspar, augite, and mica fairly well disaggregated, though even here many of the granules are compound. No. 4 differs mainly in being finer and of a lighter color, while No. 5, of a rich mahogany-brown color, appears to the unaided eye to be composed mainly of mica scales. The microscope, however, shows it to contain numerous badly stained but quite fresh feldspathic particles and cleavage flakes of augite. No. 6, the particles of which lie between 0.1 and 0.05^{mm} in diameter, shows also only minute flecks of mica recognizable macroscopically, but contains both feldspathic and augitic particles like No. 5, while Nos. 7 and 8 are deep ocherous-brown silts, offering no distinctive features to the unaided eye, and No. 9 would pass for a light-brown ocher. The material analyzed as silt (columns 5, 6, and 7 below) is the equivalent of numbers 7, 8, and 9 of this series.

The chemical changes which have taken place, together with calculations made as before, are shown in the accompanying tables:

Analyses of fresh and disintegrated diabase from Medford.

Constituents.	Fresh diabase.		Disintegrated diabase.		Silt from disintegrated diabase, numbers 7, 8, and 9 of table, on p. 380.		
	1. Bulk analysis.	2. Analysis of portion soluble in HCl and Na_2Co_3.	3. Bulk analysis.	4. Analysis of portion soluble in HCl and Na_2Co_3.	5. Per cent soluble in HCl and Na_2Co_3.	6. Per cent insoluble in HCl and Na_2Co_3.	7. Total.
SiO_2 in HCl	47.28	1.19	44.44	0.85	0.47	13.51	36.61
SiO_2 in Na_2Co_3		9.66		8.65	22.63		
Al_2O_3	20.22	4.74	23.19	4.86	21.98	5.88	40.68
Fe_2O_3	3.66	10.91	12.70	10.00	12.83		
FeO	8.89						
CaO	7.09	3.09	6.03	1.50	3.32	0.12	3.44
MgO	3.17	2.20	2.82	1.84	3.23	0.79	4.02
MnO	0.77	not det.	0.52	not det.	not det.	not det.	not det.
K_2O	2.16	1.21	1.75	0.68	1.30	0.52	1.82
Na_2O	3.94	0.50	3.93	0.17	0.90	1.24	2.14
P_2O_5	0.68	not det.	0.70	not det.	not det.	not det.	....
Ignition	2.73	2.73	3.73	3.73	10.86	0.11	10.97
	100.59	36.23	99.81	32.28	77.52	22.17	99.68

Calculated loss of material.

Constituents.	Recalculated on basis of 100.		10. Percentage loss for entire rock.	11. Percentage of each constituent saved.	12. Percentage of each constituent lost.
	8. Fresh diabase.	9. Decomposed diabase.			
SiO_2	47.01	44.51	8.48	81.97	18.03
Al_2O_3	20.11	23.24	0.00	100.00	0.00
Fe_2O_3	3.63	12.71	2.42	81.90	18.10
FeO	8.83				
CaO	7.06	6.04	1.83	74.11	25.89
MgO	3.15	2.85	0.68	78.30	21.70
MnO	0.77	0.52	0.32	58.43	41.57
K_2O	2.14	1.75	0.62	70.85	29.15
Na_2O	3.91	3.94	0.50	87.17	12.83
P_2O_5	0.68	0.70	0.08	88.61	11.39
Ignition	2.71	3.74	[a] 0.53	[b] 100.00	0.00
	100.00	100.00	14.93	....	....

[a] Gain.

[b] The calculation gives 119.49 per cent, showing that a gain in volatile matter is to be expected.

From these tables it appears that the process of decomposition has gone on more extensively than was the case with the granite described above, though the mechanical disintegration is not as great. This is due to the fact that soda-lime feldspars are more readily attacked than the potash variety, and also to the abundance of iron-rich silicates, as black mica, augite, and hornblendes, which are also susceptible.

It is evident that the decomposition has been accompanied by a leaching process, since, as shown in column 10, some 14.93 per cent of the entire rock mass has been thus carried away.

Of the material classed as silt in columns 5, 6, and 7, or as silt and clay in the table on p. 380, and which constitutes only some 3.17 per cent of the entire residue, 77.87 per cent is soluble in dilute hydrochloric acid and sodium carbonate solutions. The insoluble portion, constituting 22.13 per cent of the silt, consists of unaltered feldspar, and iron, lime, and magnesian silicates, which are easily recognizable under the microscope in minute, sharply angular particles.

More detailed information concerning this rock and the residual products of its weathering may be found in the following publications: On the petrographic characters of a dike of diabase in the Boston Basin, by W. H. Hobbs: Bull. Museum of Comparative Zoology, Vol. XVI, No. 1, 1888; and Disintegration and decomposition of diabase at Medford, Massachusetts, by George P. Merrill: Bull. Geological Society of America, Vol. VII, 1896, pp. 349–362.

No. 149. Residual Clay of Feldspathic Rock. Kaolin.

(From Hockessin, Newcastle County, Delaware. Described by G. P. Merrill.)

The kaolin deposits of northern Delaware, like those of Delaware County, Pennsylvania, are the results of the decomposition of highly feldspathic gneisses, and to a less extent of feldspathic conglomerates, themselves derived from the gneisses. As both gneisses and conglomerates are here standing practically on edge, it follows that from the same pit may be mined materials derived from both sources. The materials sent out in this series are not intended to contain any derived from the conglomerate.

The gneisses carry in addition to quartz and feldspar both white and black mica. As the feldspars decompose the black mica also yields to the decomposing agencies, and the resultant clay, from both minerals, is variously stained and colored by the oxidation of the iron. Where the mica has been very abundant the staining has gone on so extensively as to ruin the clay for high-grade ware. Sample 149 shows the material as taken from the pits. Before it was broken the gneissoid structure was still in some cases discernible.

The kaolin used in the manufacture of pottery is obtained from this crude material by a process of washing, whereby the larger fragments of quartz and still undecomposed feldspars and a portion of the mica are removed. The purest kaolin, as obtained by this process, still carries particles of feldspar in all stages of decomposition and many minute shreds of white mica and a little quartz. The individual particles of this kaolin are extremely irregular in outline, and so far as observed never show the rhombic and rhomboidal crystal outlines characteristic of true kaolinite. The crude material, when washed in water, yields many fragments of quartz, which are badly shattered and extremely irregular in outline, but which rarely show the clear glass-like fracture and brilliant polarization colors so characteristic of either vein quartz or the quartzes of granites and gneisses. On the contrary, the surfaces are dull, and by reflected light whitish, or glassy only in spots, the appearance being that of quartzes etched by alkaline solutions, and which in this case was doubtless produced by the action of the carbonates of potash, formed during the process of feldspathic decomposition.

A mechanical analysis of this washed kaolin, made under the direction of Milton Whitney, of the Department of Agriculture, yielded results as below:

Mechanical analysis of washed kaolin.

Name.	Diameter of particles.	Per cent.
	mm.	
Gravel	2 to 1	0.00
Coarse sand	1 to 0.5	0.00
Medium sand	0.5 to 0.25	0.00
Fine sand	0.25 to 0.1	0.00
Very fine sand	0.1 to 0.05	0.00
Silt	0.05 to 0.01	30.86
Fine silt	0.05 to 0.005	7.31
Clay	0.005 to 0.0001	47.78
Moisture in air-dry material		0.40
Ignition		11.40

A chemical analysis of this same washed kaolin yielded results as below. Although these results are approximately like those of kaolins as given by Dana (System of Mineralogy, 6th ed., 1893), the microscope shows the material to be far from uniform in composition but to still carry abundant crystalline particles, as quartz granules and shreds of still undecomposed feldspars. It is to the presence of this free quartz and the undecomposed silicates that is due the high total percentage of silica and the small amounts of lime, magnesia, and the alkalies shown.

The more striking features brought out by the analysis are the almost entire disappearance of the alkalies and the assumption of over 12 per cent of water.

Analysis of kaolin.

	Per cent.
SiO_2	48.73
TiO_2	.17
Al_2O_3	37.02
Fe_2O_3	.79
MnO	none
CaO	.16
MgO	.11
K_2O	.41
Na_2O	.04
H_2O at 100°	.52
H_2O at 100°+	12.83
P_2O_5	.03
Total	100.81

NO. 150. RESIDUAL CLAY OF LIMESTONE.

(FROM STAUNTON, AUGUSTA COUNTY, VIRGINIA. DESCRIBED BY G. P. MERRILL.)

The fresh rock is a dense, dark-gray, highly siliceous magnesian limestone, showing under the microscope a very fine granular aggregate of calcite granules and rhombs, but which are so muddied by included impurities as to be scarcely transparent, and of a lead-gray color.

The granules are not in all cases contiguous, but at times separated by opaque films of argillaceous matter. They never show the twin structure so characteristic of the metamorphic limestones and marbles.

The decomposition of the stone is almost purely chemical and consists in a removal, by leaching, of the calcium carbonate, leaving the less soluble silica, silicates, and iron oxides to accumulate in the form of a deep-red, highly plastic clay, which on drying becomes so indurated as to be broken only with a hammer.

So abundant is the iron oxide that the residual material is stained almost beyond recognition, and it is only when it is first boiled in dilute hydrochloric acid to remove the iron that it can be studied at all satisfactorily. When thus treated and submitted to microscopic examinations, it is found to consist mainly of very irregularly rounded and angular quartz fragments, which are more or less corroded and unmistakably of clastic origin; i. e., they existed in the limestone, not in the form of particles crystallized in place, but as mechanically included detritus formed from the breaking down of preexisting siliceous rocks. Particles of feldspars, some of which show twin bandings, are also present, and more rarely are found shreds of white and black mica, chlorite, epidote (?), and very rarely a minute but very perfectly preserved, doubly terminated, colorless crystal with forms characteristic of rutile. Both quartzes and feldspars are rough and corroded, though even the plagioclase feldspars are still in many cases sufficiently fresh to show twin striæ.

Analyses of the fresh rock and its residual clay, together with the portions soluble and insoluble in hydrochloric acid and sodium carbonate solutions, made by George Steiger, of the Geological Survey, gave results as tabulated below:

Analyses of fresh siliceous limestone and its residual clay, from near Staunton, Virginia.

	Fresh limestone.			Residual clay.		
	Insoluble.	No. 1. Soluble.	Total.	Insoluble.	No. 2. Soluble.	Total.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
SiO_2	6. 98	0. 39	7. 37	52. 81	3. 09	55. 90
TiO_2	. 09	none.	. 09	. 16	. 04	. 20
Al_2O_3	1. 39	. 53	1 92	15. 96	3. 96	19. 92
Fe_2O_3	. 25	. 04	. 29	1. 05	6. 25	7. 30
FeO	none.	. 63	. 63	. 09	. 30	. 39
MnO	none.	none.	none.	none.	none.	none.
CaO	. 04	28. 39	28. 39	. 20	. 30	. 50
MgO	. 15	18. 15	18. 30	. 75	. 43	1. 18
K_2O	. 91	. 18	1. 09	4. 51	. 28	4. 79
Na_2O	. 04	. 05	. 09	. 03	. 20	. 23
Water 100—	undet.	undet.	. 09	undet.	undet.	2. 54
Water 100+	. 15	. 34	. 49	4. 42	2. 10	6. 52
P_2O_5	none.	. 03	. 03	. 06	. 04	. 10
CO_2	none.	41. 85	41. 85	none.	. 38	. 38
Organic	undet.	undet.	undet.	....	....	....
Total	10. 00	90. 58	100. 63	80. 04	17. 37	99. 95

SiO_2 dissolved by first treating with HCl (1-10) on water bath for one hour, then with a 5 per cent solution of Na_2CO_3; No. 1, 1.09 per cent; No. 2, 4.73 per cent.

ILLUSTRATIONS OF SURFACE MODIFICATIONS.

No. 151. SPHEROIDAL WEATHERING IN IGNEOUS ROCKS.

(FROM ROSEBURG, DOUGLAS COUNTY, OREGON. DESCRIBED BY J. S. DILLER.)

All rocks exposed upon the surface of the earth are subject to meteorologic changes which tend to their destruction. The change of material under these conditions has been fully considered by Mr. Merrill in connection with the residual rocks, Nos. 147 to 150. It remains to notice some of the morphological features developed in the course of this rock destruction.

The development of the larger topographic features incident to the degradation of the land, the carving of canyons, plateaus, and mountains, and, finally, the reduction of the whole to featureless plains, are subjects wholly within a department of geology which takes little cognizance of the kinds of rocks, and may not be discussed here; but there are certain minor surface features developed in the larger process that can be illustrated by hand specimens. The first of these to be noted is the spheroidal weathering of igneous rocks.

This peculiar feature is illustrated in Pl. XLVI.[1] The ledge is composed of an igneous rock which, when it cooled and solidified, cracked and became permeated by numerous fissures. The rain water circulates through these fissures, and all portions of the rock above drainage level are exposed essentially to the weathering conditions of the surface. Fissures in rocks may originate in other ways than by contraction on the loss of heat. They may be developed by earth movements, and to this class probably belong the fissures in the figure above. They were produced long after the rock solidified.

Owing more especially to the solvent action of the water circulating in the fissures, each block bounded by them is exposed to external attack of meteorologic agents from all sides. The attack of the decomposing and disintegrating influences, since they act upon or through the exposed surface, must be proportional to the extent of that surface. The sphere has a smaller extent of surface in proportion to its volume than any other form, and is therefore the most stable form under external attack. The angular fragments of an exposed igneous rock are subject to severer attack than the same volume would receive if spherical. The angles afford a special opportunity for attack, and as a result are weathered off more rapidly than the other portions, thus reducing the angular blocks to spheroidal ones. As the weathering proceeds from without and depends upon the oscillating surface conditions, the effect is concentric, and the mass is divided into a series of shells which, under conditions affording transportation, break away, exposing the spherical surface, as seen in Plate XLVI.

Specimen 151 is a nodule from an exposure of weathered igneous rock near Roseburg, Oregon. It is diabase, whose eruption occurred probably during the Eocene. Large masses of it are exposed in the Roseburg region, and most of them, where deeply weathered, show the development of spheroidal forms to a greater or less extent. While such forms in the Roseburg diabase are generally developed by weathering along fissures, as already explained, it is possible that in some localities of the same region they may have resulted from the manner of its eruption,[2] as explained by F. Leslie Ransome for spheroidal structure in similar rocks near San Francisco.

This sort of weathering of igneous rocks, although most commonly exhibited by basic eruptives, basalts, and diabases, occurs also in felsites, as noted by Geikie,[3] and in granites, good examples of which have recently been pointed out by Mr. C. R. Keyes.[4]

These spheroids are sometimes of large size, and by the gradual erosion of the surrounding rock they are left upon the surface as

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[1] Plate copied from Fifteenth Annual Report U. S. Geol. Survey, Pl. XLIII.

[2] Eruptive Rocks of Point Bonita: Bull. University of California, Vol. I, pp. 110–113.

[3] Text Book of Geology, 3d edition, p. 391.

[4] Fifteenth Ann. Rept. U. S. Geol. Survey, p. 725.

SPHEROIDAL WEATHERING IN GRANITE NEAR WOODSTOCK, MARYLAND.

bowlders of disintegration. Such bowlders are common in many regions, especially of granular igneous rocks.

The problem presented by nodules resulting from external attack has been mathematically solved in all its relations by Dr. George F. Becker[1] and applied not only to the spheroidal weathering of rocks, but also to the formation of pebbles.

No. 152. Spheroidal Weathering in Shale.

(From Dry Creek, Shasta County, California. Described by J. S. Diller.)

This shale is of lower Cretaceous age, and is exposed along the shallow canyon of a stream flowing from the Coast Range to the Sacramento. It dips eastward at a considerable angle, and is penetrated by numerous fissures, which give the water ready access to its mass. The spheroids are generally indistinct in the bluff, but when the shale is dug out, its spheroidal fragments are often a conspicuous feature, and specimens such as No. 152 are abundant. Their origin is essentially the same as that of specimen No. 151.

The concentric shell or "onion" structure is well marked, although not perfectly developed. It is not equally evident everywhere in the large mass of Cretaceous shale in Shasta and Tehama counties. Some of the layers of these nodules contain a trace of carbonate of lime, and in places calcareous concretionary masses are abundant. They occasionally contain fossils.

No. 153. Differential Weathering of Impure Limestone.

(From Galena, Jo Daviess County, Illinois. Described by J. S. Diller.)

The two cases preceding illustrate the comparatively uniform effect of weathering upon essentially homogeneous material, where it gives rise to a nearly even surface; but in the case now to be noted the weathering develops surface differences, and may therefore be called differential.

The weathered surface of this limestone is very irregular. This irregularity is apparently due, in part at least, to the impurity of the limestone itself, which contains, according to Mr. Steiger, 1.07 per cent of insoluble matter, irregularly distributed throughout the mass, rendering it unequally sensitive to the attack of circulating waters, and thus giving rise to the inequalities of surface. The surface, however, is not smooth, and has no evident direct relation to drainage.

A surface of this kind, on a large scale, is illustrated in Pl. XLVII,[2] which shows a massive bed of lower Cambrian limestone, eroded irregularly by weathering beneath the soil. This irregular erosion by solution may be due to the unequal attack of the agents, rather than irregularity in the composition of the limestone. That the latter had little

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[1] Mon. U. S. Geol. Survey, Vol. XIII, p. 68.

[2] Plate copied from Bull. U. S. Geol. Survey No. 134 (Pl. IV).

influence is indicated by the fact that the limestones generally, whether pure or not, have an irregular weathered surface beneath the soil. This is a conspicuous feature of some of the limestones laid bare by hydraulic mining upon the western slope of the Sierra Nevada.

No. 154. DIFFERENTIAL WEATHERING, FLUTED LIMESTONE.

(FROM BAIRD, SHASTA COUNTY, CALIFORNIA. DESCRIBED BY J. S. DILLER.)

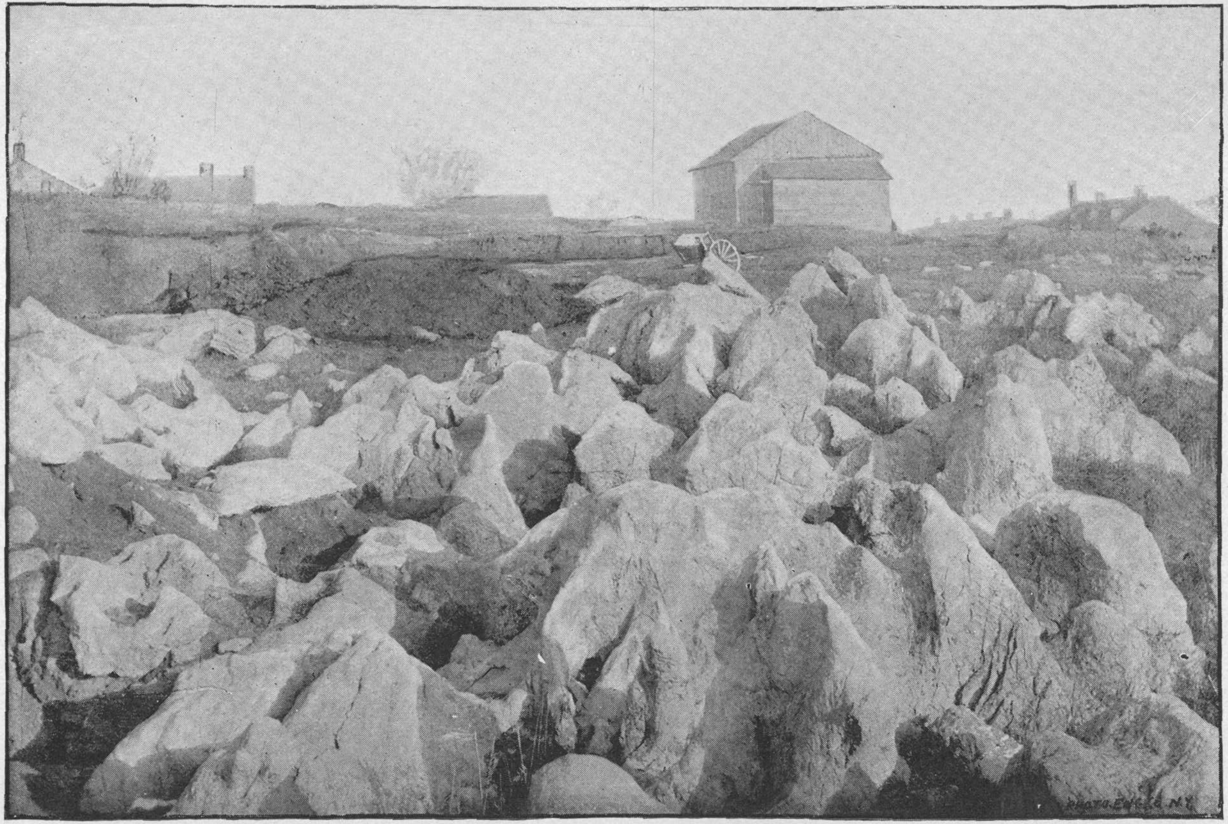
This limestone is exposed in large masses, making a mountain ridge along the McCloud River. At many points its surface bears peculiar small ridges and intervening depressions. In the field it is evident that the little valleys are lines of drainage, and it may readily be concluded that they are a form of rain erosion due to the solvent action of the water running over the surface. An examination of many ridges and valleys discloses no differences in composition or structure to which the variations in surface form may be due. From the fact that the flutings are drainage lines, it appears that they may be referred to the rilling of the water on the surface of the limestone. Where the water flows the solvent action is most intense, and a minute valley is formed by solution. This form of differential weathering is common upon limestone exposures, but is rarely so well developed as in the examples from which specimen 154 was collected.

No. 155. GLACIATED ROCK.

(FROM ROCHESTER, NEW YORK. DESCRIBED BY G. K. GILBERT.)

Rock surfaces which have been crossed by a glacier and thereby polished, striated, or furrowed, are said to be glaciated.

In the description of specimens Nos. 2 and 9 some account is given of the action of glaciers and of the formations they deposit, and mention is also made of the great ice sheet which in Pleistocene time invaded the United States. The rock fragments, coarse and fine, embedded in a glacier are included chiefly in its lower part, so that as the ice moves over the rock there is friction between the bowlders, pebbles, sand grains, and clay particles above and the bed rock beneath. Although the motion is exceedingly slow, amounting ordinarily to only a few feet in twenty-four hours, the pressure exerted by the thick ice bed is so great that this friction has an appreciable effect, and the rocks are worn away. The fine mud tends to smooth the rock, and the result of its action is a beautifully polished surface marked by fine parallel striæ. The sand grains scratch the surface and must be efficient in wearing it away. Pebbles and bowlders of hard material sometimes act like engravers' tools, plowing furrows in the rock beneath. When the ice finally melts away, as it has melted from the North American region, there remains a rock surface which is in general beautifully polished, but is also scratched, furrowed, and otherwise sculptured.



IRREGULAR WEATHERED SURFACE OF CAMBRIAN LIMESTONE AT YORK, PENNSYLVANIA.

The character of the sculpture depends also in part on the nature of the bed rock. If that is homogeneous it may be reduced to an even surface or carved in smooth forms outlined by sweeping curves; if it contains limited masses which are very hard, these may be left prominent, and in such cases a ridge of the softer rock is apt to be preserved on the lee side of the hard rock, and a U-shaped furrow carved about the front and sides. This feature is illustrated by fig. 18, photographed from a slab of limestone, containing a lump of chert.

When glaciated rock surfaces are exposed to the weather they gradually lose their polish and other characters. In the tract once covered by the great American ice sheet the best illustrations are found where the bowlder clay, which protects the rock surface from the weather, has been freshly removed, as, for example, in preparing rock for quarrying. Specimen 155 was obtained in this way. The rock is limestone belonging to the Niagara formation, and had been planed by the ice so as to constitute an even floor on which the bowlder clay rested. The ice seems to have changed its direction of motion from time to time, for besides the principal set of parallel striæ there are others crossing them obliquely. The direction of the principal striæ is in this case south 50° west.

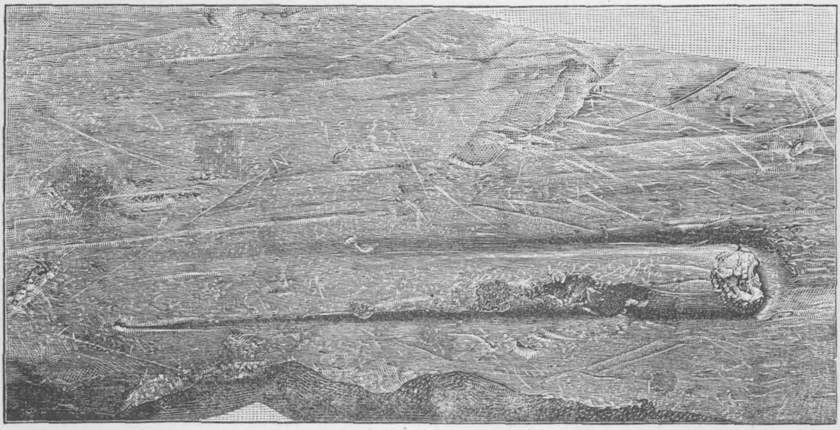


FIG. 18.—Glaciated rock surface showing frontal and lateral grooves caused by a projecting nodule of harder rock.

The subject of rock glaciation is fully discussed in Rock Scorings of the Great Ice Invasions, by T. C. Chamberlin, Seventh Annual Report, United States Geological Survey.

No. 156. Desert Varnish.

(From Tooele Valley, Tooele County, Utah. Described by G. P. Merrill.)

The tendency of weathering is not always toward immediate disintegration. In many instances, and particularly among siliceous fragmental rocks, exposure to weather results in the formation on the immediate surface of a thin coating of a more refractory nature, which for a time protects the material from further disintegration. This induration, it is assumed, is brought about through the deposition of matter held in solution by ground water, which is brought to the surface by capillarity and there evaporated. The same action, even when not attended by induration, may result in a superficial discoloration, as in the pebbles under discussion. These pebbles are of quartzite, rounded by wave action, and now, by the drying up of the lake, left exposed to the atmosphere. Mr. Gilbert describes their origin and occurrence as follows: In Tooele Valley the Provo shore-line contours alluvial cones descending from the mountains at the east and west and extended so as to meet one another at the south. The valley is open at the north and northerly winds must have brought powerful waves. These drifted the alluvial material southward along both sides of the valley and built curved bars about the head. As there was no lateral escape for the water driven up the bay by the wind, the undertow was powerful, carrying off not only mud and sand, but gravel, and leaving in the bars stones ranging in diameter from 3 or 4 inches to more than 1 foot. This coarse shingle is in places so devoid of finer material that it is barren of vegetation, and these barren tracts best exhibit the dark coating on the bowlders.

Examined in thin sections under the microscope, the bowlders are found to consist essentially of quartz granules, but they carry in addition occasional grains of microcline, a soda-lime feldspar and a considerable amount of interstitial calcite and disseminated earthy and ferruginous matter. There is also an occasional fleck of colorless mica. The zone of discoloration is quite thin, rarely extending inward for a distance of more than 2^{mm}, the color being much more intense on the immediate surface.

When thin sections for microscopic study are cut so as to show portions of both the desert varnish and interior portions, the variation in color is found to be so slight as to be almost imperceptible, and on casual inspection there seems to be no essential difference in composition such as should account for the darker color shown in the hand specimen. Closer inspection shows, however, that the interstitial calcite of the interior of the pebbles is quite lacking in the discolored outer portions, and, further, that the cavities left by its removal in solution are often lined with dark, opaque amorphous matter. The discolored portion, when tested chemically, reacts for iron and slightly for manganese. Heated in a closed tube, it yields water and gives off a very faint empyreumatic odor. Material from the interior portion of the pebbles, when treated with dilute acid, effervesces briskly, the solution reacting also for iron and manganese, but much more faintly than does the discolored portion. It is evident that the exterior coloring of the "desert varnish" is due mainly to a local segregation of oxide of iron with a little manganese and organic matter. The cause of such segregation is not, however, altogether apparent. In such cases it is often difficult to decide what, among certain phenomena, may be merely incidental and what may be causative. All things considered, it seems safe to assume that this local discoloration is due to a superficial segregation of the metallic contents of the quartzite in a state of higher oxidation, the iron, originally in form of a carbonate, becoming converted into a hydrated oxide, while the lime carbonate itself was removed in solution. The small amount of organic matter may have been added from external sources—from the waters of the original lake.

The formation of the bars from which these pebbles were collected is described by Mr. Gilbert in his report on Lake Bonneville (Monographs United States Geological Survey, Vol. I).

INDEX.

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