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THE
CHIEF COMMERCIAL GRANITES
OF
MASSACHUSETTS, NEW HAMPSHIRE
AND RHODE ISLAND

BY
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CHIEF COMMERCIAL GRANITES OF MASSACHUSETTS, NEW HAMPSHIRE, AND RHODE ISLAND.

By T. NELSON DALE.

INTRODUCTION.

In Bulletin No. 313, published in October, 1907, by the United States Geological Survey, the granites of Maine were described by the writer from both the scientific and the economic standpoint. The design of the present work is to extend the same method of treatment to the granites of greatest economic importance in Massachusetts, New Hampshire, and Rhode Island. These are the granites of Milford, Quincy, Rockport, and Becket (near Chester) in Massachusetts, of Concord, Milford, and Conway in New Hampshire, and of Westerly in Rhode Island. In addition certain granites from Auburn and Sunapee in New Hampshire are incidentally considered. The granites of Monson and Graniteville, in Massachusetts, and of Troy, in New Hampshire, and of several other places in the three States named, will be taken up in a later publication. Bulletin No. 313 contains a scientific discussion of granite adapted to the general reader, and also, in its economic portion, material of general economic interest. For convenience of reference those parts of that bulletin are here republished, but in revised form. In both bulletins some purely scientific matter necessarily appears in the economic part, in the geological summary which prefaces the description of each group of quarries.

The field work upon which this report is based, involving visits to 88 quarries, was done in 1906. The petrographic work necessitated the study of 350 thin sections. The writer is indebted to Dr. Albert Johannsen, of the United States Geological Survey, for critical revision of his determinations of the minerals of these sections, and to Messrs. E. C. Sullivan, George Steiger, and W. T. Schaller, chemists, of the Survey, for determinations of the percentages of lime soluble in hot dilute acetic acid in 23 granites. Miss A. T. Coons, of the Survey, has contributed a chapter of statistics on the granite produced at the centers referred to and in the States named. Prof. Charles Palache, of Harvard University, has consented to the insertion of a

note on a dike at Quincy. Mr. E. W. Branch, C. E., of Quincy, has allowed the reproduction of his copyrighted map of its quarries. Information as to the general geological relations of the various granites has been obtained from works on local geology by Emerson and Perry, Shaler and Tarr, Sears, Crosby, C. H. Hitchcock, Kemp, and Rice and Gregory. These are quoted or referred to in the section preceding the descriptions of the quarries of each district.

The Rosiwal method of estimating mineral percentages has been applied to all the types of granite described. These types will be found defined and classified, both scientifically and commercially, in the table on pages 211-212, which is followed by a section on their relative commercial values.

The numbers of the specimens described, to which those of the thin sections correspond, are given, so that the descriptions can be verified by consulting the collections at the National Museum. All these specimens have been prepared from blocks selected by the foremen or superintendents.

Such scientific terms as have unavoidably been used are explained in the glossary at the end, where also some of the quarrymen's terms are made intelligible to the general or scientific reader.

The names applied to the various granites in this report are, with a few exceptions, merely local or trade designations. Their employment in this economic bulletin does not affect the standing of any particular name as a geologic formation name.

PART I.—SCIENTIFIC DISCUSSION.

GENERAL FEATURES.

GRANITE PROPER.

DEFINITION.

Granite, in a general sense, is essentially an entirely crystalline igneous rock, consisting mainly of quartz, potash feldspar, and a feldspar containing both soda and lime, also of a small amount of either white or black mica or both, and sometimes of hornblende, more rarely of augite, or both. Where granite has, subsequent to its crystallization, been subjected to pressure sufficient to produce a parallelism in the arrangement of its minerals—that is, a schistosity—it is no longer a true granite, but a gneiss or granite gneiss; a sedimentary rock, however, in becoming crystalline may resemble a granite gneiss and is called a sedimentary gneiss.

ORIGIN.

Granite is now regarded as the product of the slow cooling and crystallization of molten glasslike matter at a dull-red heat—matter which contained superheated water, and was intruded from below into an overlying mass of rock of sufficient thickness not only to prevent its rapid cooling and its general extrusion at the surface, but also to resist its pressure by its own cohesion and powerfully to compress it by its own gravity. As carbonic acid can be liquefied only under pressure, its presence in liquid form within some of the microscopic cavities in the quartz of granite is alone evidence that the rock was formed under pressure. That the temperature at which granite solidified was comparatively low has been inferred from the fact that it contains minerals which lose their physical properties at temperatures higher than dull-red heat. The relations of the mineral constituents of granite to one another show the order in which they must have crystallized. This order differs from that in which they would crystallize if molten in a dry state, but laboratory experiments have shown that the presence of even a small quantity of water suffices to change that order of crystallization. The presence of superheated water in the formation of granite, inferred from the arrangement of its minerals, and the pressure indicated from a study of the contents of the microscopic cavities of its quartz show that the conditions requisite to its formation included not only the pressure of a great

overlying mass of rock but also powerful expansive pressure from below. Had this molten matter been extruded at the surface it would have cooled so rapidly that but few of its constituent molecules would have had time to arrange themselves in geometric order. The process of crystallization would have been arrested by the sudden passage of the material into the solid state and the product would have been a volcanic glass somewhat resembling that which forms cliffs in Yellowstone National Park. In granite, however, the mass has cooled slowly enough to permit the complete crystallization of the originally molten glasslike matter, and no unarranged molecules remain.

The overlying rock mass which furnished so large a part of the pressure required to form granite has at many places been removed from it by erosive processes that operated through great stretches of time. Indeed, it is only by the removal of this mass that granite is anywhere naturally exposed. Although this mass may have measured thousands of feet in thickness, its former presence is at some places attested only by a thin capping on the granite or by fragments which the lacerating action of the intruding granite has incorporated into itself.

The lacerating effect of an intrusive eruption and the subsequent erosion of some of the overlying strata have been reproduced experimentally.^a The conversion of granite itself back into a material which upon cooling under ordinary conditions has proved to be a glass, has been effected in the laboratory, and the chief mineral constituents of granite have been artificially crystallized at high temperature in the presence of water vapor under high pressure, but the conditions requisite for the production of a granitic rock from its chemical constituents have not yet been successfully imitated.

Some granite shows locally a certain alignment of its mica plates and feldspars, due to the flow of the mass while it was in a plastic state—a structure which was probably controlled by the pressure and form of the bordering rock. This “flow structure” should not be confounded with the schistosity which is due to later pressure and which also involves mineral changes and is usually regional rather than local in extent.

The great differences in the grade of texture in granites—the mineral particles ranging from an average diameter of one-fiftieth inch

^a Howe, Ernest, Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 3, pp. 294-296, Pl. XLIII. Reyer, of the Austrian Geological Survey, has illustrated a granite intrusion by this simple experiment: Upon a table a frame of clay, say 2 inches thick, is constructed about a square piece of board 1 inch thick. After removing the board a mixture of medium thick plaster and red coloring matter is poured into the inclosure. The surface of the red plaster is then sprinkled with a layer of white plaster powder. After making a lens-shaped perforation in the center of the board it is again fitted into the frame and pressed against the red and white layers until the white plaster exudes through the opening, and afterwards the red intrudes the white. The materials are allowed to harden and are then sawn to show the structure. See Reyer, Ed., *Tektonik der Granit Ergüsse von Neudeck und Carlsbad*, etc. *Jahrb. K.-k. geol. Reichsanstalt*, vol. 29, 1879, pp. 432-433, fig. 6.

(0.50 mm.) and even 0.0069 inch (0.175 mm.) to over half an inch—is attributed to differences in the rate of cooling. The portions at the margin of the mass, which cooled rather quickly, crystallized in very small crystals, while the central portions, which cooled more gradually, became coarsely crystalline.

MINERALOGICAL COMPOSITION.

Feldspar is the most conspicuous and generally the most abundant mineral in granite. By its color or colors it usually determines to a large extent the general color of the rock; and by the light which it reflects it causes also its brilliancy. It is easily distinguished from the other constituents by its smooth cleavage surfaces and milky, bluish white, or opalescent, or reddish, brownish, or greenish color. Granite usually contains two kinds of feldspar, the most abundant of which is generally potash feldspar, a silicate of alumina and potash. This occurs in one of two crystal forms, orthoclase or microcline, or in both, which, however, can be distinguished only by means of the microscope. The other feldspar (plagioclase), containing both soda and lime, although it may be of the same color as the potash feldspar, can often be distinguished from it by the very fine parallel lines on its surface. Usually it differs greatly in color from the first. The potash feldspar may be reddish or brownish; the plagioclase may be white or greenish. Under the microscope the soda-lime feldspar can be readily distinguished from the potash feldspar by its behavior in polarized light, which brings out its crystalline structure and indicates its particular variety and approximate chemical composition. A granitic rock that contains the two feldspars in equal proportions is distinguished by a special technical name.

Quartz (silica), the next most abundant constituent, is readily known by its glassy luster, uneven fracture, and brittleness. It may be colorless, bluish, opalescent or amethystine, or smoky. The quartz in the rock determines in some measure its shade. The vitreousness of the quartz greatly affects the granite.

The next most abundant constituent of granite is mica, which is present in two forms—the white (muscovite, or potash mica), essentially a silicate of alumina with potash, soda, and ferrous oxide, and the black (biotite, or magnesia mica), essentially a silicate of alumina with potash, magnesia, and both ferric and ferrous oxide. Granite may contain one or both of these. The dimensions and number of the scales of black mica largely determine the shade of many granites.

Hornblende, a constituent of many granites, although greenish (rarely bluish), may appear as dark as the black mica, but, unlike that mineral, it does not split into scales. Augite and hornblende resemble each other so closely when in minute particles that they can be distinguished only by means of the microscope. Both may occur.

In addition to these more important minerals, others are usually present in minute or microscopic quantities. Some of these, kaolin, sericite (a potash mica or muscovite), chlorite, epidote, zoisite, and calcite, as well as paragonite (soda mica), which may possibly be present, are the result of chemical changes in the feldspars or the biotite or hornblende and are therefore called "secondary." Others—like zircon, apatite, titanite, rutile, tourmaline, fluorite, garnet, magnetite, molybdenite, ilmenite, pyrite, allanite—are regarded as original "accessory constituents." Calcite also occurs in microscopic quantity as an original mineral of some granites.^a Of these minor accessories, pyrite (iron disulphide) and calcite (lime carbonate) alone have economic significance, for these may discolor or weaken the stone when dissolved or oxidized on an exposed surface.

The chemists of the United States Geological Survey have treated 10 granites from Maine and 23 from Massachusetts, New Hampshire, and Rhode Island with hot dilute acetic acid and find that the Maine granites contain 0.14 to 0.43 per cent of CaCO_3 (lime carbonate) and the others from 0.07 to 0.6 per cent.

During the preparation of the bulletin on Maine granites and of this bulletin the following accessory minerals have been detected: Garnet, zircon, titanite, magnetite, pyrite, molybdenite, fluorite, apatite, allanite, and rutile; also the following secondary minerals: Hematite, limonite, calcite, kaolin, muscovite, paragonite (probably) quartz, hornblende, riebeckite, epidote, and zoisite.

The arrangement of the important minerals in the stone will be described under the heading "Texture."

The percentages of the mineral constituents differ within wide limits in granites from different localities. The percentage of muscovite and of the ferromagnesian minerals (biotite, hornblende, augite) is always small, while that of the feldspar and quartz is large. There is considerable variation in the relative amounts of feldspar and quartz and still more in the amounts of each of the feldspars.

CHEMICAL COMPOSITION.

The chemical composition of granite is of less scientific and economic significance than its mineral composition, for, although chemical analysis shows the percentages of the constituent elements, the process by which these are determined necessarily mingles the elements of several minerals whose proportions vary and whose contribution to the physical properties of the rock differ greatly. When, however, a combination of elements occurs only in one or two of the minerals the chemical analysis serves to corroborate the evidence obtained by microscopic analysis.

^a See Zirkel, *Petrographie*, vol. 2, p. 13, and Weinschenk, *Abhandl. Math.-phys. Classe*, k. Bayer. Akad., vol. 18, p. 730, Pl. V.

Many analyses of granite have been published, but it will suffice here to give the extremes of the percentages shown by some of the more important of these and to refer the reader to works containing complete analyses.^a Four analyses of granites from Scotland, Ireland, Italy, and Sweden show the following ranges:^b

Analyses of European granites.

| | |
|--|-------------|
| SiO ₂ (silica)..... | 70.60-74.82 |
| Al ₂ O ₃ (alumina)..... | 14.86-16.40 |
| Fe ₂ O ₃ (ferric oxide)..... | .10- 1.63 |
| FeO (ferrous oxide)..... | .36- 1.64 |
| MnO (manganese oxide)..... | .00- .48 |
| MgO (magnesia)..... | .23- 1.00 |
| CaO (lime)..... | .89- 2.47 |
| Na ₂ O (soda)..... | 3.51- 6.12 |
| K ₂ O (potash)..... | 3.55- 5.10 |

Ten analyses, made at the laboratory of the United States Geological Survey, of granites from Arizona, California (2), Colorado (4), Maryland, Michigan, and Montana, show the following ranges:^c

Analyses of American granites.

| | |
|--|-------------|
| SiO ₂ (silica)..... | 66.68-77.68 |
| Al ₂ O ₃ (alumina)..... | 11.63-16.38 |
| Fe ₂ O ₃ (ferric oxide)..... | .00- 1.66 |
| FeO (ferrous oxide)..... | .09- 3.32 |
| MgO (magnesia)..... | .04- 2.19 |
| CaO (lime)..... | .12- 4.89 |
| Na ₂ O (soda)..... | 2.36- 5.16 |
| K ₂ O (potash)..... | 1.87- 6.50 |
| TiO ₂ (titanium dioxide)..... | .07- .45 |
| P ₂ O ₅ (phosphoric acid)..... | Trace- .10 |

The average of 21 analyses of even-grained Georgia granites made by Watson^d yield the following percentages:

Analyses of Georgia granites.

| | |
|--|-------|
| SiO ₂ (silica)..... | 69.97 |
| Al ₂ O ₃ (alumina)..... | 16.63 |
| Fe ₂ O ₃ (ferric oxide)..... | 1.28 |
| CaO (lime)..... | 2.13 |
| MgO (magnesia)..... | .55 |
| Na ₂ O (soda)..... | 4.73 |
| K ₂ O (potash)..... | 4.71 |

One hundred and thirty-seven analyses of Swedish granites will be found arranged in a continuous table in a recent work of Holmquist.^f

^a See Washington, H. S., Prof. Papers U. S. Geol. Survey Nos. 14, 1903, and 28, 1904; also Clarke, F. W., Bull. U. S. Geol. Survey No. 228, 1904.

^b Geikie, Archibald, Text-book of Geology, 4th ed., vol. 1, London, 1903, p. 207.

^c See Bull. U. S. Geol. Survey No. 228, p. 54, analysis D; p. 197, analysis D; p. 231, analysis A; p. 232, analysis A; p. 185, analysis B; p. 161, analyses A, C, F; p. 78, analysis A; p. 145, analysis C.

^d Watson, Thomas L., Bull. Georgia Geol. Survey No. 9-A, 1902, p. 241.

^e Extremes 68.38-72.56.

^f Holmquist, P. J., Studien über die Granite von Schweden: Bull. Geol. Inst. Univ. Upsala, VII, Nos. 13 and 14, 1904-5, pp. 77-269. Upsala, 1906.

It should be noted that in all these analyses most of the lime is to be attributed to the lime-soda feldspar and nearly all the rest of it to apatite (lime phosphate), or to hornblende and augite when these are present.

It is of interest to note in this connection that certain Scotch and Irish granites contain from 1.6 to 2.8 volumes of gas per volume of rock. This gas is inclosed in microscopic cavities within the minerals, and in the Scotch granite consists of carbon, oxygen, hydrogen, and nitrogen in the following combinations and proportions: CO_2 , 23.60; CO , 6.45; CH_4 , 3.02; N_2 , 5.13; H_2 , 61.68.^a These gases are probably present in all granites.

TEXTURE.

Definition.—By the texture of the rock is to be understood those characteristics which are apparent on its surface, or, more exactly, the forms and mutual relations of its minerals as seen without and with a microscope.

Character and grade.—The most important feature of granite is the character of its grain. Some granites are even grained; others contain more or less thinly disseminated and complete crystals of feldspar in a mass of finer, even-grained material—that is, they show what is called porphyritic texture. The next most important feature—perhaps more important—is the relative coarseness or fineness of grain in an even-grained granite. Three grades of texture of this sort may be distinguished: (1) *Coarse*, in which the feldspars generally measure over 1 cm., or two-fifths inch; (2) *medium*, in which they measure under 1 cm. (two-fifths inch) and over 0.5 cm. (one-fifth inch); (3) *fine*, in which they measure under 0.5 cm. (one-fifth inch). In some coarse-grained granites the feldspars measure one or several inches, and in some fine-grained ones all the particles range from 0.25 mm. to 1 mm. (one twenty-fifth inch) in diameter, and some average as low as 0.50 mm., or one-fiftieth inch. Extremely fine ones average 0.175 mm., or about seven one-thousandths inch.

Forms of minerals.—Even without the aid of the microscope it will be noticed that, except in granites of porphyritic texture, the minerals rarely attain their complete crystalline form. They have interfered with one another's growth. It will also be noticed that some of the crystals of feldspar in some granites are surrounded by a border of a different feldspar. Thus a red feldspar may be bordered by a white or greenish one, or vice versa. Either of these may be the potash feldspar and the other a soda-lime feldspar. It will also be noticed that many of the feldspars are not simple incomplete or complete crystals, but "twins," having the cleavage planes in one half at a different angle from those in the other half, so that when held in the sunlight only one half will reflect the light in one position.

^a Tilden, W. H., Proc. Roy. Soc. London, vol. 60, No. 366, Feb. 20, 1897, pp. 454, 455.

Arrangement of minerals.—A polished surface of any medium or coarse-grained granite shows that the quartz fills up the spaces between the feldspars—that is, was formed after them—also that both feldspars and quartz inclose particles of mica, etc., which must therefore have crystallized before them. Under the microscope the arrangement of the minerals is found to be such that they must usually have crystallized in the following order: Magnetite, pyrite, apatite, zircon, titanite, hornblende, biotite, muscovite, the feldspars, and, last of all, the quartz. It should be noted, however, that many of the feldspar crystals contain intergrown quartz, so that some of the quartz must therefore have crystallized at the same time as the feldspar. The structure of the potash feldspar in some granites is very intricate, as it contains microscopic intergrowths of a lime-soda feldspar, both having evidently crystallized at the same time or in close alternation. Also, as stated above, the potash feldspar may be rimmed with soda-lime feldspar, or vice versa.

PHYSICAL PROPERTIES.

Granite derives its physical properties from its mineralogical constitution, particularly from its large content of feldspar and quartz, and from its texture. Among these physical properties the most important are weight, cohesiveness, elasticity, flexibility, hardness, expansibility, porosity, and vitreousness. Each of these qualities will be taken up in the order in which they are here stated.

Weight.—In order to establish a fixed standard the weight of a rock is compared to that of an equal volume of distilled water. The weight thus determined is called its specific gravity. The specific gravity of granite ranges from 2.593 to 2.731. The average of these extremes is 2.662, which is equivalent to 2 long tons, or 4,480 pounds, to the cubic yard, or about 165 pounds to the cubic foot. Geikie^a calls attention to the change in the weight of granite when immersed in sea water, as given by Stevenson.^b A red granite having a specific gravity of 2.71, or 13.2 cubic feet to the ton in air, will in sea water of a specific gravity of 1.028 measure 21.30 cubic feet to the ton.

Cohesiveness.—The amount of cohesiveness of a rock is ascertained by determining its crushing strength—that is, the weight in pounds required to crush it or to destroy its cohesion. The ultimate compressive strength of granite ranges from about 15,000 to 43,973 pounds per square inch,^c but the usual range is from 18,000 to 34,000 pounds. Herrmann^d gives the crushing strength of European granites as ranging from 1,100 to over 3,000 kilograms per square centimeter.

^a Text-book of Geology, 4th ed., p. 568.

^b Stevenson, T., Harbours, p. 107.

^c These extremes are from Wisconsin granites. See Buckley, Ernest B., On the building and ornamental stones of Wisconsin: Bull. Wisconsin Geol. and Nat. Hist. Survey, No. 4, pp. 361, 390.

^d Herrmann, O., Steinbruchindustrie und Steinbruchgeologie, p. 43.

Elasticity.—Tests made at the United States Arsenal at Watertown, Mass., to determine the compressive elasticity of specimens of granite from Arkansas, Connecticut, Maine, Minnesota, and New Hampshire, show that specimens of granite, in a gaged length of 20 inches and a diameter of 5.5 inches at the middle, when placed under a load of 5,000 pounds to the square inch, suffered compression ranging from 0.0108 to 0.0245 inch, resulting in a lateral expansion ranging from 0.005 to 0.007 inch, and giving ratios of lateral expansion to longitudinal compression ranging from 1: 8 to 1: 47.^a

Flexibility.—Although granite contains a large amount of brittle material (estimated at from 30 to 60 per cent) and the interlocking of its various particles give to it great cohesion and rigidity, yet in sheets of sufficient thinness and areal extent it is flexible. Sheets half an inch thick and 4 feet long may be bent, as noted in the description of the Lawton quarry, at Norridgewock, in Bulletin No. 313, page 151. Whether flexibility in this case was conditioned upon a slight loosening of the grains by chemical and physical change is uncertain.

Hardness.—As will be seen by reference to the tests for hardness described on page 66, granites differ greatly in hardness. This difference is due not merely to differences in the percentage of quartz, but also to variations in the character of the feldspars.

Expansibility.—The expansibility of granite has been variously tested. Bartlett^b found that a piece of granite coping 5 feet long, under the effect of a winter temperature of 0° F. and a summer temperature of 96° F., expanded 0.027792 inch, or 0.000004825 inch per inch for each degree. The ordnance department at the Watertown Arsenal^c tested the granites referred to under the heading "Elasticity," and found that slabs of gaged lengths of 20 inches in passing from a cold-water bath at 32° F. through a hot-water bath at 212° F., and back again to cold water at 32° F., expanded from 0.0017 to 0.0059 inch, averaging 0.0040 inch.

Porosity.—Granite contains and absorbs water, which is held in microscopic spaces both within and between its constituent minerals. Ansted^d states that granite generally contains about 0.8 per cent of water and is capable of absorbing about 0.2 per cent more. In other words, a cubic yard of granite weighing 2 tons contains in its ordinary state about 3½ gallons of water and can absorb nearly a gallon more on being placed in pure water for a short period. Buckley^e found that the pore space or porosity in fourteen Wisconsin granites

^a Report of the tests of metals, etc., made with the United States testing machine at Watertown Arsenal, Mass. (1895), 1896, pp. 339-348.

^b Bartlett, Wm. C., Experiments on the expansion and contraction of building stones by variation of temperature: Am. Jour. Sci., 1st ser., vol. 22, 1832, pp. 136-140.

^c Op. cit., p. 322.

^d Ansted, D. T., quoted by Edward Hull in A treatise on building and ornamental stones of Great Britain and foreign countries, 1872, p. 30.

^e Op. cit., p. 400.

ranges from 0.17 to 0.392 per cent, and that the ratio of absorption (percentage of weight of absorbed water to the average dry weight of the sample) of the same granites ranges from 0.17 to 0.50. Merrill^a has shown that certain Maryland granites absorb from 0.196 to 0.258 per cent of water after drying twenty-four hours at 212° F. and then being immersed for twenty-four hours.

Vitreousness.—The vitreousness of granite is due to that of its contained quartz. Under extreme changes of temperature, as in a city fire, where water is thrown on the stone, granite exfoliates badly. This exfoliation or shelling is attributable to the unequal expansion or contraction of its outer and its inner portions under sudden changes of temperature. It is also probably connected with the vitreousness of the quartz, and possibly also in a measure with the liquids contained in microscopic cavities of the quartz. The unequal expansive ratios of the different constituent minerals would result in general disintegration, not in exfoliation.

Buckley^b subjected 2-inch cubes of five Wisconsin granites to high temperature tests and found that they were all destroyed at 1,500° F. One of them cracked at 1,000°; two others began to disintegrate at 1,200°. The most notable change was that "when struck with a hammer or scratched with a knife they emitted the sound peculiar to a burnt brick." Cutting^c applied a fire test to granites from eighteen quarries in Maine, Maryland, Massachusetts, Minnesota, New Hampshire, Vermont, and Virginia, with the result that after saturation they all stood a temperature of 500° F. without damage, but showed the first appearance of injury at 700°–800° and were rendered worthless at 900°–1,000°. Twenty-three sandstones subjected to the same tests showed the first appearance of injury at 800°–900° and became worthless at 950°–1,200°. His general results agree with those of experience as to the relative fire endurance of granite and sandstone.^d The behavior of granite under very high temperature is not attributable to any one physical property. The physical properties of granite are further discussed in Part II, under the heading "Tests of granite" (pp. 65–68).

CLASSIFICATION.

The varieties of granite are so numerous that for either scientific or economic purposes they need to be classified.

Scientific classification.—For scientific purposes granites may be classified according to their less essential mineral constituents—mica, hornblende, and augite. Thus a granite containing white mica

^a Merrill, G. P., Maryland Geol. Survey, vol. 2, pp. 94, 95.

^b Op. cit., p. 411.

^c Cutting, Hiram A., Sixth Rept. Agric. Vermont, 1880, pp. 47–54; also, Durability of building stone: Am. Jour. Sci., 3d ser., vol. 21, 1881, p. 410.

^d Merrill, G. P., Stones for building and decoration, p. 435.

is termed a muscovite granite; one containing black mica, a biotite granite; one containing both, a muscovite-biotite granite. A granite containing black mica and hornblende is called a biotite-hornblende granite. Granites may also be classified according to both their mineral and their chemical composition. These two form the basis of the latest classification of igneous rocks, which is too complex to be outlined here.^a

Economic classification.—For economic purposes granites may be classified first as to *texture*—as even grained, or porphyritic, or as coarse, medium, or fine, according to the scale given on page 14. Those of extra coarse or extra fine texture can be distinguished by the prefix *very*. This scale gives five grades of texture. Granites should also be classified as to *general color and shade*—as pinkish, reddish, lavender, or gray or warm gray (that is, a gray showing the presence of a slight reddish, reddish-purplish, or yellowish tinge), and as dark, medium, or light; and the dark and light gray may be modified by prefixing the word *very*. They may be further classified and designated by *the colors of their most conspicuous minerals*, the feldspars, quartz, and mica. A stone may thus be called a coarse, even-grained, warm-gray granite, with lavender and white feldspars, smoky quartz, and black mica; or another may be called a fine, even-grained, very light gray granite, with white feldspar, clear quartz, and both white and black mica. Lastly, they may be classified by their uses—as constructional, monumental, inscriptional, polish, or statuary granites. This scheme of classification will suffice for ordinary economic purposes. The outline of an exhaustive technical description of any granite can be constructed from the tests enumerated on pages 65–68.

GENERAL STRUCTURE.

The term “structure” embraces all the divisional planes that traverse the rock. These occur at intervals ranging from a microscopic distance to one measured by scores of feet, and either cross or, very rarely, give a course to the texture resulting from crystallization.

FLOW STRUCTURE.

Where two varieties of granite lie in contact, as at Redstone, N. H. (p. 177), the dividing line between them indicates the direction of their flow, for the same reason that the course of the flow of a stream would be shown by the demarcation between its water and that of a muddy tributary a little below their junction. In some places this direction is also indicated by streaks or sheets of mica scales parallel to the direction of the line between the granites. Such streaks, therefore,

^a See Cross, Iddings, Pirsson, Washington, *Quantitative Classification of Igneous Rocks based on Chemical and Mineral Characters, with a Systematic Nomenclature*, Chicago, 1903; also *Jour. Geology*, vol. 10, 1902, pp. 555 et seq.

when alone are regarded as indicating flow structure. They may be inclined at all angles or be in horizontal undulations with axes pitching 10° to 40° . In some Massachusetts and New Hampshire quarries the structure is parallel to the surface of the granite at its contact with overlying rocks, or surrounds in parallel bands the surface of large inclusions. (See pp. 62, 109, and fig. 5.) Flow structure also is conspicuous in the granite of Milford, Mass., and in some of the quarries of Milford, N. H. (See pp. 77, 158.) The very local character of such structural features indicates that they are not due to pressure which affected the entire region, but that they originated while the granite masses were still plastic. A granite that exhibits flow structure is called by some writers a flow gneiss.

RIFT AND GRAIN.

The rift in granite is a feature of considerable scientific interest and of much economic importance. It is an obscure microscopic foliation—either vertical, or very nearly so, or horizontal—along which the granite splits more easily than in any other direction. The grain is a foliation in a direction at right angles to this, along which the rock splits with a facility second only to that of the fracture along the rift. After a little experience an observer can detect the rift with the unaided eye, where it is marked.

The earliest mention of rift in geological literature appears to be that by J. F. W. Charpentier^a in 1778, who noticed that granite mill-stones which were cut with their largest diameter parallel to the rift were much more readily worn than those cut at right angles to it, that is, parallel to the "hard way." He attributed this to a parallel arrangement of the mineral particles. The next reference to rift is by Pötsch^b in 1803, who described it in the granites of Lausitz, in Saxony. In 1833 it was referred to by Enys and Fox^c as characterizing the granites of Penrhyn, and was referred to in 1834 by De la Beche;^d also in 1855 by Adam Sedgwick,^e who attributed it to crystalline action at the time of consolidation. In 1860 C. F. Naumann^f attributed it either to local differences of cohesion or to an inner strain possibly related to the direction of original consolidation. In 1864 G. vom Rath^g described a diorite from Monte Adamello, in the Tyrol, without dominant rift, and observed that the rift course was, on the contrary, uniform in the granite of Monte Motterone

^a Mineralogische Geographie des chursächsischen Lande, 1778. See also his Beobachtungen über die Lagerstätte der Erze, 1779.

^b Bemerkungen und Beobachtungen über das Vorkommen des Granits in geschichtete Lagen, p. 140.

^c London and Edinburgh Phil. Mag., 3d ser., vol. 2, pp. 321-327.

^d Researches in theoretical geology, and Report on the geology of Cornwall.

^e Trans. Geol. Soc. London, 2d ser., vol 3, pt. 3, p. 483.

^f Lehrbuch der Geognosie, vol. 2, 2d ed., Leipzig, 1860, pp. 191-192.

^g Beiträge zur Kenntniss der eruptiven Gesteine der Alpen: Zeitschr. d. Deutschen Geol. Gesell., vol. 16, pp. 249-260.

(Baveno). In 1876 James D. Dana stated that "granite often has a direction of easiest fracture due to the fact that the feldspar crystals have approximately a uniform position in the rock bringing the cleavage planes into parallelism."^a This is true in those places where the directions of flow structure and rift chance to coincide, and it may be true in some porphyritic granites that the porphyritic crystals are arranged with some reference to the rift, but that it is not the cause of rift is shown by the fact that the feldspar cleavages usually intersect the rift face at all angles. In 1879 Reyer^b attributed rift to an original arrangement of particles by flowage. As rift in places crosses flow structure this explanation is also inadequate. In 1893 Carl C. Riiber, in a work on the granite industry of Norway,^c described an augite syenite with inferior rift and grain, in which the cleavage planes of the individual feldspar crystals were parallel to the two cleavages, rift and grain, of the rock. Finally, in 1894, F. Zirkel,^d after reviewing the opinions of his predecessors, tentatively suggested that rift may be the result of conditions of strain brought about by pressure from one side only, which failed to find adequate relief in jointing.

The only available recent American data on this subject are furnished by Tarr, Whittle, and Finlay.^e

Tarr presents four figures reproduced from drawings made from enlarged views of thin sections showing the rift in Cape Ann hornblende-biotite granite. These figures and his descriptions indicate that rift consists of microscopic faults, most of which meander across feldspar and quartz alike, although some go around the quartz particles rather than through them. In the feldspars rift usually follows the cleavage. These minute faults are lined with microscopic fragments of the mineral they traverse and some of them send off short, minute diagonal fractures on either side. In examining such a structure it is important to make sure that the grinding of the section has not in any way modified the original fractures. Tarr adds that at Cape Ann the rift does not traverse the "knots" or the basic dikes that cross the granite.

Whittle gives two sketches made from polished surfaces of a well-known granite quarried by the Maine and New Hampshire Granite Company at Redstone, N. H. One of these sketches, made from a surface running at right angles to the rift, shows quartz and feldspar

^a Manual of Geology, 2d ed., 1876, p. 628.

^b Reyer, Ed., Tektonik der Granit Ergüsse von Neudeck und Carlsbad, etc.: Jahrb. K.-k. geol. Reichsanstalt, vol. 29, 1879, p. 415.

^c Norges granit industri; Norges Geol. undersogelse: Aarvog for 1893, No. 12, p. 45.

^d Lehrbuch der Petrographie, 2d ed., vol. 2, 1894, pp. 52-53, p. 415.

^e Tarr, R. S., The phenomena of rifting in granite: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 267-272, figs. 1-4; also Economic Geology of the United States, 1895, p. 124. Whittle, Charles L., Rifting and grain in granite: Eng. and Min. Jour., vol. 70, 1900 p. 161, figs. 1 and 2. Finlay, G. I., The granite area of Barre, Vt.: Report of Vermont State Geologist, new ser., 1902, p. 54.

grains traversed by a generally parallel set of lines corresponding to the rift planes. The lines are more numerous in the feldspar than in the quartz grains. The other sketch, made from another specimen, shows besides the rift lines another less pronounced set intersecting these at right angles. This second set corresponds to the grain. Whittle calls attention to the fact that notwithstanding the marked rift and grain at this quarry the stone stood a compression test of 22,370 pounds to the square inch, and was, therefore, not appreciably weakened by the microscopic fractures. A visit made by the writer in 1906 to the quarry at Redstone, N. H., has corroborated Whittle's observations. The details of the rift and grain structure observed are given on page 42.

Finlay, in describing the quartz of Barre granite, says: "The pronounced cracks which are seen to cross from one crystal to its neighbor, without interruption, are an indication of pressure phenomena in the magma after its consolidation. These cracks are notable as containing microscopic dendritic growths, which are analogous to the arborescent forms of MnO_2 , and possibly identical with them."

Another peculiarity of rift is that the angle of its inclination may at some places be modified by gravity. Thus, in some localities a block will split at one angle from the top, but at another from the side; or, again, at one angle where the mass of the block is at the right and at another where it is at the left of the line of fracture. Experienced granite workmen at Concord, N. H., and Quincy, Mass., report that at some places a block that would show a horizontal rift when split from one point of the compass (say the north) acquires an inclined rift if split from the south or the east or west. The cause of this is not apparent. There are also indications that a slight alteration of the feldspars may improve the rift. Finally, as is well known to granite quarrymen, rift and grain are modified by temperature, the effect of winter cold in New England (frost?) being to intensify the rift and grain where they are weak.

Herrmann^a states that in Saxony the rift is parallel to the horizontal sheets or joints. That is true for short distances in the New England quarries, but where the rift is horizontal and the sheets curve it crosses the sheets, and of course where the rift is vertical it crosses them throughout. Exceptionally, in one of the quarries at Quincy, Mass., a foreman reported to the writer a deflection of the rift in apparent relation to the increasing inclination of the sheets.

Rift and grain are not always pronounced. Either or both may be very feeble or may be absent.

At the Armbrust quarry, in Vinalhaven, Me., there is a horizontal rift confined to a 4-foot mass striking across the granite hillock.

^a Herrmann, O., *Steinbruchindustrie und Steinbruchgeologie*, Berlin, 1899, p. 109.

The presence of fairly good rift or grain is an important economic factor in the granite industry, for it diminishes both the amount of labor in drilling for blasts and in splitting.

That the rift is a factor in the crushing strength of granite is shown by the results of tests of Mount Waldo granite from Frankfort, blocks of which when placed on the bed—that is, with pressure applied at right angles to the rift—showed an ultimate strength to the square inch of 31,782 to 32,635 pounds (average, 32,208), but when placed on the side—that is, with pressure applied parallel to the rift—showed an ultimate strength of from 29,183 to 30,197 pounds (average, 29,690). In the first test the first crack appeared in the block at a pressure of from 120,000 to 123,300 pounds (average, 121,650) and in the second test it appeared at one of 107,400 to 112,600 pounds (average, 110,000 pounds).^a Rift and grain in their relations to fluidal cavities are discussed on pages 42–47.

SHEETS.

The division of granite into “sheets” or “beds” by jointlike fractures which are variously curved or nearly horizontal, being generally parallel with the granite surface, attracted the attention of geologists long ago. In 1797 De Dolomieu, and shortly before that De Saussure, described granite sheet structure.^b

In 1803 Pötsch^c published a paper on the subject. In 1841 Edward Hitchcock described what he termed the “Pseudo-stratification of granite,” near Worcester and Fitchburg, Mass., as a concentric, onion-like structure generally conforming to the rock surface.^d

In 1860 C. F. Naumann^e dealt with the subject in his text-book.

In 1863 F. von Adrian described the structure in Bohemia and regarded it as the result of cooling.^f

In 1879 Reyer^g described it from another part of Bohemia; and in 1894 Zirkel^h also treated the subject in his petrography.

Although this is the most striking feature in every granite quarry and largely makes the granite industry possible, there is a great diversity of opinion as to its cause. Whitneyⁱ writes:

The curves are arranged strictly with reference to the surface of the masses of rock, showing clearly that they must have been produced by the contraction of the material while cooling or solidifying, and also giving very strongly the impression that, in many places, we see something of the original shape of the surface as it was when the granitic mass assumed its present position.

^a Reilly, J. W., Ordnance Rept., tests of materials, etc. (1900), 1901, p. 1119. See also result of test of Concord granite, p. 147, this bulletin.

^b Journal des Mines, VII, No. 43, p. 426.

^c Op. cit.

^d Final Report, Geology of Massachusetts, p. 683.

^e Op. cit., p. 191.

^f Jahrb. K.-k. geol. Reichsanstalt, vol. 13, pp. 155–182.

^g Op. cit., p. 405.

^h Zirkel, Petrographie, vol. 2, p. 52.

ⁱ Whitney, J. D., Geology of California, vol. 1, 1865, Geology, p. 372; also pp. 227, 417, and figs. 49–54.

Shaler, a few years later,^a attributed the sheet structure to expansion due to solar heat.

C. H. Hitchcock^b notices in New Hampshire granite "numerous joints, the planes of which correspond very nearly with the slope of the hill," but does not undertake to explain them.

Vogt^c states that the sheets in granites of southeastern Norway measure from 6 inches to 6 feet in thickness and dip from 8° to 33° on the sides of the mountains, toward the valleys, but that they are horizontal on top and approximately parallel to the surface. He shows that they are of preglacial origin, attributes them to the same cause that is postulated by Whitney for those in California, and regards them as parallel to the original surface of the granite masses.

Harris,^d referring to the English granite quarries, writes: "In every quarry we visited we found that the direction of the 'beds' approximately corresponded with the outline of the hill on which it was situated." He offers no explanation of the phenomenon, however.

J. J. Crawford^e describes the sheet structure at granite quarries in Madera and Tulare counties, California, as consisting of "concentric layers conforming in a general way to the contour of the hills," but suggests no cause for them.

Herrmann,^f who made a special economic study of the granites of Saxony, writes:

Upon closer inspection it appears that the granite sheets are elongated lenses overlying one another, of which the upper one, as a rule, has its bulging part lying in the depression formed by the two underlying lenses where they come together.

Branner^g describes the exfoliation of the granitoid gneisses in Brazil, which he attributes only in part to changes of temperature. He calls attention to the fact that the linear expansion of a mass of gneiss 300 feet long at a depth of 15 feet from the surface under a surface temperature of 103° F. would amount to only 0.072 inch; and he quotes the results of Forbes, Quetelet, and others to show that the annual change of temperature can penetrate rock only to a depth of 40 feet in temperate regions and still less in the Tropics.

Merrill^h describes Stone Mountain, in Georgia, as a boss of granite 2 miles long by 1½ miles wide and 650 feet high, which owes its form

^a Shaler, N. S., Notes on the concentric structure of granitic rocks: *Proc. Boston Soc. Nat. Hist.*, vol. 12, 1869, pp. 289-293.

^b *Geology of New Hampshire*, vol. 2, 1877, pp. 511-512 and plate opposite p. 158, showing sheet structure at the "Flume."

^c Vogt, J. H. L., Sheets of granite and syenite in their relation to the present surface: *Geol. Förenings i Stockholm, Förhandl.*, 1879, No. 56, vol. 4, No. 14; also Nogle, *Bemærkninger om Granit: Christiania videnskabselsk. Förhandl.*, 1881, No. 9.

^d Harris, George F., *Granites and our granite industries*, London, 1888.

^e Twelfth Rept. State Mineralogist of California, 1894, pp. 384-387 and 3 plates.

^f Herrmann, O., *Technische Verwerthung der Lausitzer Granite: Zeitsch. für prakt. Geologie*, Nov., 1895, Heft 2, p. 435.

^g Branner, John C., Decomposition of rocks in Brazil: *Bull. Geol. Soc. America*, vol. 7, 1896; Exfoliation, pp. 269-277, Temperature and exfoliation, pp. 285-292.

^h Merrill, George P., *Rocks, rock-weathering, and soils*, 2d edition, 1906, p. 231.

wholly to exfoliation parallel to preexisting lines of weakness. The mass appears to be made up of imbricated sheets of granite which he regards as the result of torsional strains. The bosslike form is incidental and consequent. Intermittent expansion and contraction from changes of temperature have so affected the sheets that bound the mass at the sides that they have found relief in expansion in an upward direction. These ruptured sheets are rarely more than 10 inches thick, but are 10 or 20 feet in diameter.^a

Herrmann^b sums up his conclusions on the subject substantially as follows: The so-called sheets are thin near the rock surface, generally only a few centimeters thick, but become gradually thicker with increasing depth. This downward increase in the thickness of the sheets is generally more rapid where the texture of the stone is coarser. The course of the sheets is not, as Vogt claims, parallel to the original surface of the consolidating rock. It is not governed by internal strains. The attitude of the sheets corresponds to the form of the present rock surface. The sheet structure is to be looked upon as the effect of the beginning and progress of weathering from the surface inward. These weathering cracks are determined by the form of the rock surface instead of that being determined by them.

Turner^c calls attention to the sheet structure and exfoliation of Fairview Dome, in the Yosemite.

Gilbert^d shows that sheet structure occurs in synclinal as well as in anticlinal attitude—in other words, is parallel to hollows as well as hills—which he considers unfavorable to the theory that it is an original structure. He suggests that sheet structure may possibly be due to expansive stress consequent upon relief from compressive stress brought about by the removal of the mass into which the granite was intruded. Subordinately he notes that in the Sierras, at least, the dome structure and the parallel joint structure do not occur in the same place and that the former has resisted general erosion more successfully than the latter.

Dr. G. F. Becker, in a recent conversation with the writer, stated that he had found the granites and gneisses at the bottom of the Colorado Canyon both vertically and horizontally jointed. If these are true granites and are still in contact with the rocks into which they were intruded and show genuine sheet structure the phenomenon

^a For description and representations of Stone Mountain see Merrill, as above, Pl. I; Purington, Chester W., Geological and topographical features of the region about Atlanta, Ga.: Am. Geologist, vol. 14, 1894, pp. 105-108 and Pl. IV; also Watson, Thomas L., Bull. Georgia Geol. Survey No. 9-A, 1902, p. 113, and Pls. I-VIII. See also description of another granite dome—Stone Mountain, in North Carolina—by Watson and Laney, in Bull. North Carolina Geol. Survey No. 2, 1906, Pl. XXV.

^b Herrmann, O., Steinbruchindustrie und Steinbruchgeologie, 1899, pp. 109-111.

^c Turner, H. W., The Pleistocene geology of the south-central Sierra Nevada, with especial reference to the origin of the Yosemite Valley: Proc. California Acad. Sci., 3d ser., Geology, vol. 1, No. 9, 1900; Formation of domes, pp. 312-315, and Pl. XXXVII.

^d Domes and dome structure of the high Sierras: Bull. Geol. Soc. Am., vol. 15, pp. 29-36, and pl. 3, 1904.

would conclusively prove that such structure may occur independently of solar heat and load.

Mr. S. F. Emmons similarly stated that in the Mosquito (Park) Range, in Colorado, the pre-Cambrian granite and schist are cut by horizontal joints to a depth of 50 feet below their contact with the overlying Cambrian, the joints diminishing in number downward. The original load upon the granite here consisted of at least 10,000 feet of Paleozoic and between 5,000 and 6,000 feet of Cretaceous rocks. As the granite, however, was not intruded into Cambrian sediments it must have been exposed to atmospheric erosion before they were deposited. These horizontal joints may therefore have been related to solar temperature.

Mr. G. K. Gilbert has recently studied the granite domes of Georgia and attributes their sheet structure to compressive strains. He finds that the granite in these domes^a is not naturally divided into plates, but that the outer parts of the granite—the parts nearest the surface—are in a condition of compressive strain, which results in slow exfoliation and which enables quarrymen, by means of carefully regulated blasts, to develop joints that run approximately parallel to the surface, so that the granite is detached in sheets. As these sheets are divided into blocks in the process of quarrying, the blocks expand horizontally as they are released from the general mass. In these granitic domes parting planes also develop naturally within a few inches of the surface, and the expansive force is there so great as to induce conspicuous buckling in the thin sheets thus formed. This buckling is illustrated in Pl. VII, *A*, Bulletin No. 313, from a photograph taken by Mr. Gilbert. The jar of blasting precipitates this sheeting action, so that several of the domes at which quarrying is in progress show long lines of freshly formed disrupted arches. Mr. Gilbert found that the horizontal elongation, or rather the elongation coincident approximately with the contour of the dome surface, amounted, by one measurement, to three-fourths inch in a length of 40 feet.

The effects of compressive strain on granite were observed by the writer in 1907 at a quarry at the west foot of Black Mountain, a domelike mass in West Dummerston, near Brattleboro, Vt., and are illustrated in Pl. VIII, *B*. New thin sheets have thus been formed and one of the sheet fractures opened $3\frac{1}{2}$ inches.

The artificial production of sheets in granite, as practiced at Bangalore, in southern India, shows similar phenomena. It is described by H. Warth^b in substance as follows: At the surface there is a horizontal sheet of rather weathered rock 4 feet thick; below this

^a Letters to writer dated May 4 and June 11, 1906.

^b The quarrying of granite in India: *Nature*, vol. 51, 1895, p. 272.

lies a sheet of fresh rock 3 feet thick, but below this lies fresh rock without split. These sheets "are probably due to the variations of temperature, daily and seasonal." By means of wood fires plates 60 by 40 feet by 6 inches in thickness are detached in one piece. A line of fire 7 feet long is gradually elongated and moved over the granite. The effect of the fire is tested by hammering the granite in front of it, and then the fire is moved forward. The maximum length of the arc of fire is 25 feet. The burning lasts eight hours; the line of fire is advanced 6 feet per hour. The area passed over by line of fire is 460 square feet. The amount of wood used is 15 hundredweight. The average thickness of stone is 5 inches and its specific gravity is 2.62. These data show that 30 pounds of stone are quarried with 1 pound of wood. Some plates are taken out in inclined position. The action of fire is independent of the original surface of rock; also of the direction of lamination (the granite is gneissose) and of veins. The uniformity in the thickness of the sheets is attributed to the regulating influence of preexisting cracks.

Van Hise, in his treatise on metamorphism,^a is inclined to attribute sheet structure to solar temperature.

Sheet structure, as exposed at the Maine quarries, is described in Bulletin 313, on pages 33-35, and is illustrated in Pls. II, B, III, V, VI, and IX, A of that bulletin. Sheet structure, as exposed at the quarries mentioned in this bulletin, is described under each quarry. Its general character is illustrated in Pls. III, A, and V, A; its relation to surface form in Pl. VII, A, and to overlying rocks in Pls. VI, A, and IX, A.

The observations as to sheet structure, made at over 100 granite quarries in Maine and at many of those described in this bulletin, are here summarized:

1. There is a general parallelism between the sheets and the rock surface, resulting in a wavelike joint structure and surface over large areas.
2. The sheets increase in thickness more or less gradually downward.
3. The sheets are generally lenses, though in some places their form is obscure. Their thick and thin parts alternate vertically with one another. The joints that separate these superposed lenses therefore undulate in such a way that only every other set is parallel.
4. On Crotch Island, Maine, the sheet structure extends to a depth of at least 140 feet from the surface, and at Quincy to 175 feet.
5. There are indications here and there that the granite is under compressive strain, which tends to form vertical fissures or to expand the sheets horizontally so as to fill up small artificial fissures or to extend the sheet partings horizontally. (See pp. 28, 96, 126, 191.)

^a Mon. U. S. Geol. Survey, vol. 47, pp. 434-439.

The observations made in Europe and in this country, taken in connection with the various inferences geologists have drawn from them, indicate that sheet or "onion" structure in granite rocks is due to the following possible causes:

1. To expansion caused by solar heat after the exposure of the granite by erosion.

2. To contraction in the cooling of the granite while it was still under its load of sedimentary beds, the sheets being therefore approximately parallel to the original contact surface of the intrusive.

3. To expansive stress or tensile strain brought about by the diminution of the compressive stress in consequence of the removal of the overlying material.

4. To concentric weathering due to original texture or mineral composition. This action would be chiefly chemical and would be aided by vertical joints and by any superficial cracks due to expansion and contraction under changes of temperature.

5. To compressive strain akin to that which has operated in the folding of sedimentary beds.

6. To the cause named under 1 at the surface, but to the cause named under 5 lower down.

These propositions will be considered in the order given:

1. Solar heat may produce a certain amount of exfoliation in thin sheets at the surface, as is proved experimentally in the fire method of granite quarrying in India (p. 25), but as it penetrates only to a depth of 40 feet and as sheet structure is known to occur on Crotch Island, Maine, at a depth of 140 feet and at Quincy, Mass., at a depth of 175 feet, it is quite inadequate to account for sheets that are 20 to 30 feet thick and 100 to 175 feet below the surface.

2. In view of the load under which granite was probably formed, as shown by the presence of liquid carbonic acid in its quartz^a and the gradual rate at which, therefore, it probably cooled, which is also indicated by the general coarseness of its texture, it is very improbable that the temperature at its contact surface and the temperature at depths 100 or 200 feet below could have so greatly differed as to bring about such a system of joints by contraction.

3. As Gilbert states, in suggesting the theory of fracture by relief of tensile strain through the erosion of overlying masses, we have no distinct knowledge of it. It is a possible explanation.

4. Careful inspection of the rock on both sides of the sheet joints fails to show any difference in texture or mineral composition. The

^a See also Sorby, H. C., On the microscopic structure of crystals, indicating the origin of minerals and rocks: *Quart. Jour. Geol. Soc. London*, vol. 14, 1858, pp. 453 et seq.; Ward, J. Clifton, On the granitic, granitoid, and associated metamorphic rocks of the Lake district: *Ibid.*, vol. 31, 1875, pp. 568-602. Rosenbusch claims that the great variation in the relative dimensions (amount) of the liquid and the vacuoles in the cavities of granitic quartz shows conclusively that the vacuole was not due to the contraction of the liquid. *Mikroskopische Physiog. der Min. und Gesteine*, vol. ii (1), 4th edition, pp. 41, 42. For drawings of these cavities and vacuoles see Judd, J. W., *Volcanoes*, 1881, figs. 8, 9, pp. 61-66.

sheet structure traverses both rift and flow structure, and it would be possible to procure specimens showing a sheet joint traversing a single crystal of feldspar. Whatever chemical action has taken place along the sheet joints is of secondary character. Acid waters may have gained access to the joint, but have not caused it. See matter under heading Discoloration ("Sap," etc.), page 35.

5. The condition of strain described by Merrill and Gilbert as existing in the granite domes of Georgia and by Niles and Emerson in the gneiss at Monson, Mass.,^a and by the writer at West Dummerston, Vt. (p. 25 and Pl. VIII, *B*), and occurring to a lesser extent in some Maine quarries, shows that granite and gneiss are in places still under compressive strain. Another instance occurs at the quarry of the New England Granite Works, at Concord, page 148. The foreman at this quarry was in the habit of calling certain sheets, marked by the absence of discoloration, "strain sheets," to distinguish them from the others. At one place a northwest-southeast compressive strain had actually extended the strain sheet about 5 feet, and also caused a vertical fracture that extended over 15 feet diagonally from the north-south working face to a point on a vertical east-west channel 5 feet back of the face, closing up the channel to half its original width. Evidences of compressive strain were also noted at Quincy, page 96, and Rockport, Mass., page 126, and at Westerly, R. I., page 191, and have also been observed by the writer in some of the Barre and Woodbury, Vt., quarries. The practicability of developing sheet structure by the use of explosives and compressed air, as is done in some of the North Carolina granite quarries, shows that the rock is under a compressive strain there.^b

All these observations bring this theory within the domain of inductive science. If sheet structure is due to compressive strain, it is due to such a strain as would produce a series of undulating fractures extending entirely across a granite mass several miles in diameter and to a depth, as far as observed, of 175 feet from the rock surface.

6. In view of the undoubted sheeting effect of expansion under solar heat within a short distance of the surface and of the fact that some of the sheets near the surface measure but a few inches in thickness, it is quite possible that very thin surface sheets have originated in this way; but in view of what was stated under heading 5 it seems probable that compressive strain is the main factor in producing massive sheets. At the surface both causes may have cooperated. The progressive thickness of the sheets downward indi-

^a Niles, W. H., Some interesting phenomena observed in quarrying: *Proc. Boston Soc. Nat. Hist.*, vol. 14, 1872, pp. 80-87, and vol. 16, 1874, pp. 41-43. Emerson, B. K., *Geology of Old Hampshire County, Mass.*: *Mon. U. S. Geol. Survey*, vol. 39, 1898, pp. 63-65.

^b Watson, T. L., and Laney, F. B., The building and ornamental stones of North Carolina: *Bull. North Carolina Geol. Survey No. 2*, 1906, pp. 157-160.

cates that the operation of this strain is evidently also dependent upon distance either from the present surface or from a former surface or contact.

According to this view sheet structure may be said to exert a controlling influence upon surface forms, yet it seems quite admissible that granite domes as conspicuous as Stone Mountain, in Georgia, and Fairview Dome, in California, notwithstanding all the exfoliation that has taken place on them or the erosion they may have suffered, may still retain some degree of parallelism between their present form and the original contour of the granitic intrusions of which they are parts. This may be true, also, of the granite hills of Mount Desert.

The probability being admitted that the general parallelism between the present surface and the sheet structure is the result of erosion that followed the sheeting, the question still remains, What has determined the form and location of the domes? These may possibly be referred to major arches (anticlines) in the folds of the stratified rocks which originally overlay the granite. The crustal movement that produced these folds may also have brought about the intrusion of the material that formed the domes beneath them.

Although the sheet structure and the rock surface are very generally parallel, they are not universally so.

Sheet structure in granite so much resembles the structure of folded stratified rocks that underground water circulates in practically the same way along the fracture planes of one and bedding planes of the other. The exudation of water along sheet joints on vertical rock faces is seen in many of the Maine quarries, and is also shown in Pl. V, A, and Pl. IX, A, representing Rockport and Niantic quarries.

JOINTS.

Herrmann^a divides joints into two groups—joints formed by lateral compression, whose distances from one another are related to the coarseness of the rock texture, and joints due to expansion, some of which are parted and filled with calcite, quartz, pegmatite, or volcanic rock. That many joints are due to compressive or torsional strain, and that every such strain resolves itself into two components, resulting in two sets of joints that intersect at an angle of about 90°, each forming an angle of about 45° with the direction of the strain, are facts now generally recognized. Crosby^b has suggested that torsional strains may have been supplemented by vibratory ones in causing joints. Becker,^c in a recent paper, shows that four or even

^aHerrmann, O., *Steinbruchindustrie und Steinbruchgeologie*, 1899, p. 103.

^bCrosby, W. O., The origin of parallel and intersecting joints: *Am. Geologist*, vol. 12, 1893, pp. 368-375.

^cBecker, George F., Simultaneous joints: *Proc. Washington Acad. Sci.*, vol. 7, July, 1905, pp. 267-275, Pl. XIII.

more than four systems of joints may be due to a single force. He also shows that subsequent strain on a region thus jointed would tend to produce motion along the previously formed joints rather than a new system of jointing. It is conceivable that if a region had been jointed and afterwards subjected to a tensile strain, some of its joints might be parted, and if they were very deep the openings might become filled with volcanic matter from below, or, if not, with matter from above, infiltrated from overlying rocks. That motion has occurred along some of the joints in the quarries is evident from the polished and striated surfaces of the joints as well as from the faulting of the sheets.

Joints are exceptionally as curved "as the side of a ship." (See Bull. 313, Pl. VI, *B*.)

Possibly related to such curved joints are what some New England quarrymen term "toe nails." These joints strike with the sheets, but extend only from one sheet surface to the next, and have a curve which sharply intersects that of the sheet structure. Such joints seem to be due to a strain different from that which produced the sheets. They were noted at Quincy, Westerly, and Milford, N. H.

The spacing of the joints varies considerably, ranging from 1 foot to 500 feet, but usually from 10 to 50 feet.

In some localities the jointing is very irregular. The granite is broken up into various polygons, which at the surface, where weathering has made inroads, resemble boulders. Quarries opened in such places are called bowlder quarries. Another sort of irregularity in joints consists in their discontinuity or intermittence, their strike and dip for the short spaces in which they occur being uniform. Joint courses at the quarries referred to in this work are given under the quarry descriptions in Part II and where numerous are shown in diagrams.

HEADINGS.

In some places joints occur within intervals so short as to break up the rock into useless blocks. For a space of 5 to 50 feet the joints may be from 6 inches to 3 feet apart. A group of close joints is called by quarrymen a "heading," possibly because, when practicable, such a mass is left as the head or wall of the quarry. (See Bulletin 313, Pls. VIII, *A*, and IX, *B*, also this bulletin, Pl. VI, *B*.) Headings afford ample ingress for surface water, and consequently the granite within a heading is generally badly stained, if not decomposed. This will be referred to more fully under the heading "Decomposition" (p. 36).

An interesting feature of both headings and joints shown in some of the deeper quarries at Quincy, Mass. (p. 97), is their vertical discontinuity. A heading occurring at the surface may disappear

below, or a heading may abruptly appear a hundred feet below the surface and continue downward.

Headings are not easily accounted for. They may be produced by vibratory strains that recur at intervals of time. If they are so caused, the character of the fractures in some headings indicate that the strains are very complex. (See Concord, p. 145.)

The courses of headings at each quarry are given in the descriptions of the quarries in Part II.

FAULTS.

The polished and grooved faces ("slickensides") observed on many of the joints at the quarries show that faulting has occurred along them. The discontinuity of the sheets at some of the joints, causing, where the joints are slightly inclined, what quarrymen call "toeing in," may probably be attributed to faulting. This supposition assumes, of course, that the sheet structure was formed prior to the jointing. Faulting occurs also along sheets, displacing vertical flow structure, or vertical dikes. (See Bulletin 313, Pl. VIII, *B*.) It may occur along one of two intersecting dikes, displacing the other, as at the Deep Pit on Cape Ann. (See Pl. V, *B*, of this bulletin.)

MICROSCOPIC FRACTURES.

In some quarries the granite near the surface acquires a marked foliation, which appears to be parallel to the sheet structure, and in places to the rift. This foliation is known by quarrymen as "shakes." It occurs both at the top and at the bottom of the sheet, through a maximum thickness of 6 inches. It is coextensive with the discoloration known as "sap" and occurs at many places near vertical joints. Under the microscope this structure proves to consist of minute, nearly parallel fissures, of no great continuity, which traverse the mineral particles and which in the thin section examined are especially conspicuous in the quartz and the mica. The distance between these fissures measures from a tenth to a half a millimeter, or from one two hundred and fiftieth to one-fiftieth inch. The parallelism, both to the sheets and the "sap" and its relation to the vertical joints, indicates that the structure may be due to the freezing of surface water which has found its way to the sheets through the vertical joints and has entered the rift fissures.

The writer's attention was called to a similar structure in a quarry at Milford, N. H., consisting of short, parallel fractures along the rift, from one-half inch to 2 inches apart, having no apparent connection with joints or discoloration. This is probably due to strain affecting part of the granite mass and producing miniature sheet structure.

SUBJOINTS.

Careful inspection shows that the joint structure in granites does not everywhere consist of a simple fracture, but that it is at many places complex. Minute fractures branch off from the joint at an acute or right angle and penetrate the rock a few inches, or the rock for a few inches on either side of the joint is traversed by microscopic fissures that are roughly parallel to it. All such structural features may properly be called subjoints. (See further, p. 48, and Pl. III, *B*; also Bulletin 313, p. 41.)

Woodworth has studied analogous and related structures in various rocks and has described them as "joint fringe" and "feather fractures."^a

ROCK VARIATIONS.

Under the term "rock variations" are grouped all those variations from typical granite that are due to injection, segregation, infiltration, inclusion, and steam cavities.

DIKES (GRANITIC).

The granitic dikes in the quarries are of three kinds: Extremely fine grained granite (aplite), very coarse grained granite (pegmatite), and fine or medium grained granite.

The courses of these dikes at each quarry are given in the diagrams or descriptions in Part II. In thickness they range from a fraction of an inch to over 20 feet, but usually from 2 inches to 2 feet.

Aplite differs from ordinary granite by the greater fineness of its texture and its scant content of mica. It is known by quarrymen as "salt horse" or "white horse."

Aplite dikes are supposed to have originated in the same deep-seated molten mass as the granite they traverse, but they represent a later stage of igneous activity. The fissures they fill were the result of various tensional strains or contractions, possibly consequent upon the cooling of the granite.

In color these dikes vary from bluish gray to light and dark reddish. The texture of some aplites is so fine that the mineral particles can not be distinguished with the unaided eye; that of others is so coarse that the feldspar and mica may be thus detected. Under the microscope the dimensions of the particles range from 0.05 to 0.75 mm., the average being about 0.16 mm. for the finer ones and 0.50 mm. for the coarser ones. Some aplites have a porphyritic texture.

Most aplites contain a slightly higher percentage of silica than granite. Five analyses of aplites from the Far West made at the laboratory of the United States Geological Survey^b show a range of

^a Woodworth, J. B., On the fracture system of joints, with remarks on certain great fractures: Proc. Boston Soc. Nat. Hist., vol. 27, 1896, pp. 169-173, pls. 1, 2.

^b Bull. U. S. Geol. Survey No. 148, 1897, pp. 124, 150, 206, 219.

silica from 71.62 to 76.03 per cent and an average of 74.08, which is near the maximum of silica for granites generally.

Pegmatite lies at the other extreme. Its mineral constituents range usually from one-half inch to 1 foot or even several feet in diameter. It is reported that the crystals in some pegmatite dikes measure from 10 to 30 feet in length by 1 to 3 feet in width. The chief minerals in pegmatite dikes are the same as in granite, but they occur in different though varying proportions. With these minerals are often associated tourmaline, garnet, beryl, etc. Chemically these dikes generally contain more silica than the granite. Dikes of pegmatite are, as a rule, more irregular in width than those of aplite. They generally range in thickness from 1 inch to 10 feet.

The origin of pegmatite has been much discussed both in Europe and in this country.^a The coarseness of its constituent minerals indicates slow crystallization, and the irregularity of the dikes shows tensional rather than torsional strain. The banding of some pegmatite dikes and the isolated lenticular character of others indicate that the dikes were filled from heated solution, while many of them differ in no respect from dikes of igneous origin except by the coarseness of their texture. For these reasons it is thought that pegmatite dikes in granite have been formed in openings and fissures that were due, possibly, to contraction while the granite was still hot and that some of these openings were filled with matter in a state of both molten plasticity and solution under pressure, and others by heated solutions that gathered matter from the adjacent granite. Howsoever derived, this dike material crystallized very slowly.

Granite.—Finally, there are dikes that differ from all those just described, formed simply of fine or medium-grained granite. (See pp. 81, 186.)

VEINS.

Quartz veins occur rarely in the Maine granite quarries (see Bulletin 313, p. 46) and at but few of the quarries here described (see pp. 104, 105). Some of these seem to be clearly of pegmatitic origin.

DIKES (BASIC).

Dikes of dark-greenish or black, hard and dense rock (diabase, rarely basalt) are of very common occurrence in the Maine and Massachusetts quarries. The courses of some of these dikes and their relation to the joints are shown in figs. 11, 12, 14, 15, 16, 17. Some of them are represented in Pl. V, *A* and *B*, and described on pages 125, 131, 138.

^a The principal American writings on the subject are: Williams, G. H., The general relation of the granitic rocks in the middle Atlantic Piedmont Plateau; Fifteenth Ann. Rept. U. S. Geol. Survey, 1895, pp. 675-684; Crosby, W. O., and Fuller, M. L., Origin of pegmatite: Techn. Quarterly, vol. 9, 1896, pp. 326-356; Am. Geologist, vol. 19, 1897, pp. 147-180; Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, pp. 720-728.

Most of these dikes are so firmly welded to the granite that hand specimens that are one-half granite and one-half diabase are readily obtained. Thin sections of the glassy rims of dikes show that the dike sent out microscopic branches for short distances into the granite, in places surrounding some of its quartz particles. (See further on the relation of dike rims to granite, p. 50.)

The geologic age of these dikes has not been precisely determined. They are considerably more recent than the granite they traverse or the dikes of aplite and pegmatite which traverse the granite.

The diabase dikes are the result of an earth movement that either opened previously formed joints or made new ones deep enough to be injected with volcanic material. How far this may have penetrated the rocks which overlay the granite, or whether it overflowed at their surface, can not even be conjectured.

At the granite quarries, wherever this course is possible, the dikes and the headings are left to form the bounding walls of the excavations.

SEGREGATIONS (KNOTS).

Quarrymen know too well that granite is often disfigured by gray or black "knots" of circular or oval irregular curved outline, ranging in diameter from half an inch to 3 feet and exceptionally even 10 feet. These were studied by geologists long ago.^a They are finer grained than the granite in which they occur, contain nearly 10 per cent less silica, much more black mica or hornblende (which accounts for their darkness), and a little more soda-lime feldspar, and their specific gravity is about 0.09 per cent higher.

Pl. V, A, of Bulletin 313 shows twelve small knots in one of the Sullivan quarries, and on pages 49 and 50 of that bulletin thin sections of knots from the Maine quarries are described. Several varieties from the Quincy quarries are described on page 95 of this bulletin and one of exceptional character from Rockport on pages 64, 125.

In none of the knots is there a definite boundary separating them from the granite, excepting such as is caused by the change in the proportionate abundance of the darker minerals. The cause of knots is not perfectly understood. They are collections (segregations) generally of the darker, heavier, iron-magnesia minerals that took place while the rock was in a plastic state.

GEODES.

Small cavities lined with crystals occur in granite. They have been found by the writer at the Jonesboro and Marshfield quarries

^a Phillips, J. A., On concretionary patches and fragments of other rocks contained in granite: *Quart. Jour. Geol. Soc. London*, vol. 36, 1880, pp. 1-22, Pl. I. Merrill, G. P., On the black nodules or so-called inclusions in the Maine granite: *Proc. U. S. Nat. Mus.*, vol. 6, 1883, pp. 137-141. Grimsley, G. P., Basic segregations: The granites of Cecil County in northeastern Maryland: *Jour. Am. Soc. Nat. Hist.*, Apr. and July, 1894. Daly, Reginald A., Basic segregations: The geology of Ascutney Mountain, Vermont: *Bull. U. S. Geol. Survey* No. 209, 1903, p. 164.

in Maine and at Redstone, N. H. Their greatest diameter was about 12 inches, and the lining crystals were quartz, more or less amethystine, and feldspar. These were usually coated with epidote, chlorite, and calcite; the calcite generally in very obtuse rhombohedra up to half an inch across. A geode at Redstone is surrounded by a band of aplite.

Such cavities are attributed to bubbles of steam or gas that were in the rock while it was in a molten state, which gave room for the growth of crystals and later became filled with epidote and calcite.

INCLUSIONS.

Not to be confounded with "knots," although some of them are equally dark and occur near them, are irregular or angular particles of various schistose rocks which the granite incorporated into itself during its intrusion. They can usually be distinguished from the knots by their different microscopic structure. In the Maine quarries they range from an inch to 40 feet in length. Part of the jagged edge of the lower part of a large schist inclusion in granite at Freeport, Me., is shown in Pl. VII, *B*, of Bulletin 313.

Inclusions in the granites of Concord and Milford, N. H., are described on pages 151, 153, 169, 176 of this bulletin.

DISCOLORATION ("SAP," ETC.).

Rusty (limonite) staining along the upper and lower parts of the sheets and also along the joints and headings is common in granite quarries, although some quarries are almost entirely free from it. The zone of discoloration along the sheets in the Maine quarries is from one-half to 12 inches, exceptionally even 18 inches, wide on each side of the sheet parting. Its width, however, decreases gradually from the surface sheets downward. In places the sap consists of two parts—an outer dark brownish zone from three-fourths to $1\frac{1}{2}$ inches wide and an inner more yellowish zone from one-fourth to one-half inch wide. Generally, however, the discoloration diminishes gradually from without inward. In some quarries there seems to be a connection between the "shake" structure and the discoloration, since these are coextensive.

When the stone is intended for facing or trimming buildings the presence of sap is a serious matter as the stained edge of each block must be split off, which adds somewhat to the cost of production.

This discoloration has been supposed to be always due to the oxidation of the ferruginous minerals of the granite, biotite, hornblende, magnetite, and pyrite, but the Maine thin sections examined by the writer do not bear out this theory. (See Bulletin 313, p. 53 and fig. 2.)

These observations lead to the inference that the discoloration called "sap" is, in some Maine granites, not due chiefly to the oxida-

tion of the ferruginous minerals of the granite by "underground water," but chiefly to the deposition of limonite by ferruginous surface water. The water descended along the vertical joints and then flowed along the sheet partings and permeated the rock above and below them. Whether the postglacial submergence of the Maine coast had anything to do with the discoloration is not clear.

Another kind of discoloration, which is even more serious in its consequences, appears on fresh faces of granite, either in the quarry or after its removal. This consists of sporadic rusty stains from half an inch to 1 inch in diameter, arising from the oxidation of minute particles of some undetermined ferruginous mineral, possibly allanite. Such stains usually, however, arise from pyrite particles or crystals.

Daly^a describes a bluish-gray syenite, from Windsor, Vt. (feldspar, quartz, hornblende, augite, biotite), that after twenty-four hours' exposure assumes a greenish tinge, which eventually becomes more or less brownish. He has demonstrated by experiment with oxygen that this change is due to the oxidation of minute blackish granules of ferrous oxide within the feldspar, giving a yellow which, in combination with the original bluish tint of the feldspar, produces a green. The large columns of the library of Columbia University, in New York, are made of this rock.

Another kind of discoloration occurs on either side of diabase or basalt dikes, caused mainly by various alterations of the feldspars and their consequent change in shade or color. See Bulletin 313, page 91, and the examples at Rockport, Mass., and Milford, N. H., described on pages 125, 163 of this bulletin. Discoloration is thus of five kinds: That due to the infiltration of ferruginous water, that due to the oxidation of the generally disseminated ferruginous minerals (biotite, hornblende, and magnetite) by nonferruginous water, that due to the oxidation of sporadic ferruginous minerals, that arising from the oxidation of ferrous oxide within the feldspars, and that due directly or indirectly to dikes and veins. The subject of granite discoloration will be found discussed further on pages 51-55.

DECOMPOSITION.

Notwithstanding the strength and durability of granite, it is liable, under certain conditions and in the course of long time, to decompose into a clayey sand. This is the result of its physical, mineralogical, and chemical constitution and properties. One of the most striking illustrations of this is the occurrence in some of the Maine quarries of "beds" of sand or decomposed granite within the fresh granite, either between the sheets away from headings or within the headings

^aDaly, Reginald A., The geology of Ascutney Mountain, Vermont: Bull. U. S. Geol. Survey No. 209, 1903. pp. 51-53.

and along or across the sheets. Thus at the Palmer quarry, in Vinalhaven, 20 feet below the surface in the face of the quarry, there is a bed of granite sand 18 inches thick between two sheets, which at that point dip about 10° into the hill. On the southeast side of the Longfellow quarry, near Hallowell, some of the sheets within a wide heading include granite sand beds, that are about 10 inches thick. At the Shattuck Mountain quarry, near Redbeach, a 6-foot heading includes a vertical layer of granite sand 8 inches thick. Specimens taken from these various sand beds show that the disintegration begins with microscopic fractures; in some cases the enlarged rift cracks, producing the "shake" structure described on page 31, and is followed by more or less kaolinization of the feldspars. This process consists in the loss of alkali and the taking up of water, resulting in the passing of the feldspar into a white clay (kaolin).

The joint and sheet structure affords ingress to surface water, containing its usual percentage of carbonic acid, and the "rift" or "shake" structure facilitates the kaolinization of the feldspar on either side of the sheet parting by this water. As the feldspars pass into clay the rock crumbles into sand consisting of quartz, mica, and kaolin, and of feldspar in various stages of kaolinization. In some places within the range and depth of frost a large part of this work may have been done by frost alone. The sand would there be mainly the product of the "shake" structure.

In regions which have not been swept by a continental glacier any granite mass would be covered with the products of the decomposition of its own surface. In the Tropics the abundant rainfall and the organic acids from a luxuriant vegetation materially hasten the decomposition, and granitic rocks in such regions are for these reasons often covered with many feet of sand and soil.^a

The incipient stage of weathering may be observed in any long-exposed granite ledge in the milky whiteness of the feldspars. This change usually attacks the soda-lime feldspars first. The black mica, owing to its content of iron oxide, is also liable to early decomposition. The process of weathering, as it affects the rock as a whole, involves the following chemical changes: A loss of lime, magnesia, potash, and soda; a gain of water, and a relative gain of silica, alumina, and iron oxide—that is, relative to the reduced weight of the weathered rock. The subject of weathering of granite is fully treated in the writings of Merrill, Keyes, and Watson.^b

^a Branner, John C., Decomposition of rocks in Brazil: Bull. Geol. Soc. America, vol. 7, 1896; Exfoliation, p. 31.

^b Merrill, Geo. P., Disintegration of the granitic rocks of the District of Columbia: Bull. Geol. Soc. America, vol. 6, p. 321, 1895; also A treatise on rocks, rock-weathering, and soils, New York, 1897, pp. 206-214, 236, 244, 245, 257. Keyes, Charles R., The origin and relations of central Maryland granites: Fifteenth Ann. Rept. U. S. Geol. Survey, 1895, p. 725, and pls. 42-45. See also Proc. Iowa Acad. Sci., vol. 1, pt. 3, pp. 22-24, and vol. 2, pp. 27-31, Pls. II-IV, 1895. Watson, Thomas L., A preliminary report on a part of the granites and gneisses of Georgia, 1902, pp. 299, 300, 308, 329, 331, 333.

The changes in granite after it has entered into buildings or other constructions are less marked than those in the natural rock, because the blocks are not then traversed by anything analogous to sheet and joint structure, and also because the years of historic time are few compared to those of geologic time. Much has been written on the decay of granite in monuments and buildings.^a Such decay is mainly attributable to microscopic fissures produced by the unequal and repeated expansion and contraction of the different minerals of the granite under changes of solar temperature. In countries where the winter temperature is very low the action of frost within such fissures powerfully assists the process of disintegration. Thus the obelisk now in New York suffered more from three years' exposure to our climate than it had during over three thousand four hundred years in Egypt, although the fissures along which frost operated were started long before it reached this country. A minor factor in decay is the chemical action of water along fissures.^b

It is supposed that these causes of decay operate more effectively in coarse granites than in fine ones. Merrill points out that a sawn or properly prepared polished surface resists weathering more effectively than a cut or hammered one, as the latter is full of minute fractures, parallel to the surface, produced by impact, which facilitate scaling.

BLACK GRANITES.

CLASSIFICATION.

The term "black granites," although sufficient for general commercial purposes, includes a variety of rocks of different character, origin, and appearance—gabbros, diorites, diabase, etc. They have, however, three mineralogical features in common—they contain comparatively little or no quartz, their feldspar belongs entirely or almost entirely to the series which contains both soda and lime, and they contain a considerable amount of one of the pyroxenes, or hornblende or biotite, and magnetite, which accounts for the general darkness of their shade or their greenish color.

ORIGIN.

The gabbros and diorites are more or less granitic in texture, as they crystallized under conditions resembling those which attended the formation of granite. But the diabase was in part erupted through narrow fissures, forming dikes or sheets, and at many places reached the surface, always crystallizing with comparative rapidity.

^a Julien, Alexis A., *The durability of building stones in New York City: Tenth Census*, vol. 10, 1884; *Granite*, pp. 370-371; Merrill, Geo. P., *Physical, chemical, and economic properties of building stones: Maryland Geol. Survey*, vol. 2, 1898; *Granite*, pp. 92-94. Also Merrill's *Stones for building and decoration*, 3d ed., 1903; *Weathering of granite*, pp. 434, 435.

^b See Julien, Alexis A., *A study of the New York obelisk as a decayed bowlder: Annals New York Acad. Sci.*, vol. 8, 1893, pp. 93-166.

Diabase, however, occurs in Vinalhaven, Me., as stated by George Otis Smith, "in large bodies which have the form of neither dikes nor sheets, being, in fact, part of the same masses as the diorites and gabbros."

MINERALOGICAL AND CHEMICAL COMPOSITION.

Gabbro consists essentially of a lime-soda feldspar and one or both of the varieties of pyroxene known as diallage and hypersthene. The former is a foliated silicate of iron and lime with about 12 per cent of magnesia; the latter is a silicate of iron with about 24 per cent of magnesia, and each of these minerals crystallizes differently. When hypersthene alone is present the rock is called a norite; when both are present it is a hypersthene gabbro. When the mineral olivine (a greenish silicate of iron with 50 per cent of magnesia) is present also the name olivine may be prefixed to the rock name. The accessory minerals in gabbros are ilmenite (a titanate of iron), magnetite, pyrite, apatite, biotite, garnet, and rarely, quartz and metallic iron. The secondary minerals—that is, those derived from the alteration of the primary ones—are hornblende, chlorite, epidote, zoisite, analcite, serpentine, a white mica, and calcite. The percentage of silica in gabbros varies a little on either side of 50. Iron oxides and lime average 9 per cent each; magnesia, 6 per cent.

Diorite consists essentially of feldspar (of the series containing lime and soda) and hornblende with biotite, or biotite alone. Quartz, augite, and potash feldspar may or may not be present. The accessory minerals are magnetite, pyrite, titanite, zircon, apatite, garnet, allanite. The secondary are epidote, chlorite, a white mica, and calcite. When quartz is present the rock is called a quartz diorite. When black mica or augite are the preponderating iron-magnesium silicates the rock becomes a mica diorite or an augite diorite. In diorites the silica ranges from about 49 to 63 per cent, but in quartz diorite it rises to about 69 per cent, which is the minimum in granite. The iron oxides range from 0.52 to 9.70 per cent, the magnesia from less than 1 to over 11 per cent, but usually from 2 to 7 per cent.

Diabase consists essentially of a feldspar of the series containing lime, or soda and lime, together with a pyroxene or augite (alumina, lime, magnesia, iron), which, however, is frequently altered to hornblende or other secondary minerals; also magnetite or ilmenite, or both. Olivine may or may not be present, and some specimens contain a little quartz. The accessory minerals are orthoclase, biotite, pyrite, hypersthene, apatite. The secondary ones are hornblende, a white mica, chlorite, epidote, serpentine, calcite. The percentage of silica in diabase ranges from about 45 to nearly 57, of iron oxides from about 9 to 14, and of magnesia from 3 to 9.

These "black granites," as will be seen by the foregoing description, are distinguished chemically from the ordinary granites by their low percentage of silica (45 to 67 per cent), their high maxima of iron oxides (9 to 14 per cent), and of magnesia (9 to 11 per cent), and mineralogically by their dominant feldspar not being a potash feldspar, and generally also by their considerable content of the darker iron-magnesia minerals.

TEXTURE.

The general texture of the black granites corresponds in grade to that of the fine and medium granites. In the diorites the arrangement and order of crystallization of the minerals always correspond to those of the granites described on page 14. In some of the gabbros this is also true, but in others and in diabase the arrangement greatly differs. The feldspars are in needle-like crystals, between which the pyroxene has afterwards crystallized.

PHYSICAL PROPERTIES.

Aside from their great toughness, the diorites and the granitic gabbros probably differ but little in physical properties from granites of the same grade of texture. By reason both of their peculiar texture and their mineralogical composition, the diabases and gabbros with "ophitic" texture should differ considerably in physical properties from the granites. As these stones are rarely used in large buildings, owing to the difficulty of quarrying them either in blocks of sufficient size or at low enough cost, data as to their compressive strength and other useful physical properties are not available.

The specific gravity of gabbro ranges from 2.66 to about 3, that of diabase from 2.7 to 2.98, and that of diorite averages 2.95. In these rocks it thus usually exceeds that of granite.

As the black granites are used chiefly for monumental purposes, and particularly for inscriptions, their color, susceptibility to polish, and the amount of contrast between their cut or hammered and their polished surfaces are the physical properties of chief economic importance.

Doctor Merrill^a explains the cause of these contrasts very satisfactorily:

The impact of the hammer breaks up the granules on the immediate surface, so that the light falling upon it is reflected, instead of absorbed, and the resultant effect upon the eye is that of whiteness. The darker color of a polished surface is due merely to the fact that, through careful grinding, all these irregularities and reflecting surfaces are removed, the light penetrating the stone is absorbed, and the effect upon the eye is that of a more or less complete absence of light, or darkness. Obviously, then, the more transparent the feldspars and the greater the abundance of dark minerals, the

^a Merrill, Geo. P., *The physical, chemical, and economic properties of building stones: Maryland Geol. Survey, vol. 2, 1898, p. 64.*

greater will be the contrast between hammered and polished surfaces. This is a matter worthy of consideration in cases where it is wished; as in a monument, to have a polished die, surrounded by a margin of hammered work to give contrast.

The ordinary granites, while taking a high polish, do not afford such strong contrasts between hammered and polished surfaces as do the "black granites." In some black granites this seems clearly to be due to their larger percentage of the black minerals, but in others, as some of the quartz diorites, in which the black minerals do not exceed those in some gray granites, the cause of this marked contrast must be sought in some optical property of the soda-lime feldspar and in its relative abundance.

TEXT-BOOK REFERENCES ON GRANITE AND BLACK GRANITES.

As the matter contained in the foregoing pages may not fully provide answers to all questions that may arise in the minds of persons interested in tracing the phenomena in granite quarries to their causes, the names of a few reliable general works in English on the subjects considered are here given.

Diller, Joseph S. Educational series of rock specimens collected and distributed by the United States Geological Survey: Bull. U. S. Geol. Survey No. 150. 1898.

Granites, pp. 51, 170-180; gabbro, pp. 51, 52, 278-288; diorite, pp. 241-244; diabase, pp. 264-278; basalt, pp. 51, 52, 254-256.

Geikie, Archibald. Text-book of geology, fourth edition. London. 1903.

Granite, etc., pp. 89, 90, 203-209, 402-415, 715-809; gabbro, pp. 231, 232, 256; diorite, p. 223; diabase, p. 233; basalt, p. 234.

Harker, Alfred. Petrography for students: An introduction to the study of rocks under the microscope, second edition. Cambridge, Eng. 1897.

Granites, pp. 27-41; gabbros, pp. 67-83; diorite, pp. 54-66; basalts, pp. 188-203.

Hatch, Frederick H. Text-book of petrology, fourth edition. London. 1905.

Johannsen, Albert. A key for the determination of the rock forming minerals in thin section. New York. 1907.

Kemp, James F. A handbook of rocks for use without the microscope, third edition. New York. 1904.

The granites, pp. 33-38; gabbros, pp. 72-74; diorites, pp. 60-62; diabases, pp. 70-72.

Luquer, Lea M. Minerals in rock sections, revised edition. New York. 1905.

Merrill, Geo. P. A treatise on rocks, rock weathering, and soils. New York, second edition. 1906.

Igneous rocks, pp. 52-60; granites, pp. 61-64; diorites, pp. 76-77; diabases, pp. 82, 85; basalts, pp. 86, 87; weathering, pp. 150-273.

SPECIAL FEATURES.

The following thirteen sections contain such interesting illustrations, either of subjects already touched upon in the general discussion of granite (pp. 18-38) or of closely related ones, as were found in visiting the quarries for the preparation of this bulletin.

RIFT AND GRAIN RELATED TO FLUIDAL CAVITIES.

Rift and grain structure was described on pages 19–22, where reference is made to Mr. Whittle's paper on this structure as shown at Redstone, N. H.^a

During the writer's visit to Redstone a specimen of the pink granite was obtained, with a face $4\frac{3}{4}$ by 4 inches cut and polished parallel to the "hard way," that is, at right angles to both rift and grain; also a specimen of the green granite from the adjoining western quarry, 5 by 4 inches, cut and polished in the same way. Material for a thin section of the pink was also obtained and a section $1\frac{1}{2}$ by 1 inch in area was cut at right angles to both rift and grain directions. The direction of the rift at the quarries was found to be horizontal, crossing the sheets which curve in anticlinal attitude across the axis of the hill with a dip of 15° both to the east and west, while the grain is vertical with an east to west course, and corresponds with the most prominent set of joints.

A careful examination of these specimens shows rift cracks in both the feldspar and quartz of the pink granite, though they are more conspicuous in the quartz, partly because of the darkness of its shade. Grain cracks are less abundant. The green granite shows both rift and grain cracks, if anything, more abundant, though not as easily seen as in the quartz of the pink granite. The large thin section shows 12 prominent rift cracks in the quartz areas in a space of 1.2 inches measured along the grain, that is, with an average distance apart of one-tenth inch. The grain cracks are far less frequent and less continuous. That these rift and grain cracks were not caused by hammering or by cutting the section is shown by the fact that some of them are filled with secondary fibrous mica. The quartz areas also show two intersecting sets of lines, really sheets or planes of gas or liquid inclusions, the latter with vacuoles. Many of these cavities are very irregular in outline, some having several ramifications. They all range in diameter from less than 0.00285 to 0.063 millimeter. The strike of these two sets of sheets corresponds respectively to that of the rift and grain. Some of the rift or grain cracks appear to have followed the sheets of cavities, for they coincide with them. Portions of this section are shown in fig. 1.

In reexamining the thin section of granite from near Pleasant Beach, in Maine, represented in fig. 1, p. 28, of Bulletin 313, sheets of cavities were found in it, some parallel to the rift cracks and some coinciding with them, but they are not so conspicuous or continuous as those in the granite from Redstone, N. H., and thus at first escaped the writer's notice. Emerson^b in describing the granite of Becket, Mass.,

^a Whittle, C. L., Rifting and grain in granite: Eng. and Min. Jour., vol. 70, 1900, p. 161, figs. 1 and 2

^b Emerson, B. K., The geology of eastern Berkshire County, Mass.: Bull. U. S. Geol. Survey No. 159, 1899, p. 73.

uses these words: "The quartz grains were full of *sheets of cavities*, with large moving bubbles." Washington^a refers to streaks of inclusions in the greenish granite of Bay View on Cape Ann: "Gas and liquid inclusions, the latter carrying a movable bubble, are quite abundant though small and occur in *streaks*."

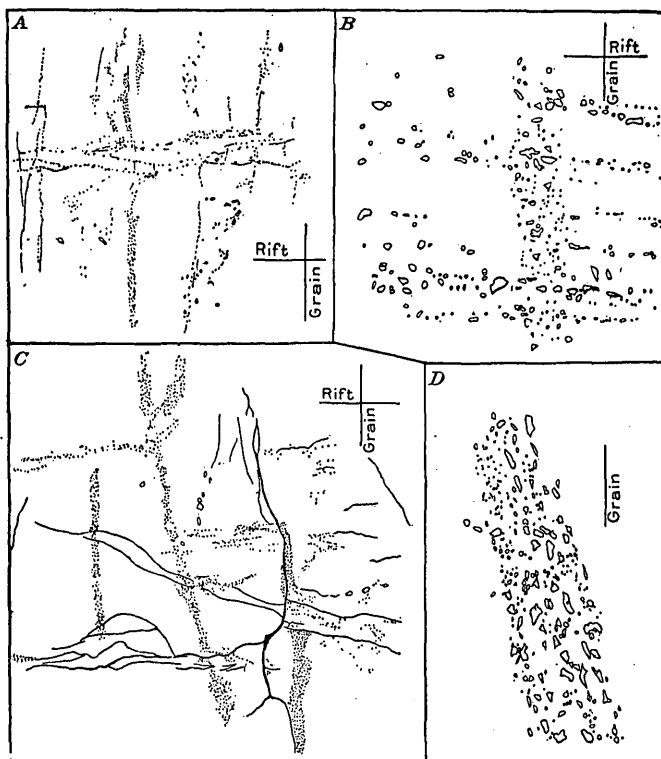


FIG. 1.—Camera lucida drawings of quartz areas in an enlarged thin section of biotite granite from Redstone, N. H., cut parallel to the "hard way." *A*, enlarged 62½ diameters, shows sheets of cavities and incipient cracks in both rift and grain directions. *B*, from a different quartz area, enlarged 175 diameters, shows the variation in the size of the cavities and their arrangement in both rift and grain directions. *C*, from still another quartz area, enlarged 23½ diameters, shows conspicuous rift and grain cracks, filled with fibrous white mica, coinciding here and there with the sheets of cavities, also two parallel exceptional fractures crossing the rift and grain directions diagonally. *D* shows part of one of the grain sheets of cavities of *C*, enlarged 175 diameters in order to show the shapes of the cavities. As most of these sheets of cavities in the section appear to undulate in the direction of the line of vision when placed under the microscope the outlines of all the cavities become visible only by altering the focus.

At the Redstone quarry at Westerly, R. I., the quartz has cavities in sheets with rift cracks parallel to them. In a veinlet of quartz and feldspar at the Calder & Carnie quarry at the same place (p. 203) the quartz particles are crowded with cavities in sheets parallel to the side of the vein and also in line with streaks of kaolinization in the feldspars. A smoky quartz vein (averaging 0.35 inch thick) of pegma-

^a Washington, H. S., The petrographical province of Essex County, Mass., I: Jour. Geol., vol. 6 (8) Nov.-Dec. 1898, p. 790.

titic origin, observed by the writer in 1907 in the A. Milne quarry at Barre, Vt., shows many roughly parallel diagonal fractures. In thin section it has a largely feldspathic border, 0.2 inch thick, which is partly micacized, and inside of it the quartz is in places granulated. Discontinuous sheets of cavities with vacuoles extend both in the direction of the vein and at right angles to it, and some cracks with granular quartz zigzag along these directions. In places the cavities are abundant but without apparent arrangement.

At the Milford Granite Company's quarry, Milford, N. H. (p. 173), the quartz of a quartz-augite diorite gneiss overlying the granite has cavities arranged in sheets intersecting one another. Sheets of cavities intersecting one another at right angles and with rift and grain cracks parallel to them were also observed in granite sections from the Becket, Mass., quarry (p. 141); and in several other granites described in this bulletin the cavities are arranged in rectangular sheets. This has also been found to be true in many sections of Vermont granites quite recently studied. One of these from Cobble Hill near Barre shows quartz with sheets of cavities with conspicuous rift cracks parallel to or coinciding with them. Some of the rift cracks polarize brightly and extend into the feldspars where they are clearly filled with fibrous muscovite. But in other sections, cut without reference to rift or grain directions, the sheets of cavities intersect at all angles or the cavities have no apparent arrangement. Many such irregularities thus result simply from the haphazard direction of the section. For this reason probably Rosenbusch refers to their occurrence in apparently irregular groups or courses only.

In the thin section of Redstone, N. H., granite, described on page 42, some of the sheets of cavities pass uninterruptedly, and without deflection from one quartz particle to another and the rest do not appear to terminate abruptly at the edge of the particle. The passage of sheets of cavities from particle to particle without interruption or deflection can be observed also in a section (109, specimen 36, b) from the adjoining green granite of Redstone, also in one (150, specimen 38, a) from the White Mountain quarry near North Conway. This is also the case in several sections of Quincy granite (234, specimen 79, f, from the Hardwick quarry, and 206, specimen 85, a, from the Mount Pleasant quarry, Milton) and in some (221, 228, specimen 91, f) from the Becket (Chester), Mass., quarry. There is also in all these sections a general parallelism in the sheets, which lie either in the rift or the grain directions or between these and the rift or grain cracks, but some sections also have sheets of cavities diagonal to those directions. Even sections cut parallel to rift or grain or at right angles to both usually show cavities, more or less abundant, which are without any apparent arrangement.

These facts point to the probability of an intimate relation between the arrangement of the inclusions and the rift and grain structure. If the cavities, containing water or liquid carbonic acid, or either of these in a gaseous form, in the quartz of granite, are correctly regarded as having originated at the time of the crystallization of the material of the granite, then the rift and grain structure would seem to be either original also or, if secondary, to have had its directions generally determined by those of the sheets of inclusions.

No such rows of fluidal cavities which Rosenbusch^a describes as connected by fine cylindrical canals and as occurring especially in granites containing quartz with crush borders, have been detected in the New England granites studied by the writer. Rosenbusch regards these as possibly of secondary origin or else caused by mountain pressure.

Van Hise^b points out that in a certain quartzite of the Black Hills rows of minute gas- or liquid-filled inclusions running in parallel lines across the entire section, transverse to the longer axes of the quartz grains, with rows of black ferrite and secondary quartz similarly oriented, are of secondary origin. He regards them as probably due to the fracture of the grains by mechanical action and the introduction of liquid along the cracks with the later deposition of secondary quartz, which has retained the liquid as inclusions.

Some vitreous Cambrian quartzite collected by the writer near Fort Ann, Washington County, N. Y., Mettawee quadrangle, in 1899, shows in thin section enlargement of the original quartz grains by secondary interstitial quartz and also sheets of liquid inclusions intersecting one another at various angles within the quartz grains. As these sheets of cavities stop abruptly at the edge of the original quartz grains, and the courses of the sheets in different grains are not parallel but quite discordant with one another it is evident that these liquid inclusions antedate the metamorphism which produced the quartzite.^c A thin section of a calcareous sandstone from the same vicinity shows similar sheets of cavities in its quartz grains, but their directions are such that they can have had no relation whatever to the bedding planes of the sandstone or to any secondary fractures in it, but their origin must date back to the granite or gneiss from which they came.

The inference to be drawn from the Black Hill and Fort Ann quartzites is that lines or sheets of fluidal cavities within the quartz grains of a quartzite may be secondary or primary—that is, they may have originated in the process of the formation of the quartzite or they may

^a Mikroskopische Physiographie, 4th edition, 1907, vol. 2 (1), pp. 41-42.

^b Van Hise, C. R., Pre-Cambrian of the Black Hills: Bull. Geol. Soc. America, vol. 1, 1890, pp. 216-218 and fig. 4; also A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, p. 620.

^c See also Merrill, G. P., Fluidal cavities in quartz grains of sandstones: Science, vol. 1, 1883, p. 221. He calls attention to the same Fort Ann sandstone or quartzite and to the rapid movement of the vacuoles within the fluidal cavities.

have been associated with that of the parent granite or gneiss itself. The thin sections themselves will indicate in most cases the mode of origin.

Still another mode of origin of fluidal cavities is illustrated in a thin section of an inclusion of plicated fine-grained biotite gneiss (quartz, microcline, biotite, muscovite, rarely allanite) in a granite (quartz monzonite) at the Morrison quarry, on Blue Mountain, in South Ryegate, Vt., visited by the writer in 1907. This section shows parallel sheets of cavities with vacuoles, passing from one quartz grain to another, without interruption or deflection, in a direction at right angles to the foliation of the gneiss. Had these cavities been formed at the time of the intrusion of the original granite from which the gneiss was formed the sheets would hardly have preserved their parallelism under the distortion of the quartz grains. Sections across the contact of schistose inclusions with their inclosing granite from other localities in Vermont show sheets of cavities in the quartz of the granite stopping abruptly at the quartz particles of the inclusion. A thin section across the contact of granite and its original schist capping at the Marr & Gordon quarry in Barre, Vt., shows many sheets of cavities with vacuoles crossing the quartz particles at distances of from 0.094 to 0.3 mm. and roughly parallel to the contact plane of the two rocks. A few shorter sheets of cavities also cross the first set at right angles and presumably in the grain direction. Although the two rocks are firmly welded together, the sheets of cavities do not extend into the quartz particles of the schist. The presumption, therefore, is that the cavities in this Ryegate specimen originated during the last stages of the formation of the gneiss and under conditions of pressure, moisture, and heat quite as great as those accompanying the granite intrusion. The sheets of cavities observed in the gneiss capping the granite at Milford, N. H. (p. 173), and in the diorite schist capping the granite at Becket, Mass. (p. 143), probably originated in the same way as those in the Ryegate inclusion.

That these fluidal cavities in the quartz of granite are not the only factor in the origin of rift and grain structure is evident from the parallelism which exists between the arrangement of the mica scales and the rift of many granites. (See p. 146.) The detection of this arrangement of the mica is the principal means of determining the course of the rift before actual experiment. Similarly the course of the hardway in a quarried block is ascertained by the greater roughness of the particles to the touch on the hardway side than on either of the others.

A remark by Buckley^a as to the rift in certain Wisconsin porphyritic rhyolites covers several possibilities as to the mode of origin of that structure in granite. "The rift may be the result of flowage

^a Buckley, E. R., On the building and ornamental stones of Wisconsin: Bull. Wisconsin Geol. and Nat. Hist. Survey, No. 4, 1898, p. 446.

planes developed before the rock was completely solidified, it may have been occasioned by alterations since the formation of the rock, or it may be the result of both."

The observations at Redstone, N. H., indicate that the arrangement of fluidal and gaseous cavities took place in rectangular directions during consolidation, and probably governed the courses of rift and grain produced by strains after consolidation; and any parallelism between the mica scales in the rift direction must be regarded as having originated at the same time as the arrangement of the fluidal cavities, and to have been governed by the same general cause.

That any alignment of the mica scales in the direction of the sheets of fluidal cavities and the rift cracks is not necessarily identical with their arrangement or that of the feldspar by flow structure is shown by the following observations in New England granite quarries: At Mount Waldo, Frankfort, Me., flow structure strikes N. 20° W., rift is horizontal and grain vertical with N. 85° W. course. At the Taintor quarry, Hallowell, Me., flow strikes N. 35° W., rift is horizontal and grain vertical with N. 70° W. course. At North Jay, Me., flow is horizontal in undulations 20 feet wide and rift is horizontal without grain. At Dodlin Hill, Norridgewock, Me., rift is horizontal, flow and grain are both vertical with N. 60° E. course. The Norite at the Hall quarry, near Baileyville, Me., has horizontal sheet, flow, and rift structure.^a

At Milford, N. H. (p. 158), flow varies greatly, N., N. 15°, 20°, 50°, 70° E., and N. 75°–80° W., rift is horizontal or nearly so, and grain about vertical with N. 60°–90° W. and 80° E. course. At the Klondike quarry, near Niantic, R. I., flow is N. 10°–20° W., dipping west, intersecting a feeble horizontal rift. At Milford, Mass., there is a wide range in both strike and dip of flow, but rift is everywhere reported as horizontal and grain as vertical with N. 40°–90° E. course. In places flow and rift are parallel (p. 77).

Incidentally, attention may here be directed to a fact familiar to all geologists engaged in the microscopic examination of granites; that is, the movement of the bubbles (vacuoles) within the fluidal cavities of the quartz particles. Whether due to the effect of light or to other causes, visible motions within a rock of such density and antiquity as granite is very suggestive. These motions were found to be as perceptible within the quartz grains of the Fort Ann quartzite (noted also by Merrill, see p. 45) as in the quartz particles of the Redstone, N. H., granite. The writer has also observed them in the quartz of segregation veins in Cambrian slate from Vermont, in which the fluidal cavities obviously originated at the time of the origin of the vein.

^a See for all these facts Bull. 313, pp. 82, 121, 151, 155, 162.

SOME SUBJOINTS DUE TO STRAINED VEINS.

On page 32 the term subjoint was applied to certain minor joints which either branch off at various angles from main joints or are parallel and close to them. It is here extended to include also series of minor parallel joints traversing quartz veins.

Such jointed veins occur in several quarries at Quincy on the North Commons. They are made conspicuous by a zone of light discoloration in the granite on either side of the vein. At the Field & Wild quarry (see p. 105) these veins recur at intervals of 2 to 25 feet, with a north and northwest strike and a southwest dip. They are crossed every inch or two by subjoint about 1 foot long, which strike about N. 15° W. and dip east like the chief joints of that quarry. At the Galvin quarry (see p. 104) similar quartz veins, striking N. 25° W. and dipping south-southwest, are crossed by vertical subjoint an inch apart and a foot long, with a northerly strike like that of the major joints. These relations are shown in Pl. III, *B*. Workmen report that the granite near such veins is harder than elsewhere.

These subjoint may be accounted for by the greater rigidity and vitreousness of the veins and the adjacent granite, thus causing them to fracture more readily than the surrounding rock under the joint-forming movements. Although parallel to the major joints such subjoint may have been formed at a different time.

PEGMATITE DIKES IN GROUPS.

The granite of Milford, N. H., is crossed by the usual pegmatite dikes, but at several quarries instead of being single or ramifying they occur in parallel sets of three to twelve and have sinuous courses. This grouping is exceptional in the 284 granite quarries thus far visited by the writer. At the old Field quarry, near the village, the individual dikes measure from one-fourth of an inch to 1 inch in width and number up to ten in a set, and the sets recur at intervals of 15 to 20 feet. At the Hayden quarry, a mile south, such dikes, from one-fourth to 1 inch wide and up to twelve in a group, recur at intervals of 20 to 30 feet. At the Young quarry, midway between these localities, the sets consist of three to eight dikes up to 3 inches thick and recur at intervals of 20 feet. The dikes here meander and unite in the most intricate manner, occupying bands of granite 5 to 10 feet thick, which in quarrying have to be discarded. Pl. VI, *B*, shows four sets of these dikes. Somewhat similar dikes were noted by the writer in a small quarry 3 miles northeast of Lewiston, Me., where a fine-grained biotite gneiss is traversed in a space of 30 feet by 27 pegmatite dikes ranging from 1 inch to 2 feet in thickness and all dipping 80°. The pegmatite of Milford, N. H., consists of oligoclase, smoky quartz, microcline, biotite, and accessory magnetite, allanite, and zircon.

It is difficult to explain the grouping and spacing of these dikes without supposing some periodicity in the application of the tension which made openings for them. The sinuosity of the courses of such dikes has been regarded as evidence that the openings were the result of tension rather than of compressive or other strain. (See Bulletin 313, p. 44.)

CYLINDRICAL AND OTHER IRREGULAR DIKES.

At the Ballou quarry, in Quincy (see map, Pl. II), the attention of geologists has been often drawn to a vertical cylindrical pegmatite dike about 2 feet in diameter, a horizontal section of which has for many years been exposed at the gradually deepening bottom of the quarry, which has now reached a depth of 150 feet. A block containing an entire cross section of this dike was shown to the writer by Mr. F. Wesley Fuller, of the Quincy Granite Company, at West Quincy. The general color of the dike is a light greenish gray, much lighter than the surrounding granite. Prof. Charles Palache, of Harvard University, who had been studying this dike before the writer's visit, gives the results of his observations in these words:^a

I determined the presence in the pegmatite of ægirine and riebeckite, the latter probably the original mineral and the other formed from it. With them is fluorite, sphalerite (zinc sulphide), and galena (lead sulphide) in minute amounts, molybdenite more abundantly, danalite doubtful. The pegmatite is in no proper sense a dike as I saw it; it seems to occupy a pipe-like branching cavity with a rude radial arrangement of its constituents inward from wall to cavity. It merges outwardly insensibly into the riebeckite granite of the region. My interest in the occurrence was aroused by the unusual size of the rare forms of amphibole and pyroxene found in it.

The writer's observations follow: The section of the cylindrical mass at the Quincy Granite Company's yard has an outer rim with abundant blue-black riebeckite crystals slightly larger than those of the surrounding granite. Within this is an intermediate zone (specimen D. XXIX, 80, b) of light greenish gray feldspar and slightly milky quartz (particles up to four-fifths inch in diameter), containing bright grass-green crystals of ægirite in sizes up to 1 by one-half inch, with some purple fluorite and rusty metallic spots. The center consists mainly of quartz, with coarse feldspar outside of it. Under the microscope the feldspars prove to be orthoclase with a finely intergrown plagioclase, also particles of albite and probably oligoclase-albite. Both feldspars have the minute crystals of riebeckite and particles of epidote typical of Quincy granite. The quartz has many fluidal cavities. There are slender epidote crystals in feldspar and quartz. The riebeckite is intergrown with ægirite, and magnetite is somewhat plentiful. The feldspars are somewhat kaolinized and there is some hematite and limonite stain. The brown-

^a From a personal letter to the writer, dated May 8, 1907, published here with the consent of Professor Palache.

ish metallic areas of the middle zone consist of magnetite, titanite, epidote, zircon in double pyramids, allanite, fluorite, ægirite, and quartz.

This cylindrical dike is thus a riebeckite-ægirite granite; that is, a granite containing varieties of hornblende and augite rich in soda and ferric oxide, but poor in alumina, magnesia, and lime, and thus resembles the surrounding granite, but its particles are much coarser and radially arranged; some of its accessory minerals are exceptional and the others, as well as its secondary minerals, are more abundant. The accessory minerals noted either by Professor Palache or by the writer include sphalerite, galenite, molybdenite, magnetite, fluorite, allanite, titanite, and zircon. The secondary minerals are kaolin, epidote, hematite, and limonite. Both ægirite and riebeckite are regarded as primary. (See p. 97.) Mr. Fuller stated that the mass as then exposed seemed to ramify downward.

Another dike of unusual form, composed of fine-grained black hornblende diabase, is exposed at the bottom of the Rockport Granite

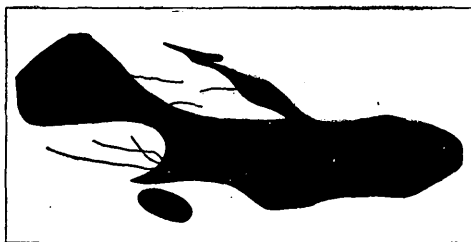


FIG. 2.—Diagram sketch of horizontal cross section of injection of hornblende diabase at Deep Pit granite quarry, near Bay View, on Cape Ann, Massachusetts. Length, north to south, 25 feet, and east to west 8 feet. The fine ramifications are up to 3 feet by 1 inch in size.

Company's "Deep Pit," near Bay View, on Cape Ann, 195 feet below the surface, as shown in Pl. V, *B*, and in more detail in fig. 2. It dips to the north. Its original upper surface, 30 feet above its present surface, is reported as not over 8 feet in diameter. As shown in Pl. V, the quarry is traversed by two intersecting basic dikes. The

one nearest to this mass, 10 feet west of it, is not a hornblende diabase (ophitic texture with hornblende and biotite), but a lamprophyre without biotite (porphyritic texture with augite). The large dike on the east side, which from its dip must traverse the granite about 80 feet east of the mass in question, proves to be also a hornblende diabase. The connection, therefore, of the central mass will, if excavations proceed deep enough, very probably be found to be with the dike on the east, not with that on the west.

Thin sections of the fine-grained rim of one of the dikelets protruding from this mass and of the granite next to it bring out interesting facts. The rim sends out branches, from an eighth to a fourth of a millimeter long, into the granite. In places both rocks are dovetailed into one another. The rim consists of minute roundish particles of hornblende and incipient crystals of feldspar and fine particles of magnetite. There are crowds of apatite crystals along the contact and a little secondary calcite. In one place the hornblende and mag-

netite of the dike are thickly disseminated in the granite; in another both rocks are merged into one containing the minerals of both.

This diabase mass appears to have been injected at the time of the intrusion of the other diabase dikes of the cape and to owe its shape to an irregular east-west fissure with a northern inclination. That the intrusion probably took place under considerable pressure and heat is shown by the commingling of the minerals of both rocks along their contact.

MUSCOVITE VEINS ("SAND SEAMS").

At some of the Concord, N. H., quarries the muscovite-biotite granite is traversed here and there by what quarrymen term "sand streaks" or "sand seams." These are veins of white mica from one-tenth to two-fifths inch wide with a border of quartz and feldspar about another tenth inch on each side. The mica plates measure up to 0.07 inch in diameter. Some of these veins, however, consist almost entirely of mica plates without any regular arrangement, attain a thickness of $1\frac{1}{2}$ inches, and have mica plates up to 0.2 inch.

Veins of kindred but not identical character were observed at Milford, N. H. At the disused Field quarry muscovite veins, half an inch wide, with a central parting, recur at intervals of 15 to 20 feet. They strike like the pegmatite dikes referred to on page 48, and are discontinuous, not exceeding 6 feet at a stretch and being in places but a few inches. At the neighboring quarries of the Milford Granite Company there is a heading striking N. 30° E., the joints of which inclose segregation veins of muscovite and quartz, the quartz in the center. These are from 0.1 to 0.5 inch wide and the granite is discolored up to half an inch on each side. This is due to the oxidation of ferruginous matter within the soda-lime feldspars, which turns them bright reddish. The biotite is also chloritized.

It will be noticed that these Concord and Milford, N. H., veins differ in that the former usually have muscovite in the center, but in the latter quartz occupies that position. Both kinds of veins may be attributed to the percolation of mineral solutions along fissures. In either case the outer mineral was deposited first. The proximity and parallelism of many of these veins to pegmatite dikes suggest that although deposited from solutions they were probably intimately related to the pegmatite dikes and formed at the same time. In that case the heading referred to at Milford antedates the sheet structure.

FELDSPARS.

COLORS.

Although the shade of a granite is largely determined by that of its quartz particles and the relative abundance and size of its black mica scales, its color is almost always determined by that of its feldspars.

The colors of feldspars in commercial granite are so varied as to be an object of interest not only to the geologist but to the quarryman and the architect. Even the small number of granites considered in this bulletin have feldspars of eight colors—bluish, greenish, olive-green, pea-green, cream color, pink, reddish, and greenish brown. Some are colorless and transparent, others are dark or light gray, while the colored ones may be either transparent, translucent, or opaque. The relative opacity is mainly determined by degree of kaolinization and micacization.

In some cases the origin of the color is not easily determinable. Thus the feldspar of Concord granite is translucent, with a slight bluish tinge, but the sections show no mineral which would produce such a tinge. In other cases, however, the results of microscopic examination are more satisfactory. Thus one of the Rockport granites (p. 132) owes its greenish tinge to chlorite scales and limonite stain. The Milford, Mass., granites (p. 75) have a delicate pink orthoclase and a yellow-greenish plagioclase. The greenish tint is due to innumerable minute crystals of epidote and a few scales of chlorite. The smallest of these epidote crystals measure about 0.001 millimeter. The orthoclase is much kaolinized and the cause of the pinkish tinge is not apparent but is supposed to be due to the presence of infinitesimal particles of reddish hematite (Fe_2O_3).

The reddish biotite granite of the Redstone quarry at Westerly, R. I. (p. 200), contains a pinkish potash feldspar and a cream-colored plagioclase, both translucent and more or less micacized. They are both stained reddish here and there by hematite (Fe_2O_3) proceeding from the oxidation of magnetite particles (Fe_3O_4). This shows how the reddish color may be brought about. A similar reddening of the feldspar along the joint faces at Redstone, N. H., is due to hematite plainly proceeding from magnetite particles (p. 181).

The olive-green granite of Rockport (p. 135) contains a grayish olive-green orthoclase which appears crowded with opaque particles, presumably kaolin, the largest of which range from 0.0028 to 0.014 millimeter. There is yellow limonitic ($\text{Fe}_4\text{O}_5\text{H}_6$) staining both along the rift cracks and about the opaque particles, some of which may be ferrous iron (FeO) instead of kaolin. This limonite stain, in connection with an original bluish tinge unaccounted for, produces the olive green. This granite contains also biotite and allanite. The similar olive-green granite from Redstone, N. H. (p. 182), owes its green tinge more to the color of the quartz than to that of the feldspar. The feldspar is a medium bluish gray with an occasional yellow-stained cleavage or rift crack. The limonite stain here clearly proceeds from the alteration of somewhat abundant particles and crystals of allanite,^a as shown in fig. 3, and also from particles of hornblende.

^a See glossary (p. 217), also Iddings and Cross, On the widespread occurrence of allanite as an accessory constituent of many rocks: *Am. Jour. Sci.* (3) vol. 30, 1885, pp. 108-111.

The bluish and greenish tints of the medium to dark gray feldspar of Quincy granite (p. 92) are due to finely disseminated crystals of bluish riebeckite, measuring from about 0.001 to 0.1 millimeter in length by about 0.001 wide, and to innumerable still more minute particles of grass-green epidote.

This bluish-greenish gray feldspar of Quincy granite assumes very different colors as the result of various alterations. In places it becomes cream colored, in others a delicate pea-green or pink, or dark greenish-brownish gray, in others a light olive gray, and in others it becomes spotted with a deep red. The mode of these occurrences, the appearance of the changed feldspars in thin section, and the probable causes of the changes are as follows:

At the Galvin quarry (Pl. III, *B*, and p. 104) the granite on either side of the quartz veins, which contain a little ilmenite and carbonate, is changed for 4 inches from its usual bluish gray to cream color. At the Field & Wild quarry (p. 104) these veins are bordered by 3-inch zones of greenish, pinkish, or light grayish discoloration. The cream and light gray seem to be due not so much to the kaolinization of the feldspars and to limonite stain from the ilmenite of the vein as to a diminution of certain minute black particles which abound in the unaltered feldspar. The pinkish and greenish colors are due to hematite and epidote. The reduction of the black particles and any kaolinization of the feldspars along these veins must be attributed to carbonic-acid waters, and these must either have come from below with the silica of the vein or from above by infiltration along the vein courses.^a

At the Cashman quarry in West Quincy (p. 113) the granite at both the north and the south ends, to a depth of over 70 feet from the rock surface, has delicate pea-green feldspars, but normal gray granite occupies the center of the quarry. Similar pea-green feldspar occurs on the south side of the Lepage quarry (p. 112) in West Quincy to a depth of 30 to 40 feet, and at the Djerf & Winquist quarry on the North Commons (p. 101) to a depth of 125 feet from the rock surface. This pea-green tint seems to be due mainly to a large addition of mi-

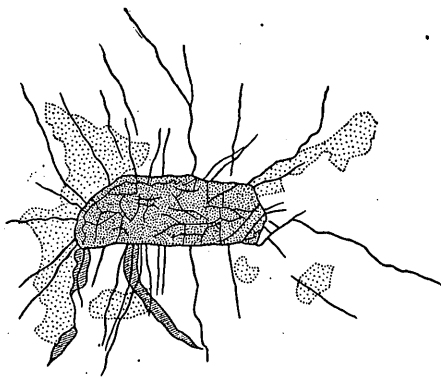


FIG. 3.—Part of a thin section of green biotite-hornblende granite from Redstone, N. H., enlarged 31½ diameters, showing a crystal of allanite with radiating cracks, which are filled with yellowish limonite stain, also bands of such stain apart from these cracks. The dotted areas are quartz, the rest feldspar. Such crystals in part account for the color of the rock.

^a Van Hise, C. R., Treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, pp. 720-728.

nute particles and crystals of light-green epidote, and secondarily to the absence or removal of the minute riebeckite crystals. There is also here and there a secondary light yellowish brown hornblende in minute prismatic crystals. The epidotization of the feldspars in a superficial zone from 30 to 125 feet thick is intelligible, but some structural feature seems necessary to account for the separation of two vertical belts of light-green granite by a normal gray one at the Cashman quarry. As epidote is a hydrous silicate of iron, alumina, and lime, and as potash feldspar is a silicate of alumina and potash, the alteration of the latter into the former involves access of calcium and iron. Some of this calcium may have been supplied by the soda-lime feldspar intergrown with the other, or both calcium carbonate and iron may have been brought into the rock.^a

As all the orthoclase of Quincy granite contains a little epidote the process of epidotization must in a measure have affected the entire granite mass, at least as far as 225 feet, the greatest depth reached. But in these light-green granites the process was carried much farther.

A pink granite occupies one-half of the Savo quarry (p. 114) in West Quincy, to a depth of 30 feet, and the pea-green granite the other half. The feldspars of the pink stone have been kaolinized and made pink. The larger riebeckite and ægirite particles have passed into masses (pseudomorphs) of quartz, magnetite, and carbonate, with some epidote and chlorite. Magnetite crystals are conspicuous in them. The minute crystals of riebeckite have disappeared. These changes in the feldspar and the ferro-soda silicates could be explained by access of carbonated surface waters and metamorphic action. The color of the feldspar must be attributed either to the reduction of limonite particles or to the oxidation of magnetite.

At the Sartori quarry (p. 120) the feldspar has become largely kaolinized and micacized, and also somewhat stained with hematite. It has lost its translucence and acquired a dull greenish-brown hue. The black silicates have passed largely into an aggregate of biotite, magnetite, carbonate, and quartz and there are no minute riebeckite crystals in the feldspars.

At the Rogers quarry in West Quincy (p. 117) the feldspars at the south end and west side become a light olive gray after exposure. In thin section faint yellowish limonite stain appears along the rift and grain and along cleavage and irregular cracks. The yellow of the stain combined with the bluish green of the riebeckite yields an olive gray. In one section bright limonite stain is seen to ramify from the large particles of intergrown riebeckite and ægirite.

At several Quincy quarries some of the granite is spotted with deep cherry-red and muddy-olive stains up to an inch in diameter. These stains surround the larger riebeckite and ægirite particles from

^a Van Hise, C. R., op. cit., p. 255.

which they penetrate the adjacent feldspars. This discarded spotted granite is called "orei" by the workmen (p. 219). In thin section many of its feldspars are seen to be permeated by bright red hematite stain, which ramifies within them from the cleavage and rift cracks, as shown in fig. 4. This stain is also accompanied here and there by yellowish limonite stain probably of later date; and there are long slender particles, probably epidote, up to 0.33 by 0.0002 millimeter, which are all parallel in the same feldspar crystal. Radiating, needle-like, and fibrous felty crystals of secondary yellowish or muddy green hornblende are attached to the riebeckite and ægirite particles. Some of the ægirite crystals are completely altered to chlorite, magnetite, and quartz. The immediate cause of the staining of the feldspar and of the formation of the fibrous hornblende and possibly of the epidote is thus the alteration of the riebeckite-ægirite particles, but the cause of that alteration is not so apparent. Their alteration to magnetite, alone, implies metamorphism. At the Cashman quarry some "orei" was found next to a steep heading, and at the Hardwick quarry the granite within a heading has a hematitic color. These occurrences suggest that the change in the black silicates may have been brought about by access of surface water along joint planes, hydrating and oxidizing the iron of the silicates, and that the granite thus stained by limonite has become reddish as the limonite under metamorphism became reduced to hematite. It is also possible that, the black silicates having under metamorphism passed partly into magnetite, this may by oxidation have yielded hematite.



FIG. 4.—Thin section of altered Quincy granite (orei), enlarged 62½ diameters, showing hematite stain in the feldspar. The large particle from which streams of stain proceed is ægirite. Its altered parts are shaded.

This reddening of the feldspar also characterizes the gray quartz monzonite of two of the Milford, N. H., quarries (pp. 163, 166) for a thickness of 10 to 50 feet from its contact with basic dikes. The change takes place chiefly in the soda-lime feldspar, which is also much kaolinized. The source of this hematite is probably the magnetite particles.

CUT SURFACES.

Reference was made in Bulletin 313 (p. 59) to the fact that if one of two commercial "granites" of identical shade be a diorite, that is, a granite with only a soda-lime feldspar, and the other a normal biotite granite, that is, with very little of that feldspar and considerable potash feldspar, the cut surface of the diorite will be very

much lighter than that of the normal granite; and it was pointed out that this is probably due to some optical property of the soda-lime feldspar. In the preparation of the material for this bulletin it has been found that the quartz monzonites of Westerly, R. I., and Milford, N. H., in which the soda-lime feldspar is in excess of the potash feldspar, cut lighter than normal granites even of lighter shade. Dr. G. P. Merrill suggests that the optical property involved here is the multiple twinning of the soda-lime feldspar which must greatly facilitate its breaking up under the hammer and thus increase the diffusion of light. As the dark purplish porphyritic rhyolite ("granite") of Montello, Wis., in which potash feldspar makes up half the rock and which has no other feldspar, hammers quite as light as the Westerly quartz monzonite, this shows that the same effect may be produced in some other way.^a

GRANITIC QUARTZ, ITS TEXTURE AND COLORS.

The observations here brought together show that granitic quartz is far from possessing the homogeneous texture or color popularly attributed to that mineral. Not only is the quartz apt to contain cavities with and without vacuoles, as was shown on p. 42, in intersecting sheets related to rift and grain cracks, but it also contains minute opaque particles, particularly abundant in smoky quartz. Some of it abounds in hair-like crystals, probably of rutile. The quartz of some granites shows by its behavior in polarized light that the arrangement of its molecules has been disturbed by mechanical strain. In two Massachusetts granites, Milford and Quincy Gold-leaf quarry, this strain has been carried far enough to granulate the quartz. The granules generally measure under a millimeter in diameter. The quartz of the granites described in this bulletin varies from colorless to blue, amethystine smoky, rose colored, and smoky of various shades. At Redstone, N. H. (p. 182), an amethystine smoky quartz has become greenish by the coating of its rift and grain cracks with limonite. Colorless quartz has the fewest cavities or particles. The smokiness appears to be due to minute black particles. But the microscope fails to show the cause of the blue, rose, and amethystine tints.^b

GRANITE DISCOLORATION AND ITS CAUSES.

In investigating the yellow-brownish discoloration, "sap," of the Maine quarries, thin sections showed that the limonite stain did not proceed from the ferruginous minerals and the inference was

^a See Buckley, E. R., On the building and ornamental stones of Wisconsin: Bull. Wisconsin Geol. and Nat. Hist. Survey, No. 4, 1898, p. 94 and Pl. V.

^b Rosenbusch, H., *Mikroskopische Physiographie der Mineralien und Gesteine*, 4th ed., 1905, vol. 1, pt. 2, Granit Quarz, pp. 93, 94.

therefore drawn that it was due to the infiltration of ferruginous surface waters along the joint planes. (See pp. 35-36 and Bulletin 313, fig. 2.)

In the granites described in the present paper this limonitic stain occurs in varying thickness up to 2 feet. It is very abundant in the Rockport quarries, where its brightness has led to its architectural use. Thin sections of the Rockport "sap" show the stain along the boundaries of particles and in all cleavage and rift cracks as well as in streaks across them. It is conspicuous about hornblende and magnetite particles. The stain has also proceeded from the cracks inward into the intervening areas. The zonal arrangement of the rust stain is also noticeable. The medium gray of the fresh granite becomes at first greenish toward the surface; this is followed by a zone of deep yellow brown; and that in turn by a much lighter yellow brown. The greenish zone is that of advancing limonitization, the next of maximum stain, and the outside is that of delimonitization, or deoxidation due to organic acids, and made still lighter by the greater kaolinization of the feldspars of the surface. In some Rockport specimens this outer paler zone is covered by an extremely thin crust of bright yellow brown, as though a secondary infiltration of limonite had taken place after the deoxidation. Although in the Rockport granite the ferruginous minerals have furnished some of the stain, it is doubtful whether they could have supplied enough to color so many sheet and joint surfaces so intensely. A thin section of discolored Westerly granite also shows the rust stain arising from biotite and magnetite particles (p. 202).

A specimen of Quincy granite from the Dell Hitchcock quarry has a rim of "sap" from 1 to 1½ inches wide, of which the inner tenth to three-tenths are dark brown and the rest light brown. The inner boundary is very uneven, the rusty part having encroached upon the granite in roundish protuberances. Some of the limonite streaks start from ægirite particles. In a piece from the Wigwam quarry the stain proceeds from magnetite particles and not from the black silicates, but some of the magnetite particles are within crystals of riebeckite. In a specimen from the pea-green granite of the Lepage quarry, out of a rusty band 1½ to 2 inches thick, an inner one-fifth inch is deep brown, but the fresh granite next to it is dark greenish. The rest, or outer part, ranges from a very light brown to cream color at the surface. The stain proceeds from the black silicates and from the vicinity of zircon crystals, which are often associated with iron in some form. An ægirite crystal is one-half hematite. The central parts of others are altered to limonite before the outer.

The following shows how large a zone of discoloration small particles of magnetite may produce. In one of the fine-grained granites

of Milford, N. H. (p. 170), there are occasional porphyritic crystals of black mica up to 1 inch long, 0.5 inch wide, and very thin, around which, after exposure, a circle of slight limonitic stain 20 inches in diameter appears on the rift surface. The stain has no appreciable thickness. The biotite probably contains, as usual, small particles of magnetite.

The conclusion from all these data is that the superficial discoloration of granite originates partly in the limonitization or rusting of particles of magnetite, biotite, or other black silicates by access of surface water, and partly also by the infiltration of ferruginous water along joint and sheet partings. These rusty rims often show three zones—an inner, in which the color is a mixture of that of the original granite and of limonite brown; a middle, in which it is exclusively limonitic, and an outer paler one caused by the deoxidation of the limonite by organic acids and the greater kaolinization of the feldspars.

As bearing on the time involved in this process, attention should be called to the very slight discoloration produced in the course of twenty-five years along a vertical blast crack in Quincy granite at the Dell Hitchcock quarry. Under the higher powers of the microscope a slight stain can be detected about the small epidote particles in the feldspars, and here and there along the boundaries of the quartz and feldspar.

OVOIDAL WEATHERING WITHIN A HEADING.

Shaler called attention to spheroidal weathering in the granite of Rockport,^a and gave a plate showing "decomposition boulders," which are the result of the progress of decay working inward from both sheet and joint surfaces. This is not unusual in granite regions. This decay is mainly due to the chemical processes described under "Decomposition" (p. 36). Spheroidal weathering in granite may, however, be partly of different origin. The writer many years ago made some colored sketches of a concentric cylindrical structure in granite at a railroad cut at Unter Brambach in Saxony, in which the surfaces an inch or two apart were coated with limonite stain. The cylindrical forms, although brought out by weathering, were apparently due to internal structure. Of like structural origin are also the concentric shelly spheroids of granite about an inner concretion of mica, a foot in diameter, described from central Bohemia by Jokély.^b

Pl. VIII, *A*, represents an ovoid mass of extremely fine quartz monzonite (45 by 33½ by 25 inches) from the Redstone quarry, near Westerly, R. I. (p. 201). This mass came from a point 30 feet below

^a Shaler, N. S., *The geology of Cape Ann, Mass.*: Ninth Ann. Rept. U. S. Geol. Survey, 1889, p. 567, Pl. LI.

^b Jokély, Johann., *Geognostische Verhältnisse in einem Theile des mittleren Böhmen*: Jahrb. K.-k. geol. Reichsanstalt, vol. 6, 1855, p. 375 and figure.

the surface within a heading 40 feet wide at the north end of the quarry, where much decomposition had taken place. As there are no indications at any of the Westerly quarries of an original spheroidal structure, this mass must be classed with those of Cape Ann, but the decomposition, instead of working on 5 sides of an exposed mass, has operated on the sides of a block formed by intersecting joints and sheets considerably below the general surface, and the egg shape is due to the unequal spacing of these partings.

DIKELIKE MASSES OF SCHIST IN GRANITE.

The dikes ordinarily occurring in granite are either granitic, including pegmatite, aplite, and granite proper, or basic. If a granite after the intrusion of such dikes be itself subjected to metamorphism so as to become schistose—that is, a gneiss—then these various dikes will also become more or less schistose. In the granite of Milford, Mass., however, there are schistose basic dikes without an equally gneissic or a parallel gneissic structure in the granite.

At the Cutting quarry (fig. 7) the west wall is formed by a vertical dike-like mass of biotite schist 2 feet thick striking N. 25° W. The east wall is formed by a heading of almost identical strike, N. 20° W., but dipping 70° E. As shown in the figure, neither of the flow directions nor the trend of rift or grain corresponds to the strike of the schist dike. The only corresponding structure is that of the heading and the inclosing walls of the dike. At the West quarry, 1½ miles southsouthwest of the last, there are two dikes of similar schist, one striking N. 67° W. and dipping 65° NNE., the other striking about N. 45° W. with nearly vertical dip. The nearest parallel structure is a joint striking N. 60° W. and dipping 47° SSW. At the Massachusetts Pink quarry, three-fifths mile southwest of the Cutting quarry, there is another schist dike, 2 feet thick, striking N. 3° W., and dipping 55° E. without other corresponding kinds of structure. The general schistosity of all these dikes is parallel to the joint faces which inclose them, and no merging between granite and schist was observed. Emerson and Perry (p. 73) note the rudely parallel films of biotite in the granite, which give it a gneissoid look, but which seem to be partly due to flow structure, and they note the undulatory extinction of the fractured quartz particles as showing a state of strain. The granular structure of the quartz areas is very noticeable on a polished face, and this very possibly resulted from the pressure which converted the dikes into schist.

In thin section the fine-grained dark greenish gray schist of the Cutting quarry dike is seen to consist of biotite, quartz, epidote in roundish grains from the alteration of feldspar and a little pyrite. The slightly more greenish schist of the dike at the second quarry consists of hornblende, quartz, biotite, epidote, and zoisite from altera-

tion of feldspar, a brownish cloudy mineral (leucoxene?), and pyrite altered to limonite. Both are evidently altered dikes of mica diorite—that is, diorite schist.

Emerson and Perry regard these dikes as a “basic differentiate of the Milford granite” (p. 73).

It is evident from the facts given that whatever may have been the relation of the deep sources of the two rocks to which Emerson and Perry refer, the dike material was intruded between parted joints in the granite. It is also evident that the change of the eruptive into schist and the alignment of its particles with reference to the inclosing walls was brought about chiefly by compression which, although sufficient to metamorphose the dikes, affected the granite but slightly; nor was the vertical pressure sufficient to plicate the dike or its inclosing walls.

Thus a basic dike traversing a mass of granite in a highly inclined position may under lateral compression become schistose without the inclosing granite acquiring a corresponding schistosity.

RIEBECKITE AND OTHER MINERALS ON JOINT FACES.

Many granite joint faces are coated with secondary minerals. These minerals include hematite, pyrite, limonite, calcite, epidote, chlorite, stilbite, quartz, muscovite, etc. (See Bulletin 313, p. 51.) All these may owe their origin to alteration of the minerals of the granite, but where calcite occurs in considerable quantity, it probably came from originally overlying calcareous rocks.

Some of the joint and even sheet faces in the Quincy quarries are coated with a blue-black mineral with a peculiar sheen due to fibrous structure parallel to the face, and with a bluish gray streak. Such black faces can be seen at the Dell Hitchcock, the Field & Wild, the Granite Railway, and Rogers quarries and at the Mount Pleasant quarry in Milton (Pl. II). On one side of this last quarry both sheet and joint faces are thus coated, and at the Rogers quarry such black joint faces, spaced from 6 inches to 4 feet, make up a heading. These black joints are apt, however, to be intermittent, extending only a few yards or even inches at a stretch.

A thin section cut diagonally to one of these joints and its parallel subjoints shows six meandering or intersecting cracks from one-eighth to $1\frac{1}{4}$ millimeters apart, filled with crystals of riebeckite (a dark-blue soda hornblende), the smallest of which are 0.02 and the largest 0.1 millimeter long, together with fibrous white mica, limonite, and very little carbonate. The granite between these fissures is broken up here and there into minute angular fragments and the feldspar is granulated. The cement of this microscopic breccia is also riebeckite, the crystals of which lie with their axes either parallel to the fracture

or across them or even projecting into the feldspar fragments. Some of the feldspars next to the joint are unusually crowded with riebeckite crystals, which probably originated in the same manner and at the same time as those within the joints.^a

The secondary and relatively recent origin of this riebeckite is evident, and its formation by segregation from the ferro-soda silicates of the granite seems also quite probable.

Prof. James P. Smith has recently explained the alteration of a certain California arkose (decomposed granite or diorite) and a sandstone, with varying proportions of impure clay, into schists consisting largely of glaucophane (a soda hornblende closely related to riebeckite) as due to a process of recrystallization under heat and pressure.^b

In the case of the riebeckite-coated joints and sheets of the Quincy riebeckite-ægirite granite some transfer of material into the joint spaces must also have taken place. The presence of this mineral on them shows that the granite of Quincy was subjected to a certain amount of metamorphism after the development of its sheet and joint structure.

Some joint faces at Milford and Becket, in Massachusetts, and Concord and Redstone, in New Hampshire, present different features. At the East quarry of Milford (p. 82) the parted joint which forms the west wall is filled with a fine-grained greenish brownish and cream-colored mass with transverse and longitudinal slickensided cracks. In thin section this proves to be a brecciated granite cemented with calcite, chlorite, fibrous muscovite, and limonite. The amount of calcite in this mass is so considerable that it seems improbable that the granite alone could have supplied it.

At the quarry of the Hudson & Chester Granite Company in Becket (p. 141) some of the joint faces of the bluish gray muscovite-biotite granite are dark greenish for one-fourth inch from the face. The granite in this zone has undergone these alterations: Formation of fibrous mica with limonite stain along cracks transverse to the face and along feldspar cleavages; formation of mica in the feldspars and of calcite both in the lime-soda feldspars and between the particles. These secondary minerals added to the original ones make these small rims quite complex.

At the "Upper or Granite Railway quarry" of John Swenson (p. 151) at Concord certain joints with a N. 65° W. course and short parallel subjoints are coated with minute quartz crystals and obtuse

^a This and the occurrence of secondary riebeckite in rift and grain cracks, mentioned on p. 107, partly confirm the suspicion expressed by A. Sauer in 1888 as to the origin of this mineral. See *Zeitschr. Deutsch. geol. Gesell.*, vol. 40, 1888, p. 145.

^b Smith, James Perrin, *Paragenesis of the minerals in the glaucophane-bearing rocks of California*: *Proc. Am. Phil. Soc.*, vol. 45, 1906, p. 183. See also summary, pp. 238, 240, 1907.

calcite rhombs standing edgewise on the joint face, and also here and there with the beginnings of 2-inch cubes of deep purple and white fluorite. Similar fluorite occurs exceptionally within the granite near the face.

At the Redstone, N. H., quarry (p. 181) the light-pink granite for an inch back of one of the major joints is a yellowish pink with patches of grass-green, while the face itself is pale brick-red, rust color, bluish, and grass-green. Thin sections show the feldspars much altered to white micas, and crossed by veinlets of them. They are also kaolinized and stained pink by hematite from the magnetite particles. There is some carbonate, limonite, chlorite, and epidote.

While nearly all the secondary minerals in these joint coatings (chlorite, epidote, muscovite, hematite, limonite, calcite, and quartz) may be accounted for by processes of "deep-seated weathering"—that is, by the alteration, largely chemical, of the minerals of the granite itself—the fluorite is more likely to have been brought from the same source as the granite itself but at a later time, and the calcite of Milford from once overlying calcareous sedimentary beds.

GRANITE CONTACTS IN RELATION TO SHEET AND FLOW STRUCTURE.

Several interesting contacts between granite and its overlying rocks were found and are shown in fig. 5 and Pls. VI, A, and IX, A. These contacts throw light on the origin of sheet structure and illustrate the nature of flow structure and of certain pegmatite dikes.

CONTACT AT MILFORD, N. H.

At the southwest corner of the Pease quarry at Milford, N. H. (p. 163), about 6 feet of mica diorite gneiss overlies the fine-grained quartz monzonite, as shown in fig. 5, with a foliation striking N. 75° W. and a dip of 20° south. The granite has a flow structure about parallel to the contact surface, but sheet structure crosses both gneiss and granite and flow structure.

At the quarries, now idle (p. 173), of the Milford Granite Company there is a working face on the west about 1,000 feet long. At its southern and northern ends granite and gneiss contacts are finely exposed. The fine-grained quartz monzonite is overlain by about 15 feet of gneiss, with a foliation striking N. 75° W. and dipping 75° south. Pl. VI, A, shows the contact at the north end of the cut. The sheet structure is lenticular horizontal, but does not continue into the gneiss, which seems to have an independent and discontinuous sheet structure of its own. The gneiss varies greatly in texture, composition, and color. In places it is coarse, black, biotitic, and hornblendic; in others medium grained, gray or white, and more quartzose and feldspathic. It appears to be a quartz-mica diorite gneiss, but contains streaks of a finely banded, light-greenish, fine-grained rock, which in thin section shows quartz, soda-lime

feldspar (oligoclase-andesine), augite, hornblende, and biotite, and thus appears to be a quartz-augite-diorite gneiss. There are also dikes of pegmatite starting from the surface of the granite and tapering out in the gneiss.

CONTACT AT NIANTIC, R. I.

At the Klondike quarry (p. 205) near Niantic, R. I., as shown in fig. 27, the fine-grained quartz monzonite is overlain on the west side by 50 feet of medium-grained biotite gneiss with porphyritic lenticular potash feldspars (microcline) up to $1\frac{1}{2}$ inches long, most of them rimmed with white soda-lime feldspar (oligoclase-andesine). The foliation of this gneiss is about horizontal. As shown in Pl. IX, A, the contact between the granite and gneiss dips somewhat steeply, and sheet structure crosses both granite and gneiss at a lesser angle. There are also dikes of pegmatite beginning at the contact and tapering upward in the gneiss. On the east side the same gneiss underlies the granite, the granite intrusion having apparently reached

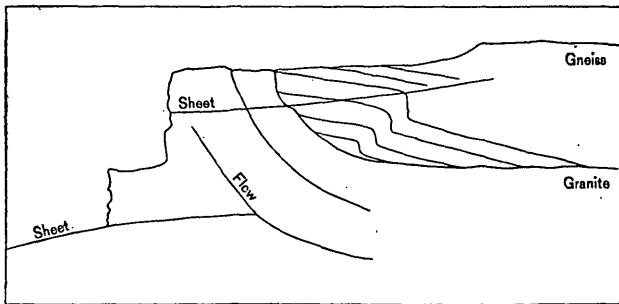


FIG. 5.—Section showing relations of granite and gneiss at the Pease quarry near Milford, N. H.; height, 10 feet. The flow structure is parallel to the contact surface, and sheet structure traverses both rocks.

at least the altitude of the present surface between two masses of the older gneiss; in other words, the original contact surface between the granite and the gneiss into which it was intruded was very irregular, having large denticulations.

CONTACT AT BECKET, MASS.

At the Becket, Mass., quarry (p. 141) a fine-grained, bluish-gray, muscovite-biotite granite partially incloses or is overlain by a mass up to 40 feet thick of very fine-grained, heavy, black, micaceous rock (quartz-mica diorite schist) described more fully on page 143. It has small white quartz and plagioclase veins of tortuous courses. There are also several small dikes of pegmatite or quartz starting from the contact and tapering out upward. Along the contact the granite shows undulating bands generally parallel to the contact surface. These consist of white bands of quartz and feldspar, up to one-fourth inch wide, recurring at intervals of 1 inch, the intervals

being darker and of biotite, muscovite, epidote, and titanite. The courses of some of these bands are sharply undulate. These bands constitute a flow structure which generally conforms to the under surface of the diorite schist.

CONCLUSIONS.

In order to make these contact phenomena intelligible to the general reader, it should be stated that the gneisses capping the granite are rocks of similar origin to the granite itself, but they have been subjected to an amount of pressure and heat sufficient to recrystallize their minerals and arrange them in parallel order, thus giving the rock a foliation or schistosity; also, the present thickness of the overlying gneisses probably represents but an insignificant part of the great masses which originally capped the granite. From the fact that the granite has not been changed in like manner, it follows that these changes must have taken place before the intrusion of the granite. The pegmatite dikes are granitic matter which in a molten condition or in heated solutions appears to have forced its way from the molten granite through fissures caused by the intrusion itself into the overlying gneiss.

The geological principles illustrated by these various contacts are: (1) Sheet structure in granite can not be the result of any property inherent in the granite alone, for it passes uninterruptedly from the granite into the overlying gneiss, and it is also quite independent of flow structure; (2) the course of flow structure in granite is governed in places by the form of the under surface of the masses into which the granite was intruded. Thus also at the Daniels quarry, in Milford, N. H. (p. 168), it accommodates itself to the form of a large inclusion, forming bands around it; (3) pegmatite dikes are apt to originate at the surface of the granite and to penetrate the rock into which it was intruded.

These pegmatite dikes were not studied in sufficient detail to obtain conclusive evidence that the pegmatization of the gneiss could not have taken place in an earlier crustal movement than that of the granitic intrusion.

ACIDIC SEGREGATIONS.

Segregations in granite consist generally of the darker, more ferruginous minerals, but in some instances they are lighter in shade than the surrounding granite and consist largely of feldspar and quartz, as are several at the Quincy quarries, described on page 95. Here also belongs the very coarse-grained large segregation found in the Rockport granite at Halibut Point, which is fully described on page 125. Although it measures 8 by 4 by 2½ feet, all but a core, 6 by 2 inches, which is bronzite, consists of potash feldspar and quartz.

PART II.—ECONOMIC DISCUSSION.

GENERAL FEATURES.

The practical side of the granite industry will now be considered. A list of the more important works on granite quarries and quarrying and other matters of economic character will be found at the end, together with a glossary of both scientific and quarry terms.

TESTS OF GRANITE.

The testing of granite is a subject of considerable importance, as may be seen by its literature.^a As pointed out by Merrill, there is danger of attaching undue importance to tests of compressive strength alone, the results of which in nearly all cases far exceed the generous margin allowed by architects beyond that required by the weightiest structures. On the other hand, there is danger of losing sight of several other important qualities which ought to be carefully tested and upon which the economic value of granite in part depends. The following tests include all the kinds made at European testing institutions or recommended by American authorities, as well as some suggested by the investigation of Maine granites.

Chemical analysis.—Chemical analysis is made in order to determine the amount of iron and lime, or to detect anything abnormal in the composition.

Determination of CaCO_3 .—Tests are made to determine the presence of lime not combined with silicates in order to ascertain the percentage of CaCO_3 (lime carbonate) present. This is done by powdering and treatment with warm dilute acetic acid.

Test for discoloration.—The method applied by Daly (Bull. U. S. Geol. Survey No. 209, p. 52) seems to be well adapted for this purpose. A piece of fresh rock is immersed in a stream of carbon-dioxide gas for 20 minutes and then kept in an atmosphere of that gas for 24 hours. Another piece of fresh rock is placed in an atmosphere of purified oxygen overnight and then exposed for 30 minutes to a temperature of 150° C. (302° F.). Any discoloration due to the carbonization or oxidation of the minutest particles of any mineral would be sure to show itself under these tests.

Mineral composition.—This is determined by the microscopic examination of a considerable number of typical thin sections. All the mineral constituents are noted, and the average size of the mineral

^a See Bibliography, p. 215.

particles in the case of the fine-textured granites is estimated. Any peculiarities of texture, rift, etc., can also be noted.

Proportions of minerals.—A method has been devised by Rosiwal, of the Austrian Geological Survey,^a by which the approximate proportions of the chief minerals (feldspar, quartz, mica, hornblende) and their average size can be determined. This consists in tracing a network of lines intersecting one another at right angles upon a polished granite surface, at intervals so far distant that no two parallel lines will traverse the same mineral particle. The total length of the lines is measured, then the diameters of all the particles of each kind of mineral are added separately and their proportion to the total length of the lines obtained. The average size of the particles of each mineral can be also calculated from the same measurements. Although this method was primarily designed for application to the coarse and medium granites, it can be extended also to the finer ones by drawing the lines upon camera-lucida drawings made from thin sections of such granites under polarized light. As the quartz is the source of the vitreousness of the rock the determination of its amount is important. The incompleteness of the collection of polished specimens of Maine granites and the short limit of time available prevented the application of this method in the preparation of the report on Maine granites, but the method was experimentally applied to the coarse reddish granite from Hardwood Island, near Jonesport,^b and has been much used in this bulletin.

Polish.—Besides the manifest object of this test it also facilitates exact descriptions of color and comparisons between different granites. The size of the mica plates determines the brilliancy and durability of the polish more than does their number—that is, a considerable number of very minute mica plates is not objectionable.

Hardness.—As pointed out by Hawes,^c the hardness of certain granites is not due entirely to the quartz, which is always equally hard and brittle and which the tools do not cut but crush, but to the feldspar, which is of variable hardness and, it might be added, has different cleavages, and the proportion of which in relation to quartz also varies. Rosiwal,^d adopting a principle established by Toula, takes a piece of smooth unpolished granite of about 2 grams weight and rubs it with emery (of 0.2 mm. diameter of particle) upon a glass or metal plate for 6 or 8 minutes until the emery loses its

^a See Rosiwal, August, Ueber geometrische Gesteinsanalysen; ein einfacher Weg zur ziffermässigen Feststellung des Quantitätsverhältnisses der Mineralbestandtheile gemengter Gesteine: Verhandl. der K.-k. geol. Reichsanstalt, vol. 32, pp. 143-175.

^b The result of this test is given on page 173 of Survey Bulletin 313.

^c Hawes, G. W. (edited by Merrill), Granite; Building stones of the United States and statistics of the quarry industry: Tenth Census, vol. 10. 1888, pp. 16-18.

^d Neue Untersuchungsergebnisse über die Härte von Mineralien und Gesteinen: Verhandl. K.-k. geol. Reichsanstalt, 1896, p. 488.

effectiveness. The granite is then weighed again and its loss of volume calculated. He found, assigning to emery an arbitrary value of 1,000 as representing its average hardness, that granite from 9 localities showed the following degrees of hardness: 31.7, 38.1, 41.7, 44.8, 48.4, 50.7, 52.9, 56.6, and 67.1. The extremes of these figures show that some granites have a general hardness more than twice as great as others.

J. F. Williams^a proposed to determine the relative hardness of granites by noting the rate of penetration of a drill of a given diameter, or by measuring the distance to which such a drill will penetrate without being sharpened, or the amount of surface of rough-pointed granite which can be reduced to a bush-hammered surface per hour. Since the introduction of pneumatic drills and surfacers these methods can be easily applied.

Compressive strength.—The methods of testing the strength of building stones have grown in precision. The first requisite is that the cubes to be tested should be sawed by diamond saws and not hammered out. The next is that the direction of both rift and grain should be indicated thereon, and that three cubes should be tested, one with pressure applied parallel to the direction of the rift, one applied parallel to that of the grain, and the third at right angles to rift and grain. Where the rift and grain are pronounced the three results will differ. As in the reports of tests made with the testing machine at the Watertown Arsenal, Mass., the number of pounds pressure at which the first crack is produced should always be given, as well as that at which the cube is crushed. It is assumed that these tests are made in a dry atmosphere.

Transverse strength, shearing strength, and compressive elasticity.—It has been found useful for certain architectural purposes to test these qualities in granite.^b

Porosity.—Buckley^c points out that the danger from frost depends not upon the amount of absorption but upon the size of the pore space. Rocks with large pore spaces stand frost better than those with small ones, because they do not retain the water that they absorb. Tests of porosity are therefore important. Buckley used the dry and saturated weights obtained for the samples used in computing the specific gravity.

The difference in these weights was multiplied by the specific gravity of the rock. This amount was added to the dry weight, giving the sum. The difference of the dry and saturated weights multiplied by the specific gravity of the rock was then divided by the sum. This last result is the actual percentage of pore space compared with the volume of the sample tested.

^a Igneous rocks of Arkansas: Ann. Rept. Geol. Survey Arkansas, vol. 1, 1890, p. 41.

^b See Buckley, Building and ornamental stones of Wisconsin, pp. 396-398. Also Rept. of tests of metal, etc., Watertown Arsenal (1895), 1896, pp. 319-322, 339-351, 407-411. Some of the results as to elasticity are given on page 16 of this report.

^c Buckley, op. cit., pp. 68, 69, 372-376, 400, 413.

Freezing and thawing.—Buckley's method^a consists in drying 1-inch and 2-inch cubes at a temperature of 110° C. and weighing them. After being saturated in distilled water they were exposed overnight to a temperature below freezing. They were then thawed out and soaked in warm distilled water. This process was continued for thirty-five days, when they were again dried at 110° C. and weighed. Finally the same stones were subjected to the tests for compressive strength and the results compared with those for stones not thus treated.

Absorption and compression.—The complete saturation of a stone and the determination of the amount of absorption are effected by a method described at length by Buckley.^b The saturated stone should then be tested for compressive strength and the result compared with that obtained from dry stone.

Behavior under fire.—This test is best applied to saturated specimens, which are then exposed in a laboratory furnace to a temperature up to 1,500° F. and the effect noted. Some of them can be allowed to cool gradually, but others should be immersed quickly in cold water; or they may be exposed to high temperature while under compression and then cooled slowly or quickly.^c

Specific gravity.—The specific gravity is the weight of the stone at 16° C. compared with that of the same volume of distilled water at 4° C. All air should first be removed from the piece to be tested by boiling in distilled water. The specific gravity is also required for the test of porosity.

Weight per cubic foot.—The weight of the dry stone per cubic foot is obtained by multiplying its specific gravity by the weight of a cubic foot of water, but from this there should be deducted "the weight of a quantity of stone of the same specific gravity equal in volume to the percentage of the pore space in the stone."^d This gives the actual weight of the stone free from interstitial water.

Coefficient of expansion.—Finally, it may be desirable to obtain the coefficient of expansion of a granite intended for some particular construction. The expansion of certain granites was determined at the Watertown Arsenal by hot and cold water baths. The stones thus tested were afterwards subjected to the test of transverse strength, when it was found that they had lost 16.93 per cent of their original strength.^e

A list of the various tests applied to building stones by German testing institutions is given by Herrmann.^f

^a Buckley, op. cit., p. 71.

^b Buckley, op. cit., pp. 64-67.

^c Buckley, op. cit., pp. 73, 411.

^d Buckley, op. cit., p. 70.

^e Rept. of tests of metal, etc., p. 320.

^f Steinbruchindustrie und Steinbruchgeologie, pp. 10. et seq.

ADAPTABILITY TO DIFFERENT USES.

The successful use of granite depends upon a careful consideration of its various adaptabilities. The granites proper include stones which vary greatly in texture, color, and shade. The coarse-textured ones are best adapted to massive structures, while the fine-textured ones are better adapted to lighter structures, monuments, and statues. The reason for this is that in coarse-textured granites the large feldspars crossing the various sculptural designs at all angles produce lines and reflections that interfere with the lights and shades produced by the sculptor's design, and thus mar their effect. The fine granites are well adapted to light structures and to fine sculpture, as is shown in the delicately carved granite flowers represented in Pl. IX, *B*. Some coarse granites, however, lend themselves well to coarse carvings, especially when these are to be placed in the higher parts of buildings. Then there is the matter of color and shade. There is large room for the exercise of artistic taste in deciding which colors and shade will best harmonize or contrast with one another in a granite structure or with the colors of other stones or materials in a composite structure. The rust-colored "sap" of Rockport has been used successfully for trimming in connection with the fresh gray granite of that place, on account of the resulting contrast (p. 125). There is also room for choice between different granites in ornamental work, because of the different amount of contrast between the polished, hammered, and rough surfaces of stones of different color and texture, although the polished surface is always darkest and the hammered lightest. The black granites and the quartz monzonites are obviously best adapted for inscriptions where legibility at a distance is the prime object, and also for all ornamental work in which more marked contrasts are desired than the ordinary granite can furnish. The black granites are sometimes combined with ordinary granite of light shade in monumental work, the die being of black granite. Some granites are noted chiefly for their high polish and its durability, and are therefore in demand for columns and wainscoting.

ECONOMIC FACTORS IN GRANITE QUARRYING.

The factors upon which the successful operation of a granite quarry depends are various. The first are petrographical and geological. These include (1) the mineral composition and texture of the rock and its physical properties; (2) its structural features—that is, the directions of the flow structure, rift, and grain, compressive strain, and contact surface with overlying or adjacent rocks of other kinds; (3) the character of the sheet structure, of the jointing, and of headings, dikes, and veins; (4) the size and number of inclusions

and "knots," and (5) the thickness of the rusty rims of sheet and joint surfaces. The economic importance of minute structural features, such as the great variation in its fissility, is exemplified in the range of the number of paving blocks which equally skilled workmen can make of different granites in one day. Thus at Quincy a paver averages 75 blocks a day (size, 12 by 8 by 4 inches). In Maine the number is from 80 to 100 of New York size (11 to 14 by 7 by 4 inches). At Milford, N. H., the average number of Philadelphia size is 200, and at Redstone, N. H., 130 of New York size, which is from 33 to 50 per cent more than is usual in Maine. At Becket (Chester), Mass., the average is 150, size not stated. Another geological factor is the "stripping" or amount of surface material, sand, etc., to be removed from the granite surface.

Other factors, such as facilities for drainage and water supply, the location of the quarry with reference to transportation facilities by land and water, and the disposal of waste, are hydrographical and geographical.

Then there is the artificial factor: The equipment of machinery for pumping, drilling, hoisting, loading, and transfer to car or ship. In the larger quarries this includes air compressors and air drills and in places stone crushers for the utilization of waste.

But when all these factors are satisfactory, success will still largely depend upon the experience and judgment of the foreman or superintendent who directs the blasting and splitting. Without his intelligent control, suitable stone, favorable natural conditions, adequate capital, equipment, and labor are of little avail. The selection of the place for blasting, the size and shape of the hole, the selection of the powder, and the size of the charge are all matters requiring careful consideration. The thickness of the sheet, the proximity of joints, the vitreousness of the stone, its rift and grain structure, the physical laws governing the action of explosives, and the direction in which the quarryman desires to split the mass are all factors in each problem.

The principles of rock blasting are set forth mathematically in a recent book by Daw,^a and a general description of quarry methods will be found in a report by Walter B. Smith.^b

The practice of foremen in the thirty principal granite quarries of Maine, as explained by them to the writer, is described in Bulletin 313, pages 69-71.

In visiting the quarries described in this bulletin a few notes on the use of explosives were made, which are here summarized.

^a Daw, A. W. and Z. W., *The blasting of rocks in mines, quarries, and tunnels, etc.*, pt. 1, London, 1898.

^b *Methods of quarrying, cutting, and polishing granite: Mineral Industries; Eleventh Census, 1892*, pp. 612-618; also *Sixteenth Ann. Rept. U. S. Geol. Survey*, pt. 4 (1894-5), pp. 446-456.

Although the general practice in the Massachusetts, New Hampshire, and Rhode Island quarries is essentially the same as in the Maine quarries, yet in some localities, owing to different conditions of rift, grain, and strain, other modes prevail, as in the following quarries:

Becket (Chester) quarry.—Blasting along a vertical grain, which is pronounced, with a free face and one free side is found to work successfully.

Milford, Mass., quarries.—Blasting along a feeble grain or the hard way, but preferably along the former, with one free face and a free side.

Quincy quarries.—Blasting along the grain parallel to the free face and with a channel on one side parallel to the rift.

Rockport.—(1) Blasting along the rift parallel to a free face and with one free side. But the lewis holes extend at least three-fourths of the distance from the free side to prevent the crack slanting to the face. (2) Blasting along the hard way parallel to the free face and with one free side. The crack slants away from the face, if at all. In one place 15 contiguous knox holes 35 feet deep, along the rift, which dipped 75° to 80°, were blasted with a free face and one free side. By this means a block 125 by 60 by 40 feet deep was loosened.

Concord.—Blasting along a north-south hard way parallel to a free face 30 feet long, with both ends tight; then channeling along the east-west grain on one side, and blasting with knox holes on the other. The hard way blast proves effective, it is thought, because of a compressive northwest-southeast strain. In other places blasting along the grain with two free sides, or, if that is not practicable, with one only.

Redstone, N. H.—Blasting along the grain, which is marked, with one free face and one free side.

Milford, N. H.—Where rift and grain are feeble, blasting in any direction with a free face and one or no free side.

Westerly.—Blasting along a north-south hard way parallel to a free face and with one free end, thus utilizing a strain which operates east-west in the direction of the grain. Very little powder is used in the fine-grained Westerly granites, owing to their delicacy.

A difference is found in blasting and splitting granite in winter and summer. A low temperature increases its cohesiveness, but, probably in connection with water, increases its fissility where the "rift" is feeble.

It is reported that in quarries in Finland the expansive power of freezing water is regularly used in splitting. This is in line with the ancient Egyptian use of the expansion of wet woody tissue. A

method of blasting in use in some of the English coal mines by means of the expansion of slaked lime may be susceptible of adaptation to the quarrying of the more delicate granites.^a

In this connection should be mentioned the method, recently adopted in the granite quarries of North Carolina, of developing an incipient sheet structure by the use of high explosives followed by the application of compressed air. (See footnote *b*, p. 28.)

METHOD OF DESCRIBING THE QUARRIES.

The quarries of the granite centers visited in Massachusetts, New Hampshire, and Rhode Island will now be described. Those of each center will be prefaced with a brief reference to the general geology of the region and also with an outline of its typical granites. The particulars as to each quarry will be taken up in the following order:

1. Name and location of quarry; name and office address of operator.
2. The granite—its trade and technical names, color, texture, and minerals; its mineral percentages estimated by the Rosiwal method as explained on page 66; its chemical composition and physical qualities as shown by any available analyses or tests. The words "coarse," "medium," and "fine," as applied to texture, are to be understood as in Bulletin 313, and as defined on page 14 of this bulletin: Coarse, having feldspars generally over two-fifths inch or 1 centimeter; medium, having feldspars under that and over one-fifth inch or one-half centimeter; and fine, having feldspars under one-fifth inch.
3. The quarry, with date of its opening and size.
4. The rock structure, comprising sheets, joints, headings—their strike, dip, and thickness—rift and grain, flow structure, dikes, veins, "knots," discoloration, and weathering. Where the structure is complex a diagram is given.
5. The plant, with the number of machines and air tools to show its capacity.
6. Transportation, including distance to dock or railroad and method of transport.
7. The product, its uses, with names and location of a few specimen buildings or monuments.

^a See Mosley, Paget, On a new method of mining coal: Jour. Iron and Steel Institute, London, 1882, pp. 53-62.

SPECIAL FEATURES.

DESCRIPTIONS OF THE GRANITES AND QUARRIES.

MASSACHUSETTS.

MILFORD.

Topography.—Milford lies in the eastern half of Massachusetts, in Worcester County, $16\frac{1}{2}$ miles southeast of Worcester. (See map, Pl. I.) It is a region of low hillocks with northerly, northeasterly, and northwesterly trends. The quarries, as shown in fig. 6, lie between N. 10° W. and N. 45° E. of Milford. Two are in Hopkinton, in Middlesex County, and twelve in the town of Milford. All are between the 300 and 500 foot levels.

General geology.—The granite of Milford has, under the name "Milford granite," been classified by Emerson and Perry as post-Cambrian.^a

They represent an area of it extending from Woonsocket, R. I., south to beyond the southern boundary of Providence County, a distance of about 21 miles. They have traced a diorite, in places a diorite schist, entirely around the granite of Milford, and regard it as a "basic differentiate of Milford granite."^b By this term is intended a basic eruptive originating in the same source as the granite, but either succeeding or preceding the intrusion of the latter. If this diorite preceded the granite it has no relation to the diorite dikes which traverse it. The fine-grained white quartzite (metamorphic sandstone) which crops out 3 miles north of Milford on the road to Hayden Row is regarded by these geologists as of Cambrian age and belonging to the "Grafton quartzite," of which there are several areas in Rhode Island along Blackstone River, also west of Providence. It is thus older than the granite.

Emerson and Perry describe "Milford granite" in these words:

A great granite area of a constant type that extends across Massachusetts and Rhode Island in the western part of the area here studied has been named by the writers from the well-known quarries in Milford, Mass. This is a compact, massive rock, somewhat above medium grain, and of light color. The light flesh color of the feldspar and the blue of the quartz give it in some places a slight pinkish tint, and it is now much used as a structural stone under the name "pink granite." Its two especially characteristic constituents, constantly present, are blue quartz and a microcline microperthite, in which albite is always dusted with minute crystals of muscovite and epidote, especially centrally, while the microcline is free from these minerals. These perthitic bands of albite also generally extend out beyond the surface of the microcline, and cover it with a more or less continuous veneer. The rock also shows a fine micrographic structure in contact with quartz. The feldspars project idiomorphically into large fields of quartz, which seem to have been single grains, but are now somewhat cracked. Most of this quartz is blue, and this color appears also in the contact zones and even in the second-

^a Emerson, B. K., and Perry, J. H., The green schists and associated granites and porphyries of Rhode Island: Bull. U. S. Geol. Survey No. 311, 1907, Pl. I.

^b Personal letter from Professor Emerson dated May 1, 1907.

ary quartz that is found in fragments of schist which are inclosed in the granite and which have been greatly altered by it. The fractured grains of quartz show with

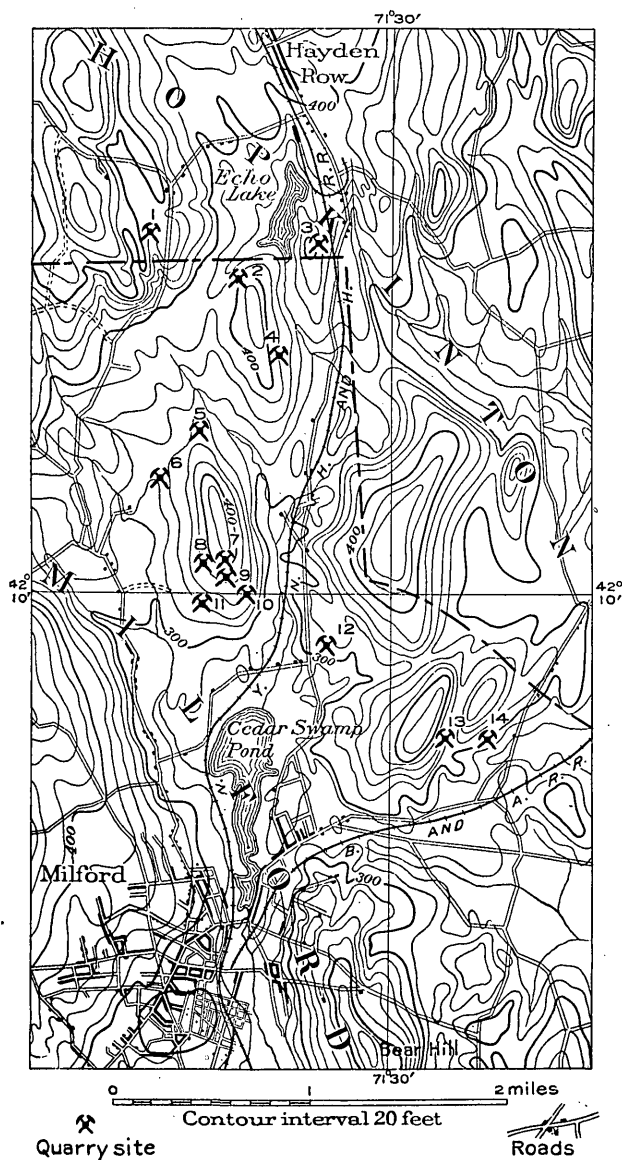


FIG. 6.—Map of Milford, Mass., showing locations of granite quarries. 1, Maguire quarry, Norcross Milford Pink Granite Company. 2, Echo Lake quarry, same company. 3, Hopkinton quarry, Massachusetts Pink Granite Company. 4, Cutting quarry (Milford Stone Company, in 1906). 5, Massachusetts Pink quarry, Massachusetts Pink Granite Company. 6, North Milford quarry, North Milford Granite Company. 7, Quarry No. 8, Webb Pink Granite Company. 8, Quarry No. 7, Webb Pink Granite Company. 9, Quarry No. 5, Webb Pink Granite Company. 10, Quarry No. 3, Webb Pink Granite Company. 11, Quarry No. 4, Webb Pink Granite Company. 12, West quarry (Milford Stone Company, in 1906). 13, East quarry (Milford Stone Company, in 1906). 14, Norcross quarry (Milford Stone Company, in 1906).

polarized light the strongest undulatory extinction, which indicates a state of strain that has probably produced the blue color. The biotite is in small amount, and is



here and there associated with epidote grains. In specimens of granite taken at the quarries at Graniteville it is evenly distributed or gathered in small blotches, as in the Milford type, and the rock in these quarries can hardly be distinguished from the Milford granite. In the northwest portion of the area, near Woonsocket, the biotite occurs in distant, interrupted, rudely parallel films, as in the rock at the Fayville quarries north of Milford.^a

Description of Milford, Mass., granite.—The following epitomizes the descriptions of rough and polished specimens and thin sections of granite given beyond. Analyses and tests are also summarized. Milford granite is a biotite granite. Its general color ranges from a light gray or light pinkish gray to a medium slightly pinkish or pinkish and greenish gray, but always with spots rich in black mica from 0.2 to 0.5 inch across and in some cases tapering out to an inch in length.

Its texture varies from medium to coarse, not porphyritic; but, owing primarily to a marked flow structure and secondarily to compression, there is some alignment of particles, giving the stone a slightly gneissoid appearance. The feldspar, quartz, and biotite are each apt to form continuous lenticular areas up to an inch in length. On the polished face the quartz is seen to be finely granular. The general appearance of the stone varies according to the relation of the direction of the cut face to that of the flow structure. Whenever the plates of black mica, which lie with their major axes in the plane of the flow structure, coincide with the face of the stone, it will show much larger black spots than when the face intersects that plane at right angles.

Its constituent minerals, in descending order of abundance, are (1) a more or less delicate pink, rarely cream-colored, potash feldspar (orthoclase and microcline), minutely intergrown with soda-lime feldspar and in places somewhat kaolinized; (2) faintly blue quartz fractured into particles up to 1.75 millimeters, in some specimens not over 0.75, showing some arrangement of cavities in sheets and in places with hair-like crystals presumably of rutile; (3) a slight yellowish green to milk white, rarely clear, striated soda-lime feldspar (albite to oligoclase-albite). When this feldspar is not clear it abounds in minute crystals and particles of epidote and zoisite, scales of white mica, and some chlorite and kaolin. The last constituent is biotite (black mica), some of it chloritized and associated with epidote. The accessory minerals are garnet, pyrite, magnetite, ilmenite, zircon, allanite,^b usually rimmed with epidote, and apatite. The secondary minerals are kaolin, white mica, epidote, zoisite, calcite (usually in the soda-lime feldspars), titanite (about probable ilmenite in biotite), and hematite. There is some radiate intergrowth of quartz and feldspar.

^a Op. cit., pp. 45, 46.

^b See glossary.

The color of the stone is governed mainly by its feldspars, pink from the potash and green from the soda-lime feldspar. These are but very slightly modified by the pale-bluish tinge of the quartz.

The somewhat gneissoid arrangement of the minerals, giving the feldspar and quartz particles uncertain boundaries in the direction of the flow, prevents the accurate application of the Rosiwal method,^a which provides that no one particle should be crossed more than once by lines parallel. A specimen from quarry No. 8 of the Webb Pink Granite Company, in which there is little if any flow structure, contained the following percentages:

Estimated mineral percentages in Milford, Mass., pink, even-grained granite.

| | |
|---------------|--------|
| Feldspar..... | 55.91 |
| Quartz..... | 35.66 |
| Biotite..... | 8.43 |
| | 100.00 |

Five tests on three specimens of the more gneissoid granite showed the following ranges:

Estimated mineral percentages in Milford, Mass, pink gneissoid granite.

| | |
|---------------|-------------|
| Feldspar..... | 49.92-70.83 |
| Quartz..... | 23.04-41.08 |
| Biotite..... | 4.72-11.29 |

These variations are due partly to the very different proportion of biotite on the different faces of the rock, as already explained.

Three complete analyses of this granite, made by L. P. Kinnicutt and R. H. Richards, are given under the respective quarries. They show these extremes:

Extremes of analyses of Milford, Mass., granite.

| | |
|--|-------------|
| SiO ₂ (silica)..... | 72.02-77.08 |
| Al ₂ O ₃ (alumina)..... | 12.54-14.43 |
| FeO (iron oxide)..... | .52- .95 |
| Fe ₂ O ₃ (iron sesquioxide)..... | .00- 1.25 |
| MnO (manganese oxide)..... | .24- .33 |
| CaO (lime)..... | .75- 1.18 |
| MgO (magnesia)..... | Trace- .01 |
| K ₂ O (potash)..... | 4.99- 5.41 |
| Na ₂ O (soda)..... | 3.64- 5.85 |

The following analysis of the granite from one of the Norcross Brothers quarries was made by Prof. C. F. Chandler, of Columbia University:^b

^a See for details p. 66.

^b Day, Wm. C., 29th Ann. Rept. U. S. Geol. Survey, pt. 6, continued, 1898, p. 221.

Analysis of Milford, Mass., granite.

| | |
|--|-------|
| SiO ₂ (silica)..... | 76.07 |
| Al ₂ O ₃ (alumina)..... | 12.67 |
| Fe ₂ O ₃ (iron sesquioxide)..... | 2.00 |
| MnO (manganese oxide)..... | .03 |
| CaO (lime)..... | .85 |
| MgO (magnesia)..... | .10 |
| K ₂ O (potash)..... | 4.71 |
| Na ₂ O (soda)..... | 3.37 |
| | <hr/> |
| | 99.80 |

Mr. E. C. Sullivan, a chemist of the United States Geological Survey, extracted, by means of hot dilute acetic acid, 0.06 per cent of CaO (lime) from an average specimen from the Cutting quarry. This lime was thus present in the form of CaCO₃ or calcite (lime carbonate) to the extent of 0.107 per cent, its presence being recognizable also under the microscope. It probably was formed from the decomposition of the lime-soda feldspar.

Six crushing tests made at the United States arsenal at Watertown show an ultimate strength of 20,000 to 29,200 pounds per square inch for Milford granite.

Those sections of the stone in which mica is least abundant take a good polish, but the others are not likely to preserve their polish in prolonged outdoor exposure. The scarcity of pyrite and magnetite on the polished face is very noticeable.

Geology of Milford, Mass., quarries.—The diorite schist dikes which traverse this granite have already been described on page 59, and the probable connection between the development of schistosity in these dikes and the stress which granulated the quartz of the granite has been pointed out. There are also dikes of aplite from half an inch to 4 feet thick, some of it a quartz monzonite in composition, and dikes of porphyritic granite with N. 10° and 35° E. and N. 20° W. courses. Some of these contain elliptical biotitic segregations (or inclusions?).

The flow structure strikes N. 10°, 35°, 40°, 45° W. and N. 77° E., dipping from 40° E. to 90°. In places it is nearly horizontal.

There are inclusions of biotite gneiss or mica diorite from a few inches to 2 feet thick, showing that this rock overlay or adjoined the granite at the time of its intrusion.

The rift is reported as everywhere horizontal and the grain as vertical with a N. 40° E. to an east-west direction. Rift and plane of flow structure are in places nearly parallel.

Sheets from 6 inches to 18 feet thick are generally irregular or undulate horizontally with inclinations up to 20°.

As will be seen from the quarry diagrams, there is a wide range in the joint courses. They are N., N. 10°, 20°–25°, 45°, 50°, 60° E.,

and N. 60°, 70°, 80° W. Those occurring at the largest number of quarries are N. to N. 10° E., N. 45°–60° E., and N. 55°–70° W. The filling of a parted joint with calcite probably derived from once overlying calcareous rocks has been noted on page 61.

The Milford, Mass., quarries.—*The Cutting quarry* is in Milford Township, 3 miles N. 5° E. of Milford and half a mile south of Echo Lake (fig. 6). Operator in 1906: Milford Stone Company, Milford, Mass.^a

The granite (specimens D, XXVIII, 13, a, b, c) is a biotite granite of light-gray shade, with a very slight pinkish tinge and conspicuous black spots. Its texture is somewhat gneissoid, medium to coarse, with particles up to about 0.5 inch. In faces cut parallel to the plane of flow structure the black spots measure fully 0.5 inch, but when cut in the transverse direction about 0.3 inch. The quartz areas are always granular, the particles up to 1 millimeter in diameter and exceptionally 1.5 millimeters. The rock consists of the following minerals, in descending order of abundance: A very delicate pink potash feldspar (orthoclase and microcline, both with minutely intergrown soda-lime feldspar); quartz with minute cavities arranged in sheets, appearing colorless in isolated particles, but in the aggregate having a very pale bluish tinge; a milk-white to pale-greenish striated lime-soda feldspar (albite to oligoclase-albite), usually crowded with particles and crystals of epidote and zoisite from 0.0094 to 0.076 millimeter in length; biotite (black mica), some of it altered to chlorite and associated with epidote. Both feldspars are somewhat kaolinized, particularly the soda lime. The accessory minerals are: Garnet, rare pyrite and magnetite, titanite, zircon, allanite crystals up to 1 millimeter long, coated with epidote, and apatite. The secondary minerals are: Kaolin, epidote, zoisite, chlorite, calcite, and hematite.

An estimate of the mineral percentages with half-inch mesh and total linear length of 45.5 inches yields:

Estimated mineral percentages in Milford, Mass., pink granite from Cutting quarry.

| | |
|----------------|--------------|
| Feldspars..... | 65.67 |
| Quartz..... | 23.04 |
| Biotite..... | 11.29 |
| | <hr/> 100.00 |

The following analysis was made by Leonard P. Kinnicut, of the Worcester Polytechnic Institute, in 1898, and is given here for reference.

^a This company went out of existence with the completion of its contract for the Pennsylvania Railroad terminal station in New York, and on January 1, 1907, all the quarries here reported as operated by this company passed into the hands of Ralph A. Stewart, Sears Building, Boston, as receiver, and became idle pending the issue of complex litigation.

Analysis of granite from the Cutting quarry, Milford, Mass.

| | |
|---|-------|
| SiO ₂ (silica)..... | 77.08 |
| Al ₂ O ₃ (alumina)..... | 12.54 |
| FeO (iron oxide)..... | .95 |
| CaO (lime)..... | .75 |
| MgO (magnesia)..... | .01 |
| K ₂ O (potash)..... | 4.99 |
| Na ₂ O (soda)..... | 3.64 |
| | <hr/> |
| | 99.96 |

Mr. E. C. Sullivan, chemist, of the United States Geological Survey, extracted 0.06 per cent of CaO (lime) from this granite by hot dilute acetic acid. This indicates the presence of 0.107 per cent of CaCO₃ (lime carbonate) or calcite, the presence of which mineral is shown in thin sections.

Two tests made at the United States arsenal at Watertown, Mass., in 1898, give it an ultimate strength of 25,252 and 27,226 pounds per square inch. The quarry, opened before 1889, measures about 500 feet north-north-west to south-south-east by 150 feet east-west, and from 20 to 50 feet deep.

The sheets are from 6 inches to 18 feet thick and are horizontal but irregular in places. The rift is reported as horizontal, and the grain as vertical. The peculiar mica diorite schistose dike on the west side is described on page 59. Aplite dikes are 5 inches to 2 feet thick. The courses of joints, flow structure, dikes, and grain are shown in fig. 7.

Heading A dips 70° east, and joint B, occurring only at the north end, dips 65° south-southeast. Bands of more biotitic granite with groups of black elliptical schistose knots or inclusions indicate the direction of flow. In thin section these show particles all under 0.1 inch, mostly biotite, next a plagioclase much altered to epidote and zoisite, and lastly quartz. Garnets in roundish grains are also present. Rusty discoloration along the sheets is from 6 to 12 inches thick.

The plant at the quarry consists of 5 derricks, 5 hoisting engines, 3 steam drills, 4 steam pumps, and 1 locomotive; at the cutting shed there are 2 compressors (capacity 1,300 and 290 cubic feet of air per

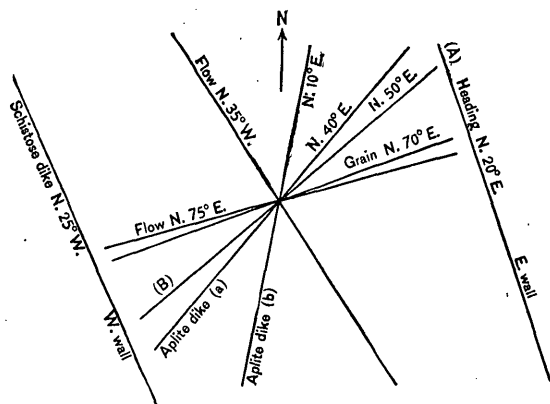


FIG. 7.—Structure at Cutting quarry, Milford, Mass.

minute), 12 surfacers, 30 air plug drills, 113 air hand drills, 2 vertical polishers, 1 polishing lathe for columns of indefinite length and 40 inches diameter, 1 revolving saw for dentals, 7 derricks, 5 hoisting engines, and a 20-ton overhead crane.

Transportation is effected by a siding from the New York, New Haven and Hartford Railroad and a track from quarry to cutting shed.

The product is used mainly for buildings. Specimen structures are the bank building, Newton, Mass.; the Washington-Georgetown street railway depot at Georgetown, D. C.; the New York State monument on Lookout Mountain, Chattanooga, Tenn., which consists of a shaft 6 feet in diameter and 50 feet high made in sections. This quarry furnished part of the base and all the lantern for the Pennsylvania Railroad terminal station at New York.

Eighty-four 31-foot sectional granite columns for the Pennsylvania Railroad station at New York were finished at the cutting shed of this quarry, but the granite blocks for them came from the other Milford quarries operated by this company. Each column is made in four or five sections the blocks for which are first roughly hewn by air plug drills and then centered, attached to an iron pivot at each end, and put in short improvised lathes. After cutting a narrow circular edge by hand on each side two or more sides are first made flat by surfacers, and the sectional column is revolved on its pivot by hand and bars while the rest of the work is done by surfacers. In making the dentals sets of circular steel saws with rectangular teeth are used in connection with chilled iron shot to make vertical incisions in the granite block at the required intervals, and the rest is done by hand.

The East quarry is in Milford Township, $1\frac{1}{4}$ miles northeast of Milford (fig. 6). Operator in 1906: Milford Stone Company, Milford, Mass.^a

The granite (specimens D, XXVIII, 14, d, e, g, h) is a biotite granite of light pinkish gray color with more or less conspicuous black spots. The general color is more pinkish than that of the Cutting quarry. Its texture is somewhat gneissoid, medium to coarse. Feldspar and mica measure up to 0.5 inch but the feldspar individuals merge into lenses an inch long, as do also the quartz and biotite. The length and width of the biotite spots in any surface depends upon whether that surface is parallel to the plane of the flow structure or to its side, or crosses it. The quartz areas are always granular, with particles up to 1.75 millimeters across. The rock consists of these minerals in descending order of abundance: A light-pink potash feldspar (microcline and orthoclase) with some intergrown soda-lime feldspar, slightly kaolinized; quartz (with minute cavities arranged in sheets), which in the aggregate has a very pale bluish tinge; a milk-white

^a See footnote, p. 78.

to light-greenish striated soda-lime feldspar (albite to oligoclase-albite), partly kaolinized and crowded with minute particles and crystals of epidote and zoisite with a few scales of white mica and rarely calcite; biotite (black mica), some of it chloritized, rarely containing ilmenite, with a rim of leucoxene. The accessory minerals are: Garnet, apatite, magnetite and pyrite (rare), ilmenite, zircon, and allanite (up to 0.6 mm.); rimmed with epidote. The secondary are: Kaolin, a white mica, epidote, zoisite, leucoxene, chlorite, and calcite. The merging of the particles by the gneissoid structure vitiates somewhat the application of the Rosiwal method of estimating the mineral percentages, and the great variation in the amount of biotite on different specimens also affects the results. Four tests on two specimens with meshes 0.5 inch and a total linear length of 28.8 inches yielded these results:

Estimated mineral percentages in Milford, Mass., gneissoid granite from the East quarry.

| | | | | |
|---------------|--------|--------|--------|--------|
| Feldspar..... | 49.92 | 58.47 | 68.22 | 70.83 |
| Quartz..... | 41.08 | 35.08 | 26.92 | 24.45 |
| Biotite..... | 9.00 | 6.45 | 4.86 | 4.72 |
| | 100.00 | 100.00 | 100.00 | 100.00 |

The following analysis of this granite, made for the company by Prof. R. H. Richards at the Massachusetts Institute of Technology, is given here for reference:

Analysis of Milford, Mass., granite from the East quarry.

| | |
|--|--------|
| SiO ₂ (silica)..... | 72.02 |
| Al ₂ O ₃ (alumina)..... | 14.43 |
| FeO (iron oxide)..... | .89 |
| Fe ₂ O ₃ (iron sesquioxide)..... | 1.25 |
| MnO (manganous oxide)..... | .33 |
| CaO (lime)..... | 1.18 |
| MgO (magnesia)..... | Trace. |
| K ₂ O (potash)..... | 5.41 |
| Na ₂ O (soda)..... | 5.85 |
| Loss in ignition..... | .35 |

The durability of the polished face on outdoor exposure will vary according to the size and number of the biotite particles.

The quarry is about 100 feet from north to south, by 300 feet from east to west, and from 40 to 80 feet deep.

The chief structural feature is a vertical granite dike 4 feet thick crossing the quarry diagonally. It is a biotite granite, medium to dark greenish to gray in color with pinkish spots. Its texture is fine to medium, with porphyritic feldspars up to 0.6 inch, and exceptionally to 1.3 inches in length. The matrix consists largely of greenish soda-lime feldspar (oligoclase-albite) partly kaolinized and epidotized, a slightly bluish granular quartz, the colors of these two

minerals giving the rock a general bluish-green tinge, and biotite (black mica). The large pink crystals are potash feldspar (orthoclase with minutely intergrown soda-lime feldspar, also microcline). There is also some potash feldspar in the groundmass. The accessory minerals are: Garnet, apatite (fairly abundant), zircon, and allanite. The secondary minerals are: Kaolin, muscovite, chlorite, epidote, zoisite, and calcite. This dike contains black segregations (inclusions?), mainly of biotite with slightly bluish quartz and epidote. The granite has a flow structure marked by darker bands striking N. 10° W. and dipping 40° E. The granite also contains irregular inclusions, from 1 to 2 feet in diameter, of a dark gray and black banded, very fine-grained, somewhat schistose mica diorite (quartz, biotite, and plagioclase, with pyrite, magnetite, and epidote). The rift is reported as horizontal and the grain as vertical. The sheets, from 1 to 15 feet thick, dip 10° – 15° SSW. The courses of dike,

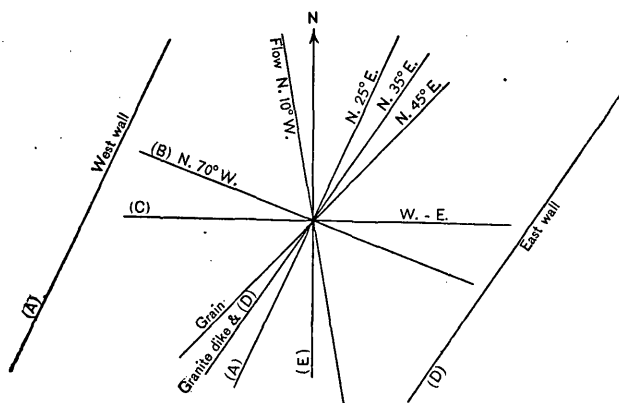


FIG. 8.—Structure at East quarry, Milford, Mass.

flow, grain, and joints are shown in fig. 8. Joints A dip 80° E. and recur at intervals of 100 to 200 feet. Joints B dip 45° – 50° SSW., and are spaced 3 feet and over; joints C dip 45° N.; joint D, one only, dips 60° NW.; joints E dip 45° W. The face of joints A on the west wall is coated with a mass of minutely brecciated granite $1\frac{3}{4}$ inches thick, cemented with calcite, chlorite, fibrous muscovite, and limonite. Joints E are slickensided horizontally. Ferruginous discoloration occurs along the sheets from 6 inches to 2 feet thick.

The plant consists of 10 derricks and 10 hoisting engines, a locomotive crane, a locomotive, an air compressor (capacity 1,900 cubic feet of air per minute), 16 surfacers, 8 large air rock drills, 40 air plug drills, 30 air hand tools, 2 saws for 13-foot granite blocks, a revolving saw for dentals, 2 polishing lathes for columns 25 by 4 feet, 5 vertical polishers, and 2 steam pumps.

Transportation is effected by a siding from the Boston and Albany Railroad.

The product is used for buildings and monuments. Specimen structures: Hanover National Bank, New York; the entire Boston Public Library, and the Public Library, Columbus, Ohio. In 1906 this quarry was furnishing part of the stone for the basement of the new National Museum at Washington, and also part of that for the Pennsylvania Railroad terminal at New York. Pl. VII, *B*, shows the storage yard of the blocks for this structure from this and other Milford quarries, and illustrates the mode of handling large contracts.

The Norcross quarry is in Milford township, nearly 2 miles north-east of Milford and about one-fourth mile east of the East quarry. (See fig. 6.) Operator, Milford Stone Company.^a

The granite (specimen D, XXVIII, 15, a) is a biotite granite of light pinkish-gray color with more or less conspicuous black spots. The general color is like that of the East quarry described on page 80, but is marked by light blood-reddish stains not over 0.25 inch across and an inch or two apart. Its texture is like that of the East quarry. The quartz grains measure up to 1.1 millimeters. Its constituents are also the same, but with the addition of red hematitic stains, which originate presumably in the oxidation of magnetite particles.

The quarry measures 175 feet from northeast to southwest, by 100 feet from northwest to southeast, and about 70 feet in depth.

The sheets, which are up to about 15 feet thick, have a low northerly dip. Joints, striking about northeast and dipping over 50° northwest, form the northwest and southeast walls. Another set with a similar strike dips 30°–45° SE., and is spaced 3 to 10 feet. A third set strikes about north or diagonally to quarry, and appears on the southwest wall. The rift is reported as better than at some of the other Milford quarries. Rusty stain, measuring up to 2 feet, appears on the east side of the quarry.

The plant consists of 9 derricks, 6 hoisting engines, a locomotive crane, an overhead electric crane (capacity, 25 tons), an air compressor (capacity, 550 cubic feet of air per minute), a large air drill, 15 air plug drills, 40 air hand tools, 3 surfacers, a circular saw for dentals, 3 polishing lathes (2 for stones 20 by 2½ feet, 1 for stones 30 by 4 feet), 4 vertical polishers, a steam pump, and a stone crusher with a capacity of 80 tons in ten hours.

The West quarry is in Milford township, 1¼ miles north-northeast of Milford. Operator in 1906, Milford Stone Company, Milford, Mass.^a

The granite (specimens D, XXVIII, 16, a, b) is a biotite granite of light pinkish gray color, like that of the Cutting quarry (p. 78), but with more conspicuous greenish feldspars and much smaller black mica spots. Its texture is medium to coarse, and is even-grained, with very little if any gneissoid structure. The feldspars measure up to 0.5 inch, the black mica to 0.3, rarely 0.4, and the

^a See footnote, p. 78.

quartz is granular. Its constituents, in descending order of abundance, are: A delicate pink potash feldspar (orthoclase and microcline, both inclosing large particles of soda-lime feldspar); quartz with some cavities in sheets, clear not bluish; a milk-white to light-greenish soda-lime feldspar (albite to oligoclase-albite), partly kaolinized and epidotized, also with some white mica and calcite; biotite (black mica), some of it chloritized. The accessory minerals are: Garnet, magnetite, pyrite; the secondary: Kaolin, a white mica, epidote, zoisite, and calcite.

A partial analysis, leaving out potash and soda, made for the company by Prof. R. H. Richards, of the Massachusetts Institute of Technology, is given here for reference:

Partial analysis of Milford, Mass., granite from West quarry.

| | |
|--|-------------|
| SiO ₂ (silica)..... | 75.77 |
| Al ₂ O ₃ (alumina)..... | 13.59 |
| FeO (iron oxide)..... | .52 |
| Fe ₂ O ₃ (iron sesquioxide)..... | 1.14 |
| MnO (manganese oxide)..... | .24 |
| CaO (lime)..... | .94 |
| MgO (magnesia)..... | Trace. |
| Loss on ignition..... | .49 |
| | <hr/> 92.69 |

The quarry, opened about 1887, measures about 300 feet by 175 feet and is 40 feet in depth.

There are on the east side conspicuous vertical dikes of medium-gray, fine-grained quartz monzonite, from 0.5 inch to 2 feet thick, striking N. 20° W., which occur at intervals of 20 to 100 feet. This consists of clear potash feldspar and cloudy light-gray soda-lime feldspar in almost equal amounts, the latter kaolinized, micacized, and altered to epidote and zoisite; quartz, with hairlike crystals of rutile and cavities; biotite, some of it altered to chlorite. Accessory minerals: Garnet, etc. Secondary minerals: Kaolin, a white mica, epidote, zoisite, chlorite, and calcite. There are two schist dikes already described on page 59. One on the north wall, 2 feet thick, strikes N. 65°-70° W., and dips 65° north-northeast; another, farther south, 20 inches thick, strikes about northwest and is vertical. The sheets, from 2 to 15 feet thick, are nearly horizontal at the north end of the quarry, but dip 15°-20° at the south end. The sheets become irregular at the bottom. Vertical joints strike N. to N. 10° E., are spaced 10 to 100 feet, and form a heading on west side. One at the north end strikes N. 60° W. and dips curving 45°-50° southwest.

The plant consists of 6 derricks, 6 hoisting engines, a locomotive crane, a 50-horsepower engine, an air compressor (capacity, 900 cubic feet of air per minute), 5 surfacers, 8 air plug drills, 12 air hand tools, a saw for 14-foot blocks, and 2 steam pumps.

Transportation is effected by a half-mile track to the New York, New Haven, and Hartford Railroad.

This quarry furnished the stone for the Bowenville station, at Fall River, Mass.; the John Hancock Insurance Company building, on Federal street, Boston; the Rhode Island Hospital Trust building, on Westminster street, Providence; the Twelfth street station of the Illinois Central Railroad at Chicago, and the base and die of the McKinley monument at Toledo, Ohio. In 1906 it was supplying part of the stone for the Pennsylvania Railroad terminal at New York and the basement of the National Museum at Washington.

This quarry is regarded as nearly worked out, owing to imperfect sheet structure at the bottom.

The Massachusetts Pink quarry is in Milford township, 2½ miles north of Milford, at the north end of a low north-south ridge. (See fig. 6.) Operator, the Massachusetts Pink Granite Company, Milford, Mass.

The granite (specimen D, XXVIII, 21, b) is a biotite granite of light-gray shade with a very slight pinkish tinge and conspicuous black spots. Its texture is somewhat gneissoid, medium to coarse, in other respects and in mineral composition closely resembling the stone of the Cutting quarry, described on page 78.

The quarry, opened in 1902, is 300 feet from east to west by 200 feet across and from 10 to 35 feet deep.

A schist dike 2 feet thick on the west side, striking N. 3° W. and dipping 55° E., has already been mentioned on page 59. The sheets, from 4 to 25 feet thick, dip low east. There are 3 sets of joints: Set A strikes N. 35° W., dips 65° E., and is spaced 100 feet; set B strikes N. 55°-60° E., dips 90°, and is spaced 30 feet; set C strikes N. 55° W. and dips 40° W. The rift is reported as horizontal, and the grain as vertical from east to west. Rusty discoloration is up to 3 inches thick on the lower sheets.

The plant consists, at the quarry, of 3 derricks, 3 hoisting engines, 2 steam drills, an air compressor (capacity, 130 cubic feet of air per minute), 4 air plug drills, a saw for stones 12 feet long, and 2 steam pumps. At the cutting shed there are 1 derrick, 1 hoisting engine, a locomotive crane, an air compressor (capacity, 314 cubic feet of air per minute), 4 surfacers, and 20 air hand tools.

Transportation is effected by a cartage of 3 miles to cutting shed at New York, New Haven and Hartford Railroad track.

The product is used for buildings, bridges, and mausoleums. Specimens: Bridge over Bronx River in Bronx Park, New York; Rochester Safe Deposit and Trust Company building, Rochester, N. Y.; Bloomingdale mausoleum in Greenwood Cemetery, N. Y. In 1906 this company was executing a contract for the McKinley national memorial at Canton, Ohio.

The *Hopkinton quarry* is in Hopkinton, Middlesex County, Mass., a mile south of Hayden Row and about $3\frac{3}{4}$ miles north-northeast of Milford. Operator, the Massachusetts Pink Granite Company, Milford, Mass. This is a small opening near the company's cutting shed, not worked in 1906.

The granite (specimen D, XXVIII, 22, a) is a biotite granite of medium slightly pinkish gray color with fine black specks. Its texture is even-grained, medium, with feldspars generally up to 0.4 inch and mica to 0.2 inch. It is thus pinker and finer grained than that of the Massachusetts Pink quarry. Its constituent minerals, in descending order of abundance, are: A pinkish potash feldspar (orthoclase and microcline), inclosing particles of soda-lime feldspar and slightly kaolinized; faint rose-colored granular quartz in particles up to 1.37 millimeters; a grayish or greenish-gray soda-lime feldspar (albite to oligoclase-albite), a little kaolinized and epidotized with some white mica; biotite (black mica), some of it chloritized. Accessory minerals are: Garnet, magnetite, apatite, zircon, and allanite (bordered with epidote). Secondary minerals: Kaolin, epidote, zoisite, chlorite, and a white mica.

The quarry is 50 feet square and 25 feet deep.

The Bishop mausoleum in Sleepy Hollow Cemetery, at Tarrytown, N. Y., is made of this stone.

The *Maguire quarry*^a is in Hopkinton, one-half mile west of Echo Lake and $3\frac{3}{4}$ miles N. 5° W. of Milford. (See fig. 6.) Operator, Norcross Milford Pink Granite Company, Milford, Mass.

The granite is a biotite granite of light-gray shade with a very slight pinkish tinge and conspicuous black spots. In texture and constituents it is reported as corresponding to the stone of the Cutting quarry described on page 78.

The quarry, opened in November, 1906, measures 300 by 100 feet and up to 15 feet in depth.

The sheets are reported as dipping about 20° northeast.

The plant consists of 2 derricks, 2 hoisting engines, and 2 steam drills.

Transportation involves cartage of 1 mile to the cutting shed on a railroad siding.

In 1906-7 this quarry was engaged in finishing work on the Pennsylvania "terminal concourse" in New York.

The *Echo Lake quarry*^b is in Milford township near the Hopkinton line and Echo Lake, $3\frac{1}{2}$ miles N. 5° E. from Milford. (See fig. 6.) Operator, Norcross Milford Pink Granite Company, Milford, Mass.

^aThe data for this quarry were obtained in writing from Mr. F. A. Whipple, the superintendent, as the quarry was opened after the writer's visit to Milford.

^bThe data for this quarry were obtained in writing from Mr. F. A. Whipple, the superintendent, as the quarry was opened after the writer's visit to Milford.

The granite is a biotite granite of light gray shade, with slight pinkish tinge, reported as a little more pinkish than that of the Cutting quarry described on page 78.

The quarry, opened in October, 1906, measures 60 by 40 feet and up to 20 feet in depth.

The sheets are reported as dipping about 20° west, but as irregular, making this a "boulder quarry" A "soft heading," that is a schist dike like that at the Cutting quarry, described on page 59, is reported as forming the west side of quarry with a north-northwest strike.

The plant consists of a derrick and hoisting engine and a steam pump.

Transportation involves cartage of 1 mile to the cutting shed which is on a railroad siding.

In 1906-7 the quarry was furnishing material for the completion of the Pennsylvania "terminal concourse" in New York.

The North Milford quarry is in Milford township, $2\frac{1}{2}$ miles about N. 7° W. from Milford and one-third mile southwest of the Massachusetts Pink quarry. (See fig. 6.) Operator, North Milford Granite Company, 116 Purchase street, Milford, Mass.

The granite is a biotite granite of light gray shade with a very slight pinkish tinge and conspicuous black spots. In texture and constituents it is identical with the stone of the Cutting quarry described on page 78.

The quarry, opened in 1905, is 100 feet square and averages 5 feet in depth.

Owing to the irregularity of sheets this is a boulder quarry. Vertical joints strike N. 80° E. and N. 25° E. The rift is reported as horizontal and the grain as vertical with N. 80° E. course.

The plant consists of 2 small derricks and 2 hoisting engines.

Transportation is by cartage $2\frac{1}{2}$ miles to the New York, New Haven, and Hartford and the Boston and Albany railroads.

The product is used for construction only. Specimen buildings: The granite part of Redmond Bank building, 31 Pine street, and the trimmings for tenements of Homes Suburban Company, One hundred and fifty-sixth street, New York. Contract in 1906: The trimmings for the residence of Hennen Jennings, northeast corner of Massachusetts avenue and Sheridan Circle, Washington, D. C.

The Carroll quarry is in Milford township, $1\frac{1}{4}$ miles north of Milford and one-half mile north-northwest of Cedar Swamp pond. (See fig. 6.) Operator, Webb Pink Granite Company, office, 40 Crescent street, Worcester, Mass.

The granite (specimen D, XXVIII, 18, b) is a biotite granite of light-gray shade with conspicuous black spots. This is the whitest of the Milford granites. Its texture is somewhat gneissoid medium to

coarse, with feldspars and mica up to 0.5 inch across and with finely granular quartz. Its constituents, in descending order of abundance, are: A cream-colored to palest pink potash feldspar (orthoclase and microcline), with minutely intergrown soda-lime feldspar and slightly kaolinized; clear, not bluish, quartz in grains up to 0.5 millimeter, and with cavities some of which are in sheets; clear to cloudy, some very pale greenish, soda-lime feldspar (albite to oligoclase-albite), not a little kaolinized and epidotized; biotite (black mica), some of it chloritized. Accessory minerals are: Garnets (minute and usually in rows), apatite, fluorite, allanite (rimmed with epidote), and zircon. Magnetite and pyrite not observed. Secondary minerals are: Kaolin, epidote, zoisite, chlorite, calcite, white mica.

The following analysis of this granite, made for the company by Robert C. Sweetzer, of the Worcester Polytechnic Institute, in 1905 is given here for reference:

Analysis of Milford, Mass., granite from the Carroll quarry.

| | |
|---|--------|
| SiO ₂ (silica) | 76.52 |
| Al ₂ O ₃ (alumina)..... | 12.21 |
| FeO (iron oxide)..... | 2.66 |
| CaO (lime)..... | .79 |
| MgO (magnesia)..... | .13 |
| K ₂ O (potash)..... | 4.68 |
| Na ₂ O (soda)..... | 2.86 |
| H ₂ O (water)..... | .41 |
| | <hr/> |
| | 100.26 |

Specific gravity 2.633.

The quarry, opened in 1905, measures about 500 by 200 feet and up to 30 feet in depth.

The sheets, from 6 inches to 15 feet thick, undulate horizontally. The rift is reported as horizontal and the grain as vertical, with N. 65° E. course. Joints A strike N. 60° W., dip 90° and are spaced 10 to 60 feet. Joints B strike N. 20° E., dip 90°, and form headings at the northwest and southeast sides and in the middle. Joints C strike N. 80° W. and dip 45° south, of which one is in the middle and another 25 feet east of it. There is a quartz vein up to 0.1 inch wide, with a N. 10° E. course. Rusty discoloration is 2 inches thick on sheet surfaces.

The plant, which includes that of Webb quarry No. 8 and the cutting machinery for the product of both, consists of 8 derricks, 6 hoisting engines, 6 locomotive cranes, 2 overhead cranes (capacity 20 tons each), 2 air compressors (capacity, 1,200 and 1,800 cubic feet of air per minute), 2 large air drills, 55 air plug drills, 84 air hand tools, 8 surfacers, and an air-driven pump. There is also a 200 kilowatt direct-current generator for operating the railroad and cranes.

Specimen structures: The Commercial National Bank, Chicago, and the John Hancock Building No. 2, in Boston, were built partly of stone from this quarry and partly from that of Webb quarry No. 8.

The Webb quarry No. 2 is in Milford township, 2 miles north of Milford. (See fig. 6.) Operator, Webb Pink Granite Company, office, 40 Crescent street, Worcester, Mass.

The granite (specimens D, XXVIII, 17, a, b) is a biotite granite of medium pinkish and greenish-gray color with black spots which are not as conspicuous as those of the Carroll or Cutting quarry stone. Its texture is even-grained, medium, with feldspars up to 0.4 and mica up to 0.2 inch in diameter, and finely granular quartz. Its constituents, arranged in descending order of abundance, are: A delicate pink potash feldspar (orthoclase and microcline), minutely intergrown with soda-lime feldspar and with quartz and more or less kaolinized; a very faintly bluish and finely granular quartz with cavities some of which are in sheets; a yellow greenish to clear soda-lime feldspar (albite to oligoclase-albite), generally kaolinized and epidotized also with some scales of white mica and chlorite; biotite (black mica). Accessory minerals are: Magnetite, apatite, and zircon. Secondary minerals are: Kaolin, epidote, zoisite, chlorite, and a white mica. Calcite not observed.

An estimate of the mineral percentages by the Rosiwal method with half-inch mesh and total linear length of 46.5 inches yields these results:

Estimated mineral percentages in Milford, Mass., granite from Webb quarry No. 8.

| | |
|---------------|--------------|
| Feldspar..... | 55.91 |
| Quartz..... | 35.66 |
| Biotite..... | 8.43 |
| | <hr/> 100.00 |

Mr. W. T. Schaller, chemist, of the United States Geological Survey, extracted from an average specimen of this granite, by means of hot dilute acetic acid, 0.04 per cent of CaO (lime), which indicates the presence of 0.07 per cent of CaCO₃ (lime carbonate), or calcite. This lime is, of course, irrespective of that combined with silica in the oligoclase feldspar and epidote.

The stone takes a fair polish, but the mica particles are sufficiently large to detract from the durability of the polish in prolonged outdoor exposure.

The quarry, opened in 1905, measures about 250 by 200 feet and up to 30 feet in depth.

A flow structure, shown by biotitic streaks, strikes N. 40° W., and dips 50° northeast. The sheets, from 5 to 12 feet thick, are horizontal in irregular undulations. Joints A strike N. 40° W., dip 90°, and are

spaced 3 to 10 feet. Joints B strike N. 15° E., dip 75° E., and recur at an interval of 8 and one of 50 feet. The rift is reported as horizontal, and the grain as vertical with an east-west course.

The description of the plant connected with this quarry, of the plant of the Carroll quarry, and of the cutting shed for both was given under Carroll quarry on page 88.

Transportation from both of these quarries is effected by tracks to sidings of the New York, New Haven and Hartford Railroad. These tracks are 3,750 feet long.

Specimen structures: Pedestal of General Devens statue at Worcester, Mass. In 1906 the company was filling a contract for the power service plant of the Pennsylvania Railroad in New York with stone from this and the Carroll quarry.

The Webb Pink Granite Company, besides the two quarries described, has several other openings or prospects on the same property.

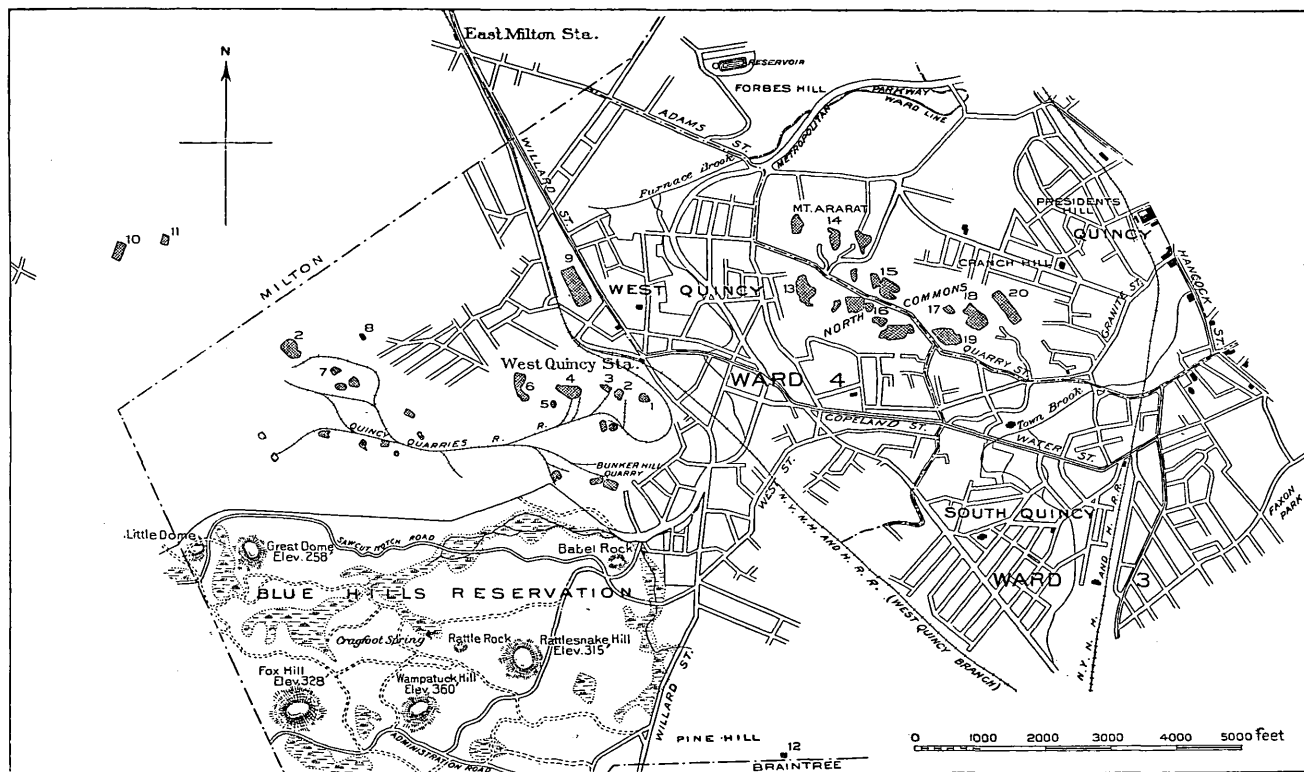
QUINCY.

Topography.—There is a conspicuous range of low hills south of Boston, known as the Blue Hills, which curves from a point (Great Blue Hill) 11 miles south-southwest of the city to a point (Forbes Hill) 7½ miles south-southeast of it, and whose tops lie between the 180 and 640 foot levels. See Boston and Dedham topographic sheets of the United States Geological Survey. The Quincy granite district lies at about the northeastern end of this range, in the townships of Quincy and Milton of Norfolk County. Some of the quarries are on the North Commons from about one-half mile west-southwest to a mile west of Quincy Center, others are in West Quincy from 1½ to 2 miles about west-southwest of the Center, and 2 are in Milton some 3 miles west of the Center. Quarry locations are shown on the map, Pl. II. The reader will find some interesting historical matter on the Quincy quarries in a chapter on the early history of the granite industry in New England by George P. Merrill.^a

General geology.—The geology of the vicinity of Quincy and Boston is very complex and difficult, and has long been under investigation and discussion by several resident and other geologists.^b As the results of these investigations have not yet been published in final form the following outline of the salient geological features must be regarded as only provisional. The granite of Quincy was part of a great deeply buried mass of molten granitic material of various

^a Rept. Smithsonian Institution, 1885-6, pt. 2, pp. 285-288.

^b Crosby, W. O., Genetic and structural relations of the igneous rocks of the Lower Neponset Valley: Mass. Am. Geol., July-August, 1905, pp. 39-41; Emerson and Perry, The green schists and associated granites and porphyries of Rhode Island: Bull. U. S. Geol. Survey No. 311, 1907, Quincy granitic group, p. 51; Professor Crosby's forthcoming Part IV, Boston Basin Series (Bost. Soc. Nat. Hist.), will contain Prof. Florence Bascom's complete work on both the volcanics and plutonics of the Boston basin; Mansfield, G. R., The origin and structure of the Roxbury conglomerate: Bull. Mus. Comp. Zool. Harvard Coll. (Geol. Ser., VIII, 4) vol. 49, 1906. General summary, pp. 259, 260, also p. 161, map, pl. 7, section pl. 6.



MAP SHOWING LOCATIONS OF QUINCY GRANITE QUARRIES.

- | | | |
|---|---|---|
| 1. Wigwam quarry, Badger Brothers. | 9. Rogers quarry, Quincy Quarries Company. | 15. Ballou quarry, John C. Ballou. |
| 2. Reinhalter quarry, Thomas F. Mannex. | 10. Maguire & O'Heron quarry, Milton. | 16. Djerf & Winquist quarry. |
| 3. Swingle quarry, J. S. Swingle. | 11. Mount Pleasant quarry, Mount Pleasant Quarry Company, Milton. | 17. Sahlsten quarry, Theodore Sahlsten. |
| 4. Granite Railway quarry, Granite Railway Company. | 12. Angelo Sartori & Brothers' quarry. | 18. McKenzie & Pattison quarry. |
| 5. Lepage quarry, Lepage Granite Quarry Company. | 13. Dell Hitchcock quarry, Quincy Quarries Company. | 19. Hardwick quarry, C. H. Hardwick & Co. |
| 6. John Cashman quarry. | 14. Merry Mount quarry, Merry Mount Granite Company. | 20. Field & Wild quarry. |
| 7. Gold-leaf quarry, Quincy Quarries Company. | | 21. Fuller quarry, Quincy Quarries Company. |
| 8. Savo Granite Company's quarry. | | |

kinds, which was intruded into a considerable mass of overlying slates, etc., of Cambrian and possibly of later age, which in places were entirely removed by subsequent erosion. That these slates were originally marine clayey sediments is shown by the presence of fossil crustaceans in some of them in the town of Braintree. After a long interval a large part of the region became again submerged during the Carboniferous period, and the advancing sea either deposited a conglomerate or covered a torrential one containing pebbles from the exposed igneous and sedimentary rocks of Cambrian or post-Cambrian time. The granite pebbles of the conglomerate area which adjoins the Blue Hills on the north are not Quincy granite, but contain pink and green feldspars like the granite of Dedham and Randolph.^a

This submergence continued until the conglomerate was overlaid by a considerable accumulation of clayey sediments. During the post-Carboniferous crustal movement, which affected a large part of the continent, these clays became slate and were powerfully folded; basic dikes were also intruded into the granite and the overlying beds. The corrugation and elevation of the surface in post-Carboniferous time exposed the Carboniferous beds to erosion, so that portions of the granite surface which had been covered by them again became exposed. In Triassic time more basic dikes forced their way through fissures in the granite. Events in this region were further complicated by the occurrence of eruptions of very siliceous rocks at various points and times. It should also be borne in mind that although the granitic material was intruded into what appear to be Cambrian beds, there is some uncertainty as to when, between Cambrian and Carboniferous time, the intrusion took place. In this connection attention might be directed to the possibility that a granitic intrusion in Cambrian rocks may point to more than a local crustal movement toward the close of Cambrian time.^b

Description of Quincy granite.—The following epitomizes the writer's descriptions of rough and polished specimens and thin sections of granite from all the quarries as given farther on. The more recent scientific accounts of this granite are by Wadsworth, Merrill, White, and Washington.^c

Quincy granite is a riebeckite-ægirite granite, riebeckite and ægirite being varieties of hornblende and augite, respectively, both rich in

^a See Mansfield, *op. cit.*

^b See Dale, T. N., The geology of the north end of the Taconic range: *Am. Jour. Sci.* (4), vol. 17, p. 185, 1904; also *Geology of Hudson Valley between the Hoosic and the Kinderhook*: *Bull. U. S. Geol. Survey* No. 242, 1904, pp. 47, 53, 55.

^c Wadsworth, M. E., Notes on the petrography of Quincy and Rockport: *Proc. Bost. Soc. Nat. Hist.*, vol. 19, 1881, pp. 309-316; Merrill, G. P., The collection of building and ornamental stones in the United States National Museum: *Rept. Smithsonian Institution*, 1885-6, pt. 2, pp. 409, 418; White, T. G., A contribution to the petrography of the Boston Basin: *Proc. Bost. Soc. Nat. Hist.*, vol. 28, 1897, pp. 128-132; Washington, H. S., Sölvbergite and tinguaita from Essex County: *Mass. Am. Jour. Sci.* (4), vol. 6, 1898, p. 181.

soda (8 to 10 per cent) and in iron sesquioxide (about 28 per cent) but poor in alumina, magnesia, and lime. The general color of the fresh normal granite ranges from a medium gray or bluish or greenish or purplish gray to a very dark bluish gray, all with black spots which, on closer inspection, are blue-black or green-black or a mixture of both.

Its texture is medium to coarse and even grained, with feldspars up to 0.4 and 0.5 inch, and the black silicates up to 0.3 and 0.4 inch.

Its constituents, in descending order of abundance, are: (1) A medium to dark bluish or greenish-bluish gray feldspar (orthoclase, much of it twinned) always with minutely intergrown soda-lime feldspar (albite to oligoclase-albite). It is apparently more or less darkened by a varying number of extremely minute particles of a black mineral, which are not absolutely distinguishable from opaque particles of kaolin, and is always slightly epidotized by minute particles of grass-green epidote, and whitened by partial kaolinization or black streaked by clusters of radiating fibrous crystals of dark brown hornblende. The fresh feldspar always contains crystals of blue-brownish riebeckite from 0.01 to 1.0 millimeter long by up to 0.01 millimeter in width. These crystals, and also the epidote, are in many specimens arranged in two rectangular directions, one that of the twinning plane, the other that of the intergrown soda-lime feldspar. In some sections (p. 107) the feldspars were found crossed by rift and grain cracks filled or overlain by minute crystals of riebeckite, thus evidently of secondary origin like those on joint planes described on page 60. (2) Medium to dark smoky quartz, some of it with a slight bluish tinge. It contains cavities (many with liquid and movable vacuoles) arranged in streaks and sheets and measuring from 0.0028 to 0.02 millimeter in length. This quartz also incloses minute black particles, and in places hairlike crystals, presumably of rutile, more rarely minute crystals of riebeckite, one measuring 0.178 by 0.0047 millimeter. (3) A little lime-soda feldspar (albite to oligoclase-albite). (4) Riebeckite (blue-black in hand specimen, but Prussian blue and brownish gray in thin section) and ægirite (green-black in hand specimen, but light green to emerald green in thin section), both minerals being in many specimens intergrown. The ægirite may surround riebeckite or these relations may be reversed. In some specimens riebeckite in slender crystals appears like a secondary growth on ægirite. The ægirite in others appears as filling spaces between the other minerals. Basal sections of it appear as if corroded. All of the riebeckite can not be secondary, because it appears in minute crystals within the quartz and forms the center of large crystals of ægirite. Nor can all the ægirite be secondary, because crystals of it also occur within quartz particles and also surrounded by radiating

crystals of riebeckite. (See page 110.^a) The ægirite is apt to contain particles of magnetite and carbonate.

The accessory minerals are: Ilmenite, magnetite (probably), pyrite (very rare), zircon in doubly terminated crystals, fluorite, titanite, and the minute black particles in quartz. The secondary minerals are: Kaolin, epidote, yellow-brown to orange hornblende in fibrous crystals, chlorite, calcite, leucoxene, hematite, limonite (associated with zircon and ægirite), and part of the riebeckite. One of the altered granites (Sartori quarry) contains spherulites which polarize like zircon.

Estimates of the mineral percentages by the Rosiwal method yield the following figures for the "medium," "dark," and "extra dark:"

Estimated mineral percentages in Quincy granite, extremes and averages.

| | Average. |
|--|----------|
| Feldspars, 55.80 to 69.51..... | 60.02 |
| Quartz, 22.06 to 33.74..... | 30.60 |
| Riebeckite and ægirite, 7.47 to 11.10..... | 9.37 |

Of course the microscopic particles of the soda-iron silicates are not included in these figures.

The following analysis of Quincy granite was published by Henry S. Washington in 1898:^b

Analysis of riebeckite-ægirite granite from the Hardwick quarry, Quincy, Mass.

| | |
|--|--------------|
| SiO ₂ (silica) | 73.93 |
| TiO ₂ (titanium dioxide)..... | .18 |
| Al ₂ O ₃ (alumina)..... | 12.29 |
| Fe ₂ O ₃ (iron sesquioxide)..... | 2.91 |
| FeO (iron oxide)..... | 1.55 |
| MnO (manganese oxide)..... | Trace. |
| MgO (magnesia)..... | .04 |
| CaO (lime)..... | .31 |
| Na ₂ O (soda) | 4.66 |
| K ₂ O (potash) | 4.63 |
| H ₂ O (water above 110°)..... | .41 |
| | <hr/> 100.91 |

Specific gravity 2.642 at 22° C.

Messrs. E. C. Sullivan and G. Steiger, chemists, of the United States Geological Survey, extracted by means of hot dilute acetic acid per-

^a For analyses and optical features of riebeckite and ægirite see Rosenbusch, H., *Mikroskopische Physiog. d. Min. u. Gesteine*, 4th ed., 1905, vol. 1, pt. 2, pp. 213, 244; for discussion as to their origin see Murgoci, G. M., On the genesis of riebeckite and riebeckite rocks: *Am. Jour. Sci.* (4) vol. 20, 1905, pp. 133-145; and Cross, W., on some secondary minerals of the amphibole and pyroxene group: *Am. Jour. Sci.* (3), vol. 39, 1890, pp. 359-370. Murgoci (op. cit., p. 138) sums up the views on the origin of these two minerals thus: "Some petrologists have considered the ægirite as a transformation product of riebeckite, and others have taken the riebeckite for a secondary product of ægirite. Most petrologists state, however, that riebeckite and ægirite are primary in their rocks." On the next page in a footnote he adds: "The best argument for the primary existence of the ægirite is its occurrence in the same rock, with little thin needles of riebeckite, which could not resist even the slowest and slightest action of transformation."

^b See *Am. Jour. Sci.*, 4th ser., vol. 6, 1898, p. 181; also *Jour. Geol.*, vol. 6, 1898, p. 793.

centages ranging from 0.11 to 0.28 per cent of CaO (lime) from specimens from four quarries in Quincy and Milton. This lime indicates the presence of from 0.196 to 0.50 per cent of CaCO_3 (lime carbonate) or calcite.

Quincy granite for monumental purposes goes under the names of "medium," "dark," and "extra dark." The estimated mineral percentages show that these differences in shade are due in part to a variation in the amounts of the black silicates and of the smoky quartz. In part they are also due to a variation in the degree of kaolinization of the feldspars and in the abundance of black particles and of hornblende in them. The smokiness of the quartz appears to be due to infinitesimal particles of some black mineral. The bluish tint of the feldspars is due to microscopic crystals of riebeckite and its greenish hue to minute epidotes. The contrast of shade is chiefly between the black silicates and the combined quartz and feldspar except where the feldspar is whitened by kaolinization, which causes it to stand out from the quartz. "Light Quincy granite," which is of medium-gray shade, is considered second grade and sells for rock face and hammered work.

Quincy granite is noted for its high polish, which comes out strikingly on columns and balls, as shown in Pl. IV. This susceptibility to high polish is due to the absence of mica and to the coarser cleavage of the varieties of hornblende and augite which take its place. The imperfections which occur in the polish of some blocks are due to particles of ægirite partially altered before quarrying. (See p. 55.)

A peculiar variety of Quincy granite, known as "Gold leaf," described on page 115, is the lightest monumental stone quarried there. Its general color is medium bluish-green gray, speckled with black and light yellow brown. The quartz, clear to light smoky, is finely granular, like that of Milford, Mass., and sparkles on the polished face. Wherever the yellow spots, which are caused by limonite stain, coincide with the granular quartz, they are more conspicuous. In other respects its constituents are identical with those of the riebeckite-ægirite granite of Quincy. A minor variety is that of the Ballou quarry, which has sparsely disseminated minute cherry-red dots, probably from the oxidation of magnetite particles.

Other and cheaper varieties of Quincy granite are suitable only for building purposes. Such are the "extra light" (pea-green), the pink, and the greenish brown, described on pages 112, 114, 120. The "oreï" (hematitic) finds its way to the dumps. These various colors are due to changes in the feldspars or ægirite, brought about by underground alterations which have been long in process. (See further p. 55.) The yellow, rusty discoloration (sap) referred to on page 35 is of still later date, affecting the stone for a few inches only along the sheet and joint surfaces.

Geology of Quincy quarries.—The cylindrical pegmatite dike with large ægirite crystals at the Ballou quarry, first studied by Prof. C. Palache, has already been described on page 49. Quartz veins up to an inch thick, probably of pegmatitic origin, and giving rise to sub-joints and zones of lighter color, occur at several quarries and are described on page 48 and illustrated in Pl. III, B. Some of these veins contain ilmenite and a carbonate besides a little fluorite. Some minute ones (0.04 to 0.1 inch wide) are also apt to contain fluorite and calcite.

At the Granite Railway quarry in West Quincy there is a 15-foot diabase dike striking about N. 75° W. in which the feldspar is altered to a white mica. It has a greenish rim, in which the augite is all chloritized. At the Merry Mount quarry on the North Commons a 5-foot dike, striking about north, appears to be a garnetiferous biotite lamprophyre. At the Djerf & Winqvist quarry, near the last, two basic dikes strike about east, and another occurs near the Dell Hitchcock quarry, but these were not microscopically studied.

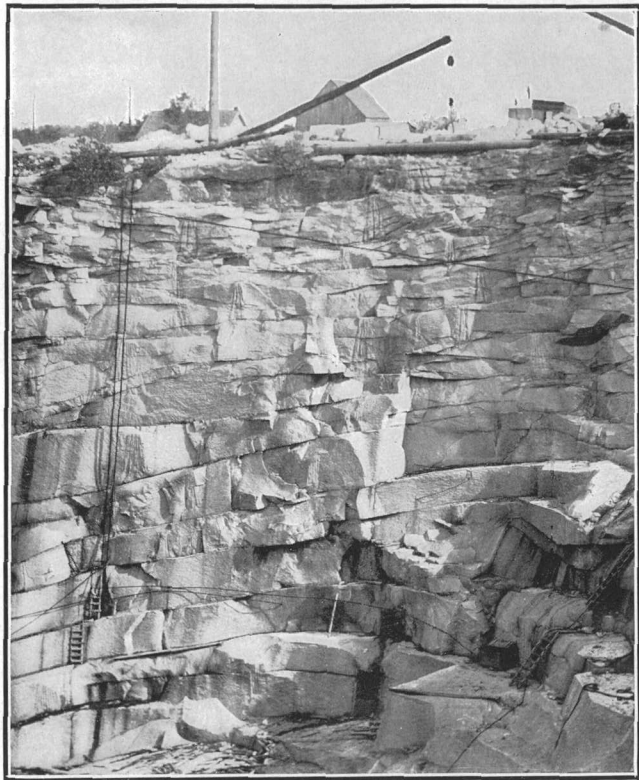
The segregations (knots) are of three kinds: (1) Very fine-grained aplitic, dark bluish gray with a matrix of potash feldspar, quartz, and more or less soda-lime feldspar (albite to oligoclase-albite), with particles from 0.025 to 0.3 millimeter, containing porphyritic crystals of ægirite (with some riebeckite) up to 0.84 by 0.09 millimeter, which appear as if corroded. Zircon, magnetite, orilmenite, and abundant apatite occur as accessories. There are also minute crystals of riebeckite and titanite, with secondary limonite and carbonate. (2) Medium-grained and medium gray, lighter or of same shade as the inclosing granite. These are identical with the granite, but the orthoclase tends to complete its crystals. One such knot contains a complete section of an ægirite crystal in the center of a quartz area many times its size. Another has secondary orange fibrous hornblende growing on ægirite. Zircon and fluorite are accessory. (3) Some muddy yellow to greenish knots consist of potash feldspar (orthoclase) minutely intergrown with soda-lime feldspar, in twins from 0.2 to 1.0 millimeter long, and quartz, with ægirite and riebeckite, which usually appear to fill spaces between the other minerals. The soda-silicates are more or less altered to fibrous muscovite and carbonate; the feldspars are also streaked with white mica and contain secondary epidote. The usual magnetite, apatite, and riebeckite are present.

The dimensions of the large knots given in the quarry descriptions were obtained from the foremen. It is assumed that they are segregations, not inclusions. The sizes range from half an inch to 2 feet by 1 foot 6 inches, 2 feet 6 inches by 2 feet 6 inches, 3 feet by 4 inches, and 6 feet by 2 feet. They are usually small and roundish or elliptical.

Rift in the Quincy quarries is reported as generally vertical or nearly so with a course from N. 65° W. to due west, and the grain as vertical or nearly so and about north to south. The grain is generally feeble. Rift courses of N., N. 10° E., and N. 30° W. are reported at a few quarries, and at three the grain is reported as horizontal. At the Swingle quarry, which is crossed by a diagonal heading striking north, the rift is reported to be north-south on the west side of that heading but as east-west on its east side. The angle of inclination of both rift and grain is reported as subject to modifications, some of which are probably only local; others are due to general physical principles. At the Reinhalter quarry the rift is vertical below but not quite vertical near the surface. Mr. Cashman states that in his quarry the grain is 90° when the sheet is split from the top, but if split from the side it is steeply inclined. Mr. Galvin reports that the grain is horizontal when the drilling is done from east to west, but dips 20° when it is done from north to south. The degree of dip of rift and grain is affected by gravity; that is, it is proportioned to the heft of the block on one side or the other of the fracture. Two foremen find that when the sheets are inclined the dip of the rift swerves from the vertical. At the Field & Wild quarry rift and grain are reported as varying greatly in different blocks. The subject of rift will be found more fully discussed on page 19, and its apparent relation to the sheets of fluidal cavities is explained on page 42.

The crushing of cores between drill holes made in channeling shows that the Quincy granite mass is now under compressive strains from the north and south and the east and west. This strain in some quarries appears to increase with their depth. At one quarry not only are north-south channels closed by it, but diagonal subjoints are started from the channel.

Sheet structure in Quincy is regular in places, as at the Dell Hitchcock quarry (Pl. III, A), where it consists of lenses with an undulating course usually parallel to the rock surface, and increasing in thickness downward. But it is oftener obscure and irregular owing to the shortening and thickening of the lenses, which results in "boulder quarries." Sheet structure extends to a depth of 150 feet from the rock surface at the Ballou quarry on the North Commons and to a depth of 175 feet in the Reinhalter quarry in West Quincy. The inclination of the sheets is in places as high as 45° , and their thickness ranges from 6 inches to 27 feet. They are rarely intersected by sharp curving joints or partings known as "toe nails." The origin of sheet structure will be found somewhat fully discussed on pages 22, 29. In quarrying it is safe to count on a gradual increase in the thickness of the sheets downward. If for a space thin sheets recur they may be expected to give way to thicker ones below. The quarry adjacent to the Dell Hitchcock is reported to have been



A. DELL HITCHCOCK GRANITE QUARRY, NORTH COMMONS, QUINCY, MASS., FROM THE WEST SIDE.

Showing lenticular sheets and their increase in thickness downward. Depth, 100 feet.



B. SOUTH SIDE OF GALVIN GRANITE QUARRY, NORTH COMMONS, QUINCY, MASS.

Showing westward-dipping quartz veins crossed by short vertical subjoints.

abandoned because of the appearance of thin sheets below and the assumption that they would not be succeeded by thicker ones. At the Reinhalter quarry, which in 1906 was 225 feet deep, the lowest mass, already 45 feet thick, had not then been penetrated.

The general character of the jointing can be inferred from the quarry diagrams, figs. 9-12. The principal joint systems are: (A) That striking N. 60° to 85° W. to N. 83° E., and its complementary set (B), N. to N. 20° E.; then a single set (C), striking N. 10° to 30° W., and lastly one (D) striking N. 25° to 55° W., with its complementary set (E) striking N. 45° to 50° W. A noticeable feature in some of the deeper quarries is the vertical discontinuity of the headings. Some of the bottom ones disappear upward within 100 feet of the surface; others again which occur at the surface disappear below. Some of the joints are also intermittent. The possibility of a bad heading dying out below is as encouraging to the quarryman as the possibility of the appearance of a new one below is discouraging. This discontinuity in the joints and headings reflects the complex character of the stresses to which the region was exposed.

The remarkable black joint coatings of riebeckite have been described on page 60. At one of the Milton quarries this appears on the sheet surfaces also, and the adjacent granite is lighter in shade.

From these summaries on the granite and on its geology as exposed at the quarries the following inferences may be drawn: The riebeckite-ægirite granite of Quincy had ægirite as one of its original constituents and riebeckite as another, but some of its riebeckite is clearly secondary, as shown by its occurrence in rift cracks and on sheet and joint faces. The formation of this mineral on these faces indicates that the granite after acquiring its sheet and joint structure was subjected to metamorphism, probably that which accompanied the post-Carboniferous crustal movement. The source of this secondary riebeckite may well have been the ægirite itself. The hematite-spotted granite ("oreï"), the pink granite, and the greenish-brown granite (described on pages 54, 55), while evidently due to the alteration of the ægirite particles to magnetite, hematite, green hornblende, biotite, and chlorite, owe these mineral changes partly to processes of deep-seated alteration and partly to regional metamorphism, and the pea-green variety is due to deep-seated epidotization of its feldspars, which may have involved access of calcareous and ferruginous waters. The latest change was the brownish iron staining along sheet and joint surfaces, which is attributable to percolating surface water oxidizing the magnetite, and soda-iron silicates and possibly also adding fresh supplies of iron sesquioxide obtained from deposits once overlying the granite.

The Quincy quarries.—*The Dell Hitchcock quarry* is on the North Commons, south of Quarry street. (See map, Pl. II, No. 13.) Operator, The Quincy Quarries Company, Quincy, Mass.

The granite (specimen, D, XXVIII, 67, d), "dark Quincy," is a riebeckite-ægirite granite of somewhat dark and slightly bluish-gray color with black spots. Its texture is medium to coarse, even grained, with feldspar up to 0.5 inch, and black silicates usually not over 0.3, but occasionally 0.5 inch. Its constituents, in descending order of abundance, are: A medium bluish and greenish gray potash feldspar (orthoclase, usually twinned) minutely intergrown with soda-lime feldspar, and inclosing minute crystals of riebeckite and particles of epidote, and in places somewhat kaolinized; smoky quartz with cavities (some with liquid and vacuoles), and black particles in streaks or sheets; a little separate soda-lime feldspar (albite to oligoclase-albite); ægirite, much of it intergrown with riebeckite. The accessory minerals are: Magnetite, zircon, and fluorite. The secondary: Kaolin, calcite, epidote, and brown fibrous hornblende and chlorite in rift cracks in feldspar.

The contrast in the rough stone is entirely between the black silicates and the combined quartz and feldspar.

A specimen (D, XXVIII, 67, c) of the "light Quincy" is more of a medium gray with a slight greenish tinge. Its general composition is the same as the "dark Quincy" with probably more kaolin and epidote in the feldspars. The contrasts are more marked.

The quarry, opened before 1826, is about 500 feet N. 25° E. by 500 feet N. 65° W. and 100 feet deep. (See Pl. III, A.)

The sheets, from 6 inches to 12 feet thick, are lenticular, undulating horizontal. As shown in the plate the upper 30 feet consists of very thin sheets which, owing to their thinness and rustiness, are valueless. Joints A strike N. 70° W., dip 90°, and are spaced irregularly, but never completely cross the quarry. A set with similar strike, but dipping 30°–35° north-northeast, is represented by two or three at the north end, and two on the east wall near the south end. Joints C strike N. 20° W., dip 90°, and are spaced 14 to 30 and 400 feet. At the bottom there are short intermittent joints dipping east and in other directions, which are coated with riebeckite and thus have blue-black surfaces. (See further on p. 60.) The rift is reported as vertical with a N. 65° W. course, and the feeble grain as at right angles to it and vertical. A dark bluish-gray knot (67, e) contains porphyritic crystals of ægirite, as described under group 1 on page 95. There are also some of group 3. The boundaries between the "light" and "dark" granite are not well defined. Rusty discoloration is from 2 to 18 inches thick. Where it is only 2 inches the feldspar is usually slightly greenish for several inches back.

The plant consists of 3 derricks, 3 hoisting engines, 1 "tag engine," an air compressor (capacity 313 cubic feet of air per minute), 4 steam drills, 11 air-plug drills, and 2 steam pumps.

Transportation involves a cartage of three-fourth mile to railroad, and averages about a mile to local cutting sheds.

Specimen: Three bases and die of the Jefferson monument at Louisville, Ky.

The Merry Mount quarry is on the North Commons, north of Quarry street. (See map, Pl. II, No. 14.) Operator, Merry Mount Granite Company, Quincy, Mass.

The granite (specimen D, XXIX, 86, a), "dark medium Quincy," is a riebeckite-ægirite granite of somewhat dark, slightly purplish gray color. Its shade is slightly darker than that of 67, d. The texture is medium to coarse, even grained, with feldspar up to 0.5 inch and black silicates up to 0.3 inch. Its constituents, in descending order of abundance, are: A medium and dark or slightly greenish-gray potash feldspar (orthoclase, generally twinned), always minutely intergrown with soda-lime feldspar (albite to oligoclase-albite), in places somewhat kaolinized and inclosing riebeckite crystals up to 0.094 by 0.0094 millimeter and particles of epidote, also hematite stain; smoky quartz with streaks or sheets of cavities and minute black particles; a little separate soda-lime feldspar (oligoclase-andesine); blue-black riebeckite and green-black ægirite, either separate or intergrown. The accessory minerals are: Zircon (abundant in crystals up to 0.47 millimeter) and fluorite. Secondary: Kaolin, epidote, limonite, and hematite.

The purplish tinge of this granite is evidently due to hematite in the feldspar. The contrast in the rough stone is entirely between the black silicates and the general gray of the quartz and feldspar.

Mr. E. C. Sullivan, chemist, of the United States Geological Survey, extracted 0.11 per cent of CaO (lime) from this granite by means of hot dilute acetic acid, which indicates the presence of 0.19 per cent of CaCO₃ (lime carbonate) calcite. The presence of this mineral is also shown by the microscope.

A specimen of "medium Quincy" (D, XXIX, 86, b) is a trifle lighter in shade and has a slightly greenish tinge. Its texture and constituents are the same, except that the feldspar borders on light-gray, hematite stain is absent, and a particle of pyrite appears. The quartz is darker than much of the feldspar.

The quarry, opened in 1856, measures about 300 feet north to south by 200 across and from 130 to 150 feet in depth.

On the west wall is a 5-foot dike of lamprophyre, described on p. 95, which has a N. 10° E. strike. The sheets are lenticular in all directions and mainly horizontal, ranging from 1 to 16 feet in thickness. They thicken downward, but with thin sheets at intervals, to a depth

of 40 feet. Joints B strike N. 10° E., dip 90° , or steep west, are spaced 5 to 20 feet, and form a heading near the dike. One diagonal joint (D) strikes N. 50° E. and dips 70° northwest. The rift is reported as striking N. 10° E. and vertically or steeply west, and the grain as east to west, dipping steeply north. In individual blocks the rift is considerably affected by gravity. Knots, both dark and light, are from 1 to 6 inches across, but some are reported as 2 feet 6 inches in two diameters. Rusty discoloration on sheet surfaces is from 1 to 6 inches thick.

The plant consists of 4 derricks, 2 hoisting engines, 2 air compressors (capacity 100 and 250 cubic feet of air per minute), 2 steam drills, 14 air-plug drills, 8 air hand tools, and a steam pump.

Transportation involves cartage of a mile to railroad or cutting shed.

The product consists chiefly of the "dark medium." Specimen: The Barney mausoleum at Springfield, Mass.

The Ballou quarry is on the North Commons, north of Quarry street. (See map, Pl. II, No. 15.) Operator, John C. Ballou, 6 Rogers street, West Quincy, Mass.

The granite (specimen D, XXIX, 80, a), "dark Quincy with minute red dots," is a riebeckite-ægirite granite of dark slightly purplish-gray color, with sparse inconspicuous reddish stains. Its shade is slightly darker than that of 86, a (Merry Mount "dark medium"). Its texture is medium to coarse, even grained, with feldspars up to 0.5 inch and black silicates to 0.3 inch. Its constituents, in descending order of abundance, are: A dark-gray potash feldspar (orthoclase twinned), minutely intergrown with soda-lime feldspar, in places somewhat kaolinized, rarely with hematite stain along its cleavage planes, and inclosing particles of epidote and crystals of riebeckite up to 0.114 millimeter long; smoky quartz of very slight bluish tinge, with abundant cavities up to 0.0094 and exceptionally 0.037 millimeter in diameter, in streaks or sheets intersecting one another at all angles, and with very minute black particles. The quartz incloses a riebeckite crystal 0.178 by 0.0047 millimeter; a little separate soda-lime feldspar (albite to oligoclase-albite); and finally riebeckite, some of it intergrown with ægirite, the latter containing magnetite and carbonate. The accessory minerals are: Zircon and magnetite. The secondary: Kaolin, epidote, hematite, limonite (about the zircon), and calcite.

The contrast is confined to that between the black silicates and the dark gray of the feldspar and quartz with its faint reddish spots.

Mr. George Steiger, chemist, of the United States Geological Survey, extracted 0.28 per cent of CaO (lime) from this stone by means of hot dilute acetic acid, which indicates a content of 0.5 per cent of CaCO_3 (lime carbonate) calcite, the presence of which mineral is also shown by the microscope.

The quarry, opened before 1856, measures about 200 feet from north to south by 100 feet across, but with a recess on the south wall 16 by 18 feet. Its depth is 150 feet.

An interesting cylindrical pegmatite dike, a section of which is exposed at the bottom of the quarry, has been described on page 49. The sheets, from 8 inches to 20 feet thick, increasing in thickness downward, are lenticular, irregular, dipping both north and south. The sheet structure extends at least to a depth of 150 feet from the rock surface, below which there is no parting for 16 feet. Joints A strike about N. 80° W., dip 70° north, are spaced 3 to 30 feet, form a short heading in about the center and one on the northeast side. Joints B strike nearly north, dip 90° and steeply west, form headings at east and west walls, one, 100 feet from west wall, and another (30 to 40 feet wide) 75 feet west of east end. Joints C, striking N. 10° to 30° W., form a heading at the northwest corner of the quarry. The rift is reported as about north-south, the grain as east to west, both vertical. Discoloration is up to 3 inches wide along the joint faces, but is scarcely present on sheet surfaces.

The plant consists of 3 derricks, 2 hoisting engines, an air compressor (capacity 174 cubic feet of air per minute), 3 steam drills, a surfacer, 6 air plug drills, 4 air hand tools, and 2 steam pumps.

Transportation involves cartage of 1 mile to railroad and various distances to cutting sheds.

The product is used mainly for monuments and the inferior stock for paving. The chief market is Philadelphia. Specimen structure: Masonic Building, Philadelphia.

The Djerf & Winqvist quarry is on the North Commons, south of Quarry street. (See map, Pl. II, No. 16.) Operator, Djerf & Winqvist, Quincy, Mass.

The granite, "extra light," is a riebeckite-ægirite granite of light pea-greenish gray color and medium to coarse texture. It is identical in composition with that of the Lepage quarry (specimen D, XXVIII, 76, a), described on page 112. It owes its green color to the epidotization of the feldspar. The quartz is amethystine, not smoky. The contrast is chiefly between the black silicates and the feldspar, but there is also some between the purplish tinge of the quartz and the light green of the feldspar. Were the stone suitable for monumental work its colors would be attractive on the polished surface.

The quarry, opened in 1887, measures about 300 by 250 feet and 125 feet in depth.

There is a basic dike 6 feet thick, along the south side dipping steeply to the south; a like one a little north of the north wall dips steeply to the north. The sheets, from 2 to 22 feet thick, dip low north. In places they are thick at the top. The quarry is unusually free of joints. Joints A strike about N. 80° W., dip steeply

north, and from north and south walls only. Joints B strike nearly north, from east and west walls only; one diagonal joint (E) striking N. 45° W., dips 45° to 50° southwest. The rusty stain along sheet surfaces is from one-fourth inch to 6 inches thick.

The plant consists of 2 derricks, 2 hoisting engines, a steam drill, 3 air plug drills, and a steam pump. Compressed air is obtained from the Dell Hitchcock quarry.

Transportation involves cartage of 1 mile to railroad.

The product is used entirely for building and hammered work. Some of it finds a market in New York.

The Sahlsten quarry is on the North Commons, north of Quarry street, about 1,000 feet east of the last. (See map, Pl. II, No. 17.) Operator, Theodore Sahlsten, 34 Mattson street, Quincy, Mass.

The granite, "medium," is a riebeckite-ægirite granite, like that of the Hardwick quarry described below.

The quarry is triangular in area, with sides measuring 100, 75, and 145 feet, respectively, and being from 50 to 75 feet deep.

The sheets from 1 to 10 feet thick, dip 40° southwest. Joints C strike N. 20° W., dip 90°, and are spaced 10 to 20 feet. Joints D, striking N. 55° E., dipping 90°, are spaced 60 feet, and form the south wall. Joints E are diagonal, strike N. 45° W., dip 70° northeast, are spaced 10 to 20 feet, and occur at northeast corner only. Gray knots measure up to 12 by 18 inches. Rusty stain is up to 6 inches thick on the sheet surfaces.

The product is used for monuments and bases, cellar stone, and paving.

The Hardwick quarry is on the North Commons opposite the corner of Quarry and Smith streets. (See map, Pl. II, No. 19.) Operator, C. H. Hardwick & Co., Quincy, Mass.

The granite (specimen D, XXIX, 79, d), "medium," is a riebeckite-ægirite granite of dark, slightly purplish gray color, a trifle darker than 86, a (the "dark medium" of Merry Mount quarry), and a little darker and more purplish than 67, d (the "dark" of Dell Hitchcock quarry). It is of medium, even-grained texture with feldspars and black silicates up to 0.4 inch. Its constituents, in descending order of abundance, are: A medium and dark, slightly purplish gray potash feldspar (orthoclase, usually twinned), always with minutely intergrown soda-lime feldspar and exceptionally with quartz also. In places it is somewhat kaolinized, contains minute epidotes and crystals of riebeckite from 0.0094 to 0.066 millimeter long up to 0.0094 millimeter wide; light smoky quartz with intersecting streaks or sheets of cavities from less than 0.0043 to 0.02 millimeter long, also with very minute black particles; riebeckite and ægirite, the latter with black nonmetallic particles (limonite?); a little soda-lime feldspar (albite to oligoclase-albite). Accessory: Magnetite. Sec-

ondary: Kaolin, epidote, brownish-yellow fibrous hornblende on riebeckite, and limonite(?).

The contrast is largely between the black silicates and the gray of the quartz and feldspar.

The "light" of the same quarry (specimen D, XXIX, 79, f) is a similar granite of medium gray, inclining to dark, shade without bluish or greenish or purplish tinge, with blue-black and very dark green spots, and of medium texture with feldspar and riebeckite up to 0.4 inch. Its constituents are identical with those of the "medium" already described, except that the feldspar is in places stained with hematite, in others with limonite, proceeding from limonite associated with zircon, and that the ægirite appears to be slightly altered. There is some leucoxene adjacent to ilmenite. The ægirite contains not a little magnetite. Fluorite is among the accessory minerals.

The contrast between the black silicates and the other minerals in the "light" is greater than in the "medium," because the feldspars are lighter.

The "dark" (specimen 79, e) is darker than the "medium" and of same shade as the "dark" of the Granite Railway quarry (68, b), page 109, but of marked purplish tinge. Its texture is medium to coarse.

An analysis of a granite from this quarry is given on page 93.

The quarry, first opened in a small way in 1790, but first operated by the Hardwick family in 1848, measures about 300 feet east and west by 150 feet across, and 125 feet in depth.

The sheets, from 8 inches to 20 feet thick, usually increasing in thickness downward, but in places thin to a depth of 50 feet, are lenticular and horizontal. Joints A, striking N. 80°-85° W., dipping 55°-65° N., are spaced 10, 30, and 60 feet, and form a heading on the west wall. Joints C, striking N. 30° W., dipping 70° SW., are spaced 5, 25, and 150 feet, and form a heading 30 feet wide in the eastern half of quarry. These joints are intermittent. The rift is reported as vertical, with a course not far from N. 30° W., and the grain as horizontal. The boundary between the "medium" and the "light" is irregular. Within the headings the stone has a marked purplish tint from hematite stain. There are rows of riebeckite particles up to half an inch wide with a N. 85° W. course and a dip of 55° S. There are also quartz veinlets with a N. 20° W. course and a dip of 50°-75° E., less than 0.1 inch thick, which in places give way to black silicates. In thin section this black part consists chiefly of quartz, ægirite, and magnetite, with a little zircon (in doubly terminated pyramids), purple fluorite, and carbonate. Aplitic knots of group 1, described on page 95, measure up to 3 feet by 4 inches. Light-gray knots of group 2, with porphyritic feldspar, occur also. Rusty stain along the sheet surfaces is from three-fourths inch to 6 inches thick. The

drainage of the quarry is said to contain magnesia, iron, and lime. The rock surface is covered with 6 to 16 feet of sand and boulders.

The plant consists of 5 derricks, 2 hoisting engines, an air compressor (capacity 275 cubic feet of air per minute), 3 steam drills, 4 air plug drills, 3 air hand tools, 5 polishers, and a steam pump.

Transportation involves cartage of 1 mile to railroad and varying distances to local cutting sheds.

The product is chiefly the "medium," but includes some "dark" and "light," the last being used for bases and hammered work. Specimen structures: The addition to Gore Hall at Harvard University, erected in 1870; the custom-house at New Orleans; the Lewis Cass monument at Detroit, Mich.; a 5-foot polished ball in Fairmount Cemetery, Newark, N. J.

The Galvin quarry is on the North Commons, between the McKenzie & Pattison and the Hardwick quarry. (See map, Pl. II.) Operator, The Galvin Granite Company (John P. Galvin), Quincy, Mass.

The granite, similar to that of the Hardwick quarry, is a riebeckite-ægirite granite of dark or medium gray shade.

The quarry is 150 feet square by 100 deep and has 10 feet of stripping.

The chief geological feature is the presence of pegmatite quartz veins at intervals of 2 to 10 feet, striking N. 25° W. and dipping 50° S. 25° W. These veins, up to 1 inch thick, occupy the center of belts of light granite 10 inches wide, and are crossed by vertical subjoints striking about north and not over 1 foot long. They have already been referred to on page 48, and are shown in Pl. III, *B*. The sheets, from 1 to 14 feet thick, are lenticular and horizontal. Joints A strike N. 80° W., dip 90°, and form the north and south walls. B strike north, dip 90°, and form the east wall. C strike and dip with the veins, are spaced 2 to 25 feet and form a heading on the east wall. The rift is reported as vertical, with a N. 80° W. course, and the grain as horizontal, but dips 20° W. when the drilling is done from north to south. Black and gray knots measure from 1 inch up to 2 feet 6 inches in two diameters. Rusty discoloration on sheet surfaces is up to 1 foot thick, in cases even 2 feet.

The plant consists of 2 derricks, 2 hoisting engines, a steam drill, and a steam pump.

The product is carted to local cutters.

The McKenzie & Pattison quarry, idle in 1906, is on the North Commons. (See map, Pl. II, No. 18.) This has on its northwest side quartz veins, like those of the Galvin quarry, striking N. 50° W. and dipping 50° S. 50° W., forming the center of bands of whitish and brownish discoloration.

The Field & Wild quarry is on the North Commons between the last quarry and Cranch street. (See map, Pl. II, No. 20.) Operator, Field & Wild, Quincy, Mass.

The granite, "dark," "medium," and "light," is a riebeckite-ægirite granite of dark and medium gray shade.

The quarry, opened in about 1840, measures about 600 feet from northwest to southeast by 150 feet across and from 75 to 100 feet in depth.

The rock surface on the northeast side dips steeply east with sheets from 1 to 3 feet thick parallel to it. Some thin sheets occur also in the upper 20 feet on the southwest side. Joints B, striking N. 15° E., dipping 90° and steeply east, spaced 10 to 50 feet, occur at the northwest end only. Joints C, striking N. 15° W., dipping 80° E., are spaced 1 to 8 feet. Joints D, striking N. 45° E., dipping 70°-85° N. 45° W., are spaced 20 to 50 feet. Joints E, striking about N. 45° W., dipping 30°-50° S. 45° W., are spaced 2 to 8 feet. These are conspicuous in the southeastern half of the quarry. Some intermittent joints are coated with riebeckite. The rift is said to vary greatly in direction both in the quarry and in different blocks. There are numerous quartz veins like those at the Galvin and McKenzie & Patison quarries, striking about N. 45° W., dipping 45° S. 45° W., at intervals of 2 to 25 feet. They are mostly crossed by subjoins 1 foot long, parallel to joints C, an inch or two apart. Some of them have a central fracture. In places they are only one-fiftieth inch thick. A thin section of one shows quartz crowded with cavities in intersecting streaks, crystals of ilmenite (probably), and carbonate. The hand specimen shows fluorite along the edge of the vein. The feldspars adjacent to the vein are traversed by fibrous muscovite, also kaolinized, epidotized, stained with limonite, and otherwise altered. (See p. 95.) Knots up to over 6 inches, some of them of group 2 (p. 95), with porphyritic feldspars, occur.

The plant consists of 3 derricks, 3 hoisting engines, an air compressor (capacity 195 cubic feet of air per minute), a large air drill, 6 air plug drills, 6 air hand tools, and 2 steam pumps.

Transportation involves cartage of 1 mile to railroad.

The product consists of "dark" and "medium" for monuments and "light" for bases, etc. Specimen monuments and structures: The Howe monument at Greenwood Cemetery, New York; Gerkin monument at Great Barrington, Mass.; Joseph Robertson monument at Mount Wollaston Cemetery, Quincy; Payne Building at Cleveland, Ohio.

The above quarries include all which were in operation in 1906 on the North Commons. The following are in West Quincy:

The Wigwam quarry is on Willard street, 570 feet south of West Quincy station. (See map, Pl. II, No. 1.) Operator, Badger Brothers, 107 Willard street, West Quincy, Mass.

The granite, chiefly "dark" and "extra dark," with some "medium" and "light," is a riebeckite-ægirite granite of dark, very dark, or medium bluish gray color and of medium to coarse, even-grained texture.

Its constituent minerals are similar to those of specimens D, XXVIII, 68, b ("dark"), and D, XXIX, 78, a ("extra dark"), described on pages 107, 109, but the stone is reported as coarser in parts of the quarry than in adjacent quarries. The stone of the east side becomes lighter on exposure, even after polishing.

A polished specimen (D, XXVIII, 73, a) of the "medium" shows the feldspars ranging from a dark gray to a greenish medium gray, and cream colored in spots owing to kaolinization. The contrasts between the black silicates, the grayish quartz and feldspars, and the cream-colored parts of the feldspars are marked and give the stone a mottled shading.

An estimate of the mineral percentages made by applying the Rosiwal method to this specimen, with a mesh of 0.6 inch and total linear length of 20.4 inches, yields these figures:

Estimated mineral percentages in Quincy granite from the Wigwam quarry.

| | |
|------------------------------|--------------|
| Feldspars..... | 69.51 |
| Quartz..... | 8.43 |
| Riebeckite and aegirite..... | 22.06 |
| | <hr/> 100.00 |

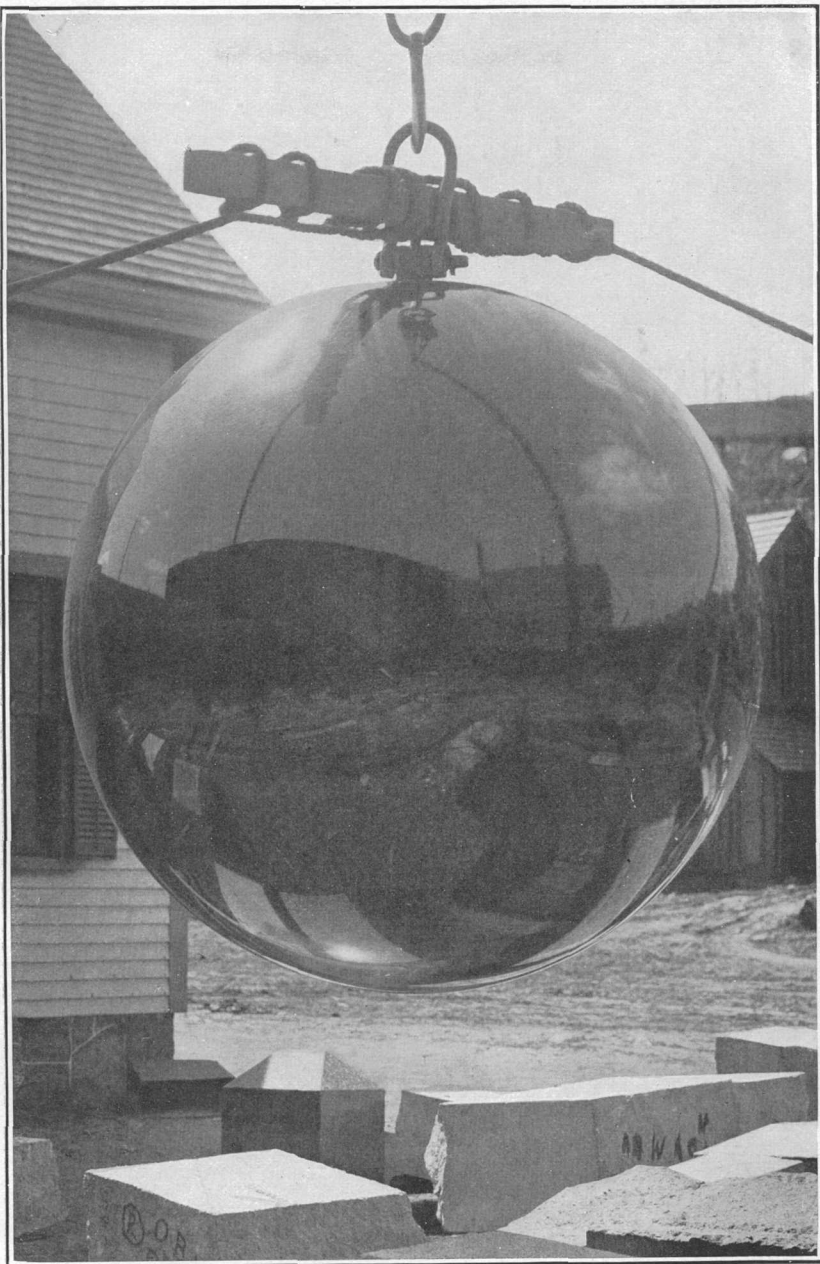
The quarry, opened between 1820 and 1830, measures about 250 feet in a N. 65° W. direction by 100 feet across, and from 100 to 160 feet in depth.

The sheets at the surface, on the north and west sides, are from 1 to 3 feet thick, and dip 50° northeast. On the south and east sides there are traces of sheet structure in the upper 40 feet but none below that. Joints A, striking N. 83° E. and vertical, are spaced 6 to 20 feet. Joints B, striking N. 10° E. and vertical, are spaced 3 to 18 feet, and form the southwest wall. Owing to its irregular sheets and the spacing of the joints this is technically a "boulder quarry." The rift is reported as vertical, with an east-west course on the south side, but on the north as dipping steeply north, and the grain as vertical north to south. Black knots are reported up to 6 feet by 2 feet. Greenish and muddy yellow ones of group 3, page 95, measure up to 1 foot in length by a few inches in width. Reddish and greenish spots ("orei," p. 54) occur in the upper 30 feet. Rusty stain, from one-half inch to 18 inches thick, is abundant along the joint faces.

The plant consists of 5 derricks, 2 hoisting engines, 2 air compressors (capacity 225 cubic feet of air per minute), 3 steam drills, 6 air plug drills, 6 air hand tools, 6 polishers, and a steam pump. The compressors and polishers are run by a 150-horsepower engine.

A siding reaches the quarry, but blocks for finishing are carted a few hundred feet to the cutting shed, which is on the main line.

The product finds its market through local dealers. It consists chiefly of the "dark" and "extra dark" for monuments. Specimens: Polished columns in monument to Solomon Willard, architect of



BALL OF POLISHED QUINCY GRANITE FROM THE WIGWAM QUARRY.

Diameter, 76 inches; weight, 22,000 pounds.

Bunker Hill monument, in Hall Cemetery, West Quincy; polished columns in New Orleans custom-house, and a polished ball, 6 feet 6 inches in diameter, at Rock Island, Ill., cemetery. A photograph of this is reproduced in Plate IV.

The Reinhalter quarry is 570 feet south-southwest of the West Quincy station. (See map, Pl. II, No. 2.) Operator, Thomas F. Mannex, West Quincy, Mass.

The granite (specimen D, XXIX, 78, a), "extra dark," is a riebeckite-ægirite granite of very dark bluish gray color and of medium to coarse, even-grained texture, with feldspars up to 0.5 and black silicates up to 0.3 inch. Its constituents, in descending order of abundance, are: A dark and medium gray potash feldspar (orthoclase, mostly twinned) minutely intergrown with soda-lime feldspar, darkened probably by a black mineral in very minute particles. It incloses minute crystals of riebeckite, and particles of epidote; smoky quartz with intersecting streaks and sheets of cavities, very minute black particles and isolated crystals of ægirite; blue-black riebeckite and green-black ægirite, in places intergrown; a little separate soda-lime feldspar (albite to oligoclase-albite). Accessory minerals are: Zircon (rather abundant), ilmenite, and pyrite. Cracks in orthoclase and quartz, intersecting at right angles, probably rift and grain cracks, contain or are crossed by secondary minute riebeckite crystals. The feldspar is much darker on either side of these cracks. The secondary minerals are: Epidote, leucoxene, and part of the riebeckite.

The "medium" of this quarry is a dark, very slightly greenish gray stone of the same texture. Its shade is like the "medium" of the Hardwick quarry (p. 102), but its tint is different. It is darker than the "dark" of the Dell Hitchcock quarry, but differs from that also in tint.

The quarry, opened before 1871, measures 200 feet by 150 on one side and 200 feet on the other, and is 225 in depth.

The sheets, from 14 inches to 20 feet thick, extend to within 50 feet of the bottom or 175 feet from the rock surface. At a point on the east side, 150 feet down, they dip east. On the south side, 175 feet down, they strike N. 85° W. and dip 25°-35° S. Below the sheet structure there is a mass 55 feet thick (100 by 45 feet) without horizontal parting. The joint and rift courses are shown in fig. 9. Joints A dip 90°, form the north and south walls, and recur at intervals of 10 and 35 feet. At 35 feet from the north wall they form a 10-foot heading which extends from a point 100 feet below the surface to the bottom. Joints B are vertical, form the east wall, are intermittent, and are spaced 30 and 60 to 70 feet. The east wall is intersected by a wide heading striking N. 20° E. and dipping steeply east. Joints C dip 90° and form the west wall. Joints D are vertical and exceptional. In about the center of the top of the north wall is a 25-foot heading, which at a point 50 feet down disappears behind it. The heading A

The quarry, opened about 1846, measures about 200 feet from north to south by 175 feet across and 200 in depth.

Irregular horizontal sheets are apparent only to a depth of 100 feet, below which point joints and headings predominate. This is a boulder quarry and its management is difficult. Joint and rift courses are shown in fig. 10. Joints A are vertical or dip 75° south, form a heading on the north wall, and are spaced 10 to 30 feet. Joints C are vertical and form a heading on the east, 30 feet wide, which separates this from the Reinhalter quarry. Joints D, diagonal, form a heading on the west wall dipping 75° SE., and another extending from east to south walls. They are spaced 2 to 10 feet, and some dip 90° . Joints B, also diagonal, dip 70° east, and form a heading intersecting the south wall and another at the northwest corner. The rift is reported as vertical with a north-south course west of heading C, but with an east-west course east of it. This anomaly may be due to faulting. Knots, green or black, are reported as measuring from 6 inches to 2 feet in diameter. Rusty stain is from one-half inch to 2 inches thick on sheet surfaces at the bottom.

The plant consists of 2 derricks, 2 hoisting engines, an air compressor (capacity 348 cubic feet of air per minute), 4 steam drills, 12 air plug drills, and 4 steam pumps.

Transportation is by a railroad siding for out of town shipments, but by cartage, averaging about 1 mile, to local dealers.

The product is used mostly for monuments. Shipments have been made to Connecticut, Rhode Island, New Hampshire, Maine, New York, New Jersey, Pennsylvania, Delaware, Ohio, Indiana, Illinois, Michigan, Wisconsin, and Missouri. The usual maximum size of blocks quarried is 150 cubic feet, but blocks 40 by 6 by 8 feet are obtainable.

The *Granite Railway quarry* derives its name from a primitive railroad constructed in 1826 to bring the granite for Bunker Hill Monument from a neighboring opening to tide water at Neponset River. The quarry now worked is about 1,050 feet west-southwest of West Quincy station. (See map, Pl. II, No. 4.) Operator, The Granite Railway Company, Quincy, Mass.

The granite (specimens, D, XXVIII, 68, b, h), "Quincy dark blue railway," is a riebeckite-ægirite granite of dark bluish gray color, and medium to coarse, even-grained texture, with feldspars up to 0.5 inch

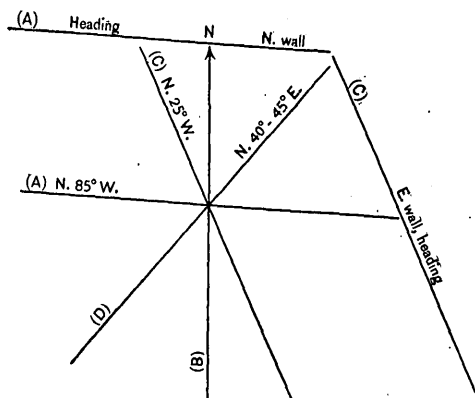


FIG. 10.—Structure at the Swingle quarry in West Quincy, Mass.

and black silicates up to 0.3 inch. Its constituents, in descending order of abundance, are: A dark bluish-greenish gray, black-streaked potash feldspar (orthoclase, in twins), minutely intergrown with soda-lime feldspar, apparently darkened by microscopic black particles and also somewhat kaolinized, containing blue-brownish crystals of riebeckite down to 0.009 millimeter long, also irregular particles of green epidote and some slender ones up to 0.37 millimeter long arranged either along the twinning plane or the plane of intergrowth with the soda-lime feldspar. The black streaks are due to clusters of radiating fibrous crystals of a brown hornblende; smoky quartz with intersecting streaks or sheets of cavities, from less than 0.0028 to 0.0085 millimeter, also with abundant microscopic black particles; blue-black riebeckite and green-black ægirite in many cases intergrown. Basal sections of the latter appear corroded; separate soda-lime feldspar (albite to oligoclase-albite) in very small amount. The accessory minerals are: Ilmenite, zircon in doubly terminated pyramids, and apatite. The secondary: Epidote, kaolin, leucoxene, hematite and limonite stain (rare), brown hornblende, and, as shown by test, calcite.

The contrast between the smoke shade of the quartz and the slightly bluish-greenish gray of the feldspar is small. It lies mainly between these and the black silicates.

An estimate of the mineral percentages by the Rosiwal method yields the following results, with a mesh of 0.4 inch and a total linear length of 71.2 inches.

Estimated mineral percentages in Quincy granite from the Granite Railway quarry.

| | |
|-----------------------------|--------------|
| Feldspars..... | 58.79 |
| Quartz..... | 33.74 |
| Riebeckite and ægirite..... | 7.47 |
| | <hr/> 100.00 |

Of course the last figure does not include the microscopic particles of the two black silicates.

Mr. E. C. Sullivan, chemist, of the United States Geological Survey, extracted 0.13 per cent of CaO (lime) from this granite by means of hot dilute acetic acid, which indicates the presence of 0.25 per cent of CaCO₃ (lime carbonate) calcite.

The "extra dark" of the same quarry (specimen D, XXVIII, 68, c) is darker than 68, b, but a trifle lighter than the "extra dark" of the Swingle quarry. The feldspar seems to be darkened by more brown hornblende and more abundant other black particles. There is also a dark orange hornblende. The minute riebeckite crystals and long slender epidote particles are both arranged with reference to the twinning of the feldspars. An ægirite particle (0.2 by 0.14 millimeter) coated with radiating crystals of riebeckite (up to 0.09 millimeter

long) occurs within a quartz area. Purple fluorite is mingled with the riebeckite.

The quarry, opened in 1826, is roughly T-shaped, the top of the T measuring about 800 feet N. 75° W. by 450 feet N. 10° E., and the stem being about 250 by 20 feet. Its depth ranges from 50 to 70 feet, but 30 feet of rock had been removed from the present edge of the quarry. In 1906 a mass about 100 feet square, rising 30 to 40 feet above the edge and devoid of sheet structure, projected into the quarry west of the stem of the T.

A 15-foot diabase dike dipping 60° NNE, with a greenish rim a foot thick on its under side, bounds the quarry on the southwest. (See p. 95.) The granite under the dike has three sets of joints, one dipping about 50° in the opposite direction, one parallel to the dike, and a third striking N. 22° E. with the dip of the dike. The sheets are in places regular, in other places they are in short lenses, and in others are altogether absent. This is a boulder quarry. The courses of dike, joints, and rift are shown in fig. 11. Joints A dip 55° southwest, form a heading on the northeast, and are spaced 1 to 12 feet. Joints B are vertical, form the east and west walls, and are spaced irregularly up to 300 feet. Joints C, diagonal and dipping 70° west, form a heading at the west angle of the T in the projecting mass.

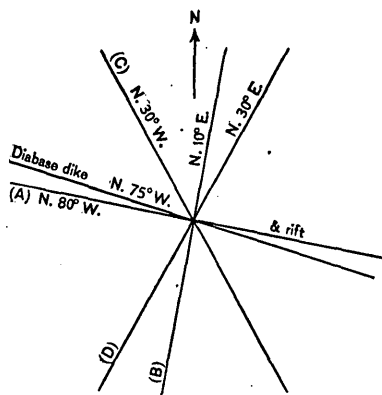


FIG. 11.—Structure at Granite Railway quarry, West Quincy, Mass.

Joints D, diagonal and dipping about 55° east, are coated with riebeckite and hence are called "black seams." (See p. 60.) They occur intermittently on the south side of the quarry. The rift is reported as vertical with a N. 80° W. course, and the grain as also vertical at right angles to it, but feeble. In the western part of the top of the T there is a mass of hematitic and chloritic granite ("ore") extending 30 feet down from the surface. This is described fully on page 54. Knots of dark-gray shade measure up to 12 by 6 inches. Rusty stain is from 3 to 12 inches thick on joint and sheet faces in the deeper part of quarry.

This company operates another quarry, opened in 1905, known as No. 4, Nos. 1, 2, and 3 being designations of parts of the last quarry. No. 4 lies west of the Swingle quarry and measures about 200 feet N. 15° E. by 75 to 100 feet east and is from 15 to 40 deep. The sheets, from 6 inches to 8 feet thick, are horizontal or dip north with the hill

surface. The Bunker Hill quarry, which furnished stone for that monument, lies about 1,800 feet south of No. 4, but is now idle. (See map, Pl. II.)

The plant at these quarries includes 8 derricks, 7 hoisting engines, 4 steam drills, and 4 steam pumps. The cutting shed at the foot of the hill contains an air compressor (capacity, 630 cubic feet of air per minute), 40 air-plug drills, 15 air hand tools, 3 surfacers, 8 polishers, and 2 overhead cranes of 10 and 20 tons capacity.

Transportation is effected by a siding from the New York, New Haven and Hartford Railroad.

The product is used mostly for monuments and polished building fronts. Much of it goes to the Middle West. Specimens: The Bunker Hill Monument and a polished monument 23 feet high to W. C. Whitney, Secretary of the Navy, at Woodlawn Cemetery, New York. The waste is used for cellar stone, riprap, and paving.

The Lepage quarry is between the Granite Railway and the Cashman quarries. (See map, Pl. II, No. 5.) Operator, Lepage Granite Company, West Quincy, Mass.

The granite (specimen D, XXVIII, 76, a), "extra light," is a riebeckite-ægirite granite of light pea-greenish gray color, and medium to coarse even-grained texture, with feldspars up to 0.5 inch and black silicates to 0.4 inch. Its constituents, in descending order of abundance, are: A light pea-green potash feldspar (orthoclase, mostly twinned), minutely intergrown with soda-lime feldspar. It is somewhat kaolinized and more epidotized than that of the gray granites of the region, but contains far fewer minute crystals of riebeckite. The epidote is apt to be parallel to the twinning plane of the orthoclase or the plane of intergrowth of the two feldspars; amethystine quartz, showing effects of strain, and containing intersecting streaks and sheets of cavities, also minute black particles; blue-black riebeckite and green-black ægirite, in cases intergrown; soda-lime feldspar (albite to oligoclase-albite). The accessory minerals are: Zircon, pyrite, and fluorite. The secondary: Kaolin, epidote, carbonate, limonite, and slender crystals of orange-yellow hornblende radiating from ægirite particles.

As pointed out on page 53, the color of the granite and its feldspar seems to be due to the increase of epidote and to the absence or alteration of the minute riebeckite crystals. Kaolinization has also lightened its shade.

The chief contrast is between the black silicates and the rest of the stone, the next between the feldspar and quartz. It takes a poor polish and is only used for bridges, curbing, paving, etc. On the north side of the quarry there is some "dark" adapted to monumental work.

The quarry, opened in 1905, is about 100 feet north to south by 60 to 80 feet across and from 30 to 45 feet deep.

The sheets, from 1 to 5 feet thick, dip 10° south. Joints A strike N. 80° – 85° W., dip 70° – 80° north, form the south wall, and are spaced 4 to 10 feet. Joints C strike N. 15° W., dip 90° and 70° east, form the west wall and a heading on the east wall, and are spaced 3 to 10 feet. The rift is reported as 90° with an east-west course, and the grain as vertical, north-south. The abundance of joints has proved a drawback. Rusty stain, already referred to on page 57, is from 1 to 2 inches thick. Blocks of the pea-green stone bordered by the bright yellowish-brown stain afford striking contrasts. (Specimen D, XXVIII, 76, b.)

The plant includes a derrick, hoisting engine, steam drill, and steam pump. Two plug drills are operated by compressed air from the Granite Railway plant.

Transportation involves cartage of 1 and 2 miles.

The product consists of some dark for monuments, but of more "extra light" for construction and street work.

The *Cashman quarry* is about 1,800 feet west of the West Quincy station. (See map, Pl. II, No. 6.) Operator, John Cashman, 49 Cross street, West Quincy, Mass.

The granite, "extra dark," "medium," and "extra light," is a riebeckite-ægirite granite of very dark, or medium bluish gray, or of light pea-greenish gray color, and of medium to coarse, even-grained texture. Its constituents correspond to those of the several varieties of Quincy granite as described on pages 109, 110, 112.

The quarry, opened about 1876, is of irregular area owing to several offsets or projecting parts on the north, east, and west sides. It is roughly about 350 feet long, north-south, by 225 feet across and from 70 to 100 feet deep. Mr. Cashman controls and operates only the southern two-thirds of the opening, the rest being idle.

The sheets, from 1 to 5 feet thick, are lenticular and flat on the south side, but dip north with the surface at the north. They extend to the bottom of the quarry. Joints A strike nearly east-west, dip steeply north or south, form a heading on the north side, and are spaced 10 to 75 feet. Joints B strike about north, dip 90° , form headings on east side and 35 feet west of it, and are spaced 10 to 30 feet. The rift is reported as vertical, about east-west, but in places dipping away from the vertical, north or south. When split from the side the rift in those places is vertical. The grain is said to dip steeply with north-south course. A workman stated that the rift in the "extra light" was superior to that in the dark stone, and the blocks in sight showed smooth rift breaks. The "extra light" occurs at both north and south ends of the quarry and the dark in the center. Near

a heading at southeast corner the granite is hematitic ("oreï"). (See p. 54.) Rusty stain is from 1 to 3 inches thick on both light and dark stone. The rock surface is covered with 5 to 10 feet of fragments of weathered granite, sand, and boulders.

The plant consists of 3 derricks, 3 hoisting engines, 2 swinging engines, an air compressor (capacity, 134 cubic feet of air per minute), 2 steam drills, 4 air plug drills, and 2 steam pumps.

Transportation involves cartage of 2 miles.

The product is monumental and bridge work, the former being four times more in value than the latter. Specimen structures: Arch bridge across Furnace Brook Parkway in West Quincy; five bridges between South Braintree and Whitman on the Plymouth division of the New York, New Haven and Hartford Railroad.

The Savo quarry is about four-fifths mile west-northwest of West Quincy station. (See map, Pl. II, No. 8.) Operator, Savo Granite Company, 16 Quarry street, Quincy, Mass.

The granite (specimen D, XXIX, 84, a) is an altered riebeckite-ægirite granite of pinkish medium gray color and medium to coarse even-grained texture, with feldspars up to 0.5 inch and greenish silicates up to 0.2 inch. Its constituents are, in descending order of abundance: A light-pinkish, not transparent potash feldspar (orthoclase, twinned) with minutely intergrown soda-lime feldspar, considerably kaolinized, but containing little epidote and no riebeckite. Its pinkish color must be attributed to hematite, arising either from the oxidation of FeO in the feldspar or of magnetite in the other particles; smoky quartz with intersecting streaks or sheets of cavities and minute black particles; riebeckite and ægirite altered to quartz, magnetite, carbonate, epidote and in some cases chlorite; a little soda-lime feldspar (oligoclase-andesine). The accessory minerals are: Zircon (rather large), and fluorite. The secondary: Kaolin, epidote, carbonate, magnetite (some in crystals), chlorite, and hematite. A veinlet crossing several feldspars consists for a part of its course of epidote, in another part of quartz and in another of calcite. (See further on this granite, p. 54.) The pink tint fades somewhat on exposure.

The quarry, opened in 1905, measures about 135 feet N. 55° W. by 50 feet across and 40 feet in depth.

The sheets, from 1 to 8 feet thick, dip 45° N. 25° E., without reference to present surface. Joints A strike N. 70° W., dip about 60° N. 20° E., and S. 20° W. Of this set there are two at the south end. Joints C strike N. 30° W., dip 90° and steeply west, and form east and west walls. The pink granite occupies the southern half of the quarry and the pea green the northern half. The rift is reported as vertical, north-south, and the grain as horizontal. Rusty stain is from 8 to 12 inches thick. The stripping is from 8 to 13 feet thick.

The plant consists of 2 derricks, a hoisting engine, a steam drill, and a steam pump.

Transportation involves cartage of nearly $1\frac{1}{2}$ miles to West Quincy.

The product up to October 17, 1906, had been confined to cellar stone and curbing. It was hoped, however, that as the quarry deepened unaltered gray granite suitable for monumental use would be found. If the pink is part of a zone of slightly metamorphosed surface alteration that hope will be realized.

The Gold-leaf quarry is 4,500 feet N. 80° W. from the West Quincy station. (See map, Pl. II, No. 7.) Operator, The Quincy Quarries Company, Quincy, Mass.

The granite (specimens D, XXVIII, 71, a, b) "Gold-leaf Quincy" is a riebeckite-ægirite granite of medium bluish-green gray color (a trifle lighter than 67, c, the "light" of Dell Hitchcock quarry) speckled with black and yellow brown. Its texture is medium to coarse, even grained, with feldspars up to 0.5 inch and black silicates to 0.3 inch, and yellow brown stains to 0.5 inch, but the quartz areas are finely granular. Its constituents, in descending order of abundance, are: Medium bluish-green-gray potash feldspar (orthoclase, twinned) minutely intergrown with soda-lime feldspar, in places granulated, somewhat kaolinized and epidotized, and containing many minute crystals of riebeckite, to which with the epidote the feldspar owes its peculiar color; quartz, clear to light smoky, almost without cavities, all granulated in particles mostly under 1 millimeter, rarely 2 millimeters in diameter; blue-black riebeckite and green-black ægirite, in places associated with limonite (and hematite?); soda-lime feldspar (albite and probably oligoclase-albite) in small amount. Fluorite is accessory. Secondary limonite occurs in irregular areas, mostly not related to the particles of black silicate, and this produces the yellow-brown stains. The epidote is secondary also.

An estimate of the mineral percentages by the Rosiwal method, with a mesh of 0.5 inch and a total linear length of 74 inches, yields these figures:

Estimated mineral percentages in Gold-leaf Quincy granite.

| | |
|-----------------------------|--------------|
| Feldspars..... | 67.37 |
| Quartz..... | 23.01 |
| Riebeckite and ægirite..... | 9.62 |
| | <hr/> 100.00 |

As compared with other Quincy granites these proportions approximate those of the Wigwam quarry stone. It is the lightest of the Quincy monumental granites. The contrasts between the light bluish green of the feldspar and the black particles and the yellow-brown stains are marked. The minute particles of granulated quartz

reflect the light and, as it were, spangle the surface, and where the limonite stain coincides with the quartz areas the yellow brown spots are the more conspicuous. Hence the trade name "Gold leaf." It takes a high polish, but as small pits are apt to appear in the quartz areas, probably owing to the dropping out of minute quartz particles, it seems better adapted to indoor ornamentation.

The quarry is about 125 feet square, and from 20 to over 50 in depth.

Joints A strike N. 80° W., vertically and steeply north, form the north wall and are spaced about 50 feet. Joints C strike N. 10° W., dip 30° east, form 3 headings in the eastern half, and are spaced 4 to 15 feet. These apparently serve as, or in fact are, sheets. Fine-grained gray knots of group 1 (p. 95), measure 6 inches in diameter.

The Quincy Quarries Company owns a large cutting plant a few hundred feet southeast of this quarry, which in 1906 was let to Robert Cantley. It includes an overhead crane of 20 tons capacity, an air compressor (capacity 290 cubic feet of air per minute), one air plug drill, 35 air hand tools, 5 lathes for stones 21 feet by 5 feet 6 inches, 6 double polishing lathes for stone up to 22 feet by 5 feet 6 inches, one for balls, balusters, and small work, 3 polishers, a stone crusher, and a 151-horsepower engine for driving the lathes, polishers, etc.^a

This quarry was idle in 1906 as were also 2 other openings controlled by the same company, situated a few hundred feet south and southeast of it.^b Twelve columns, 19 feet 6 inches by 3 feet 4 inches have been obtained from the "Gold-leaf" quarry.

Transportation from both quarry and cutting shed is by sidings connected with the Granite branch of the New York, New Haven and Hartford Railroad, as shown in Pl. II.

The Rogers quarry is at the north foot of the "Blue Hills," 1,500 feet northwest of the West Quincy station on Willard street. (See map, Pl. II, No. 9.) Operator, The Quincy Quarries Company, Quincy, Mass.

The granite (specimen D, XXVIII, 70, d), "extra dark," is a riebeckite-ægirite granite of very dark purplish gray color and of medium to coarse texture, with feldspars up to 0.5 and black silicates up to 0.3 inch. Its constituents are like those of the Reinhalter and the Granite Railway "extra dark" granite, described on pages 107, 109. The feldspars have more whitish kaolinized streaks, hence the general shade is slightly lighter than the granites referred to

^a In 1906 500 balusters of Milford, Mass., pink granite were being finished at this plant for the Pennsylvania Terminal Station at New York under a contract with the Milford Stone Company. (See p. 78.)

^b One of these openings, known as the Fuller quarry (Pl. II, No. 21), is owned by the Quincy Granite Company but let to the Quincy Quarries Company. It was opened about 1850, and measures about 600 by 400 feet and 150 feet in depth. The Quincy Granite Company now confines itself to cutting and polishing.

(78, a, and 68, c), and minute hematitic stains account for its more purplish hue. This quarry also yields the "dark."

The quarry, opened in 1832, measures about 600 feet from north to south by 175 feet across and from 40 to 150 feet, or an average of 95 feet in depth.

The sheets are short and thick lenses, which render the structure obscure and irregular. Joint courses are shown in fig. 12. Joints A dip 90° or steeply north and are spaced 10 to 20 feet. Joints B, dipping steeply east, form headings on east and west walls and are spaced 10 to 20 feet. Joints C, dipping 50° east, form a heading at the north-west corner, the faces of which are coated with riebeckite, and are spaced 6 inches to 4 feet. (See on these black joints, p. 60.) This heading intersects a heading of B. Joints D, diagonal, dip 40° S. 45° W., and are spaced 2 to 20 feet. At the south end several faces dipping 30° – 60° N. may belong to A. The rift is reported as vertical with east-west course and the grain as also vertical, at right angles, but feeble.

A basic dike, 2 feet thick, at the north end dips 65° north. Fine-grained aplitic knots probably of group 1, page 95, occur. The largest knot reported was 3 by $1\frac{1}{2}$ feet. Rusty stain is from 1 to 12 inches thick. In places all the granite to a depth

of 30 feet is somewhat stained, but in others good stone occurs at the top. At the south end, west side, the granite upon exposure discolours readily to a medium slightly olive gray. Specimen D, XXVIII, 70, b, described on page 54, had been exposed three years at a point 30 feet down. In thin section the stain is seen to proceed from particles of riebeckite and ægirite. This feature marked the stone at that point as far down as excavations had gone in 1906.

The plant consists of 5 derricks, 5 hoisting engines, an air compressor (capacity 290 cubic feet of air per minute), 2 steam drills, 8 air plug drills, and a stone crusher (capacity 150 tons per day).

Transportation is effected by a siding from the New York, New Haven and Hartford Railroad.

The product is used for monuments, and the waste for road material, etc.

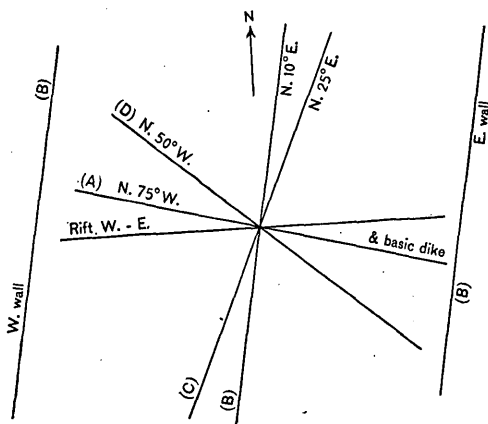


FIG. 12.—Structure at Rogers quarry, West Quincy, Mass.

The following two quarries are in Milton:

The *Mount Pleasant quarry* is at the northwest foot of the Blue Hills, in Milton Township, on Lyman road, off Pleasant street. (See map, Pl. II, No. 11.) Operator (1906), The Mount Pleasant Quarry Company, H. H. Folsom, receiver, East Milton, Mass.

The granite (specimen D, XXIX, 85, a), "dark Quincy," is a riebeckite-ægirite granite of dark bluish gray color, a trifle lighter than 68, b ("dark blue railway"), and with a more bluish tinge. Its texture is medium to coarse, even-grained, with feldspars up to 0.5 inch and black silicates to 0.3 inch. Its constituents, in descending order of abundance, are: A medium to dark bluish gray potash feldspar (orthoclase, mostly twinned) minutely intergrown with soda-lime feldspar, in places somewhat kaolinized, with unusually abundant minute crystals of riebeckite and some particles of epidote, also minute orange-colored hornblende crystals; quartz, dark smoky, with very slight bluish tinge, containing minute cavities and black particles in intersecting streaks and sheets; blue-black riebeckite and green-black ægirite in cases intergrown; soda-lime feldspar (albite and probably oligoclase-albite) in very small amount. Accessory: Fluorite and allanite. Secondary: Kaolin, epidote, calcite, limonite, and probably the orange hornblende.

The blueness of this stone is clearly due to the abundant riebeckite crystals in the feldspars. This comes out on the polished face. (See specimen 88, a, which is identical, but from the adjoining quarry, p. 119.)

Mr. George Steiger, chemist of the United States Geological Survey, extracted from this granite by means of hot dilute acetic acid 0.15 per cent of CaO (lime), which indicates a content of 0.26 per cent of CaCO₃ or calcite, the presence of which mineral is also shown by the microscope.

The quarry, opened in 1901, measures about 125 by 100 feet and 100 feet in depth.

The sheets, from 5 to 27 feet thick, are horizontal and turn to dip gently east. Some of the sheet surfaces on the west side are coated with riebeckite. (See p. 60.) Joints B strike N. 10° E., dip 90° and steeply east, form the east wall, and are spaced 5 to 11 feet. Joints A strike N. 60° W., form a heading on the south side, and are spaced 2 to 15 feet. Joints E, diagonal, strike about northwest and form a heading near the west wall, which has a dark-bluish stone northeast of it, but inferior light stone southwest of it. Black riebeckite-coated joint and sheet faces abound in this part. The rift is reported as vertical with a nearly N. 10° E. course. Rusty stain is up to 2 inches thick on the lower sheets. The surface has from 5 to 10 feet of stripping.

The plant includes 3 derricks, a hoisting engine, a hand derrick, 3 steam drills, and a pump.

Transportation involves cartage of $2\frac{1}{4}$ miles to the railroad at West Quincy or of 3 miles to cutting sheds at Quincy.

The chief product is used for monuments.

The *Maguire & O'Heron quarry* is at the northwest foot of the Blue Hills, in Milton Township, about 800 feet southwest of the last quarry, off Pleasant street. (See map, Pl. II, No. 10.) Operator, Maguire & O'Heron, East Milton, Mass.

The granite (specimen D, XXIX, 88, a), "dark Quincy," is a riebeckite-ægirite granite of dark bluish gray color like that of the adjoining Mount Pleasant quarry (specimen 85, a). Its texture and constituents are also identical.

The polished face brings out the marked bluish tinge of the feldspars, which are streaked with whitish kaolinized parts and contrast somewhat with the smoky quartz, but much more with the black silicates. This stone differs from the "dark blue railway" (specimen D, XXVIII, 68, h, p. 109) by its slightly more bluish tinge, which is due to the greater abundance of microscopic riebeckite crystals in the feldspars.

An estimate of the mineral percentages by the Rosiwal method, with a mesh of 0.5 inch and a total linear length of 20 inches, yields these figures:

Estimated mineral percentages in Quincy granite from the Maguire & O'Heron quarry.

| | |
|--|--------------|
| Feldspars..... | 55.80 |
| Quartz..... | 33.10 |
| Riebeckite and ægirite (excluding microscopic particles) | 11.10 |
| | <hr/> 100.00 |

The quarry, opened in a small way about 1882, but in a larger way in 1901, measures about 250 feet, N. 35° E. by from 75 to 150 feet across and 70 feet in depth. Its width at north and south ends is irregular, averaging about 100 feet.

The sheets, from 3 to 15 feet thick, dip as high as 20° southwest. Joints B strike north, dip steeply east, form a 50-foot heading on the southwest wall, and are spaced 3 to 20 feet. Joints C strike N. 20° - 25° W., dip 75° ENE., and form a heading in the middle of the south end. Joints D strike N. 35° E., dip vertically and steeply west, form the east and west walls, and are spaced 3 to 100 feet. The rift is reported as nearly vertical, with a north course, and the grain as horizontal. Quartz veins, from 1 to 3 inches thick, dipping 30° southeast and inclosed in belts of whitish discoloration, recur at intervals of 3 to 18 feet. (See pp. 48, 53.) Rusty stain is from 3 to 18 inches thick on the lower sheets.

The plant consists of 3 derricks and 2 hoisting engines, 2 air compressors (capacity 130 and 230 cubic feet of air per minute), a steam drill, 12 air plug drills, 18 air hand tools, 3 polishers, a steam pump, an overhead crane (capacity 15 tons), and a 35-horsepower engine for the cutting shed.

Transportation involves cartage of nearly a mile and a half to the cutting shed at East Milton and of another mile to the railroad at West Quincy.

The product is used mostly for monuments and the waste for cellar stone. Specimen monuments: The Bradley monument, at Purdy Station N. Y., monument to Samuel Neilson, the Irish patriot, at Poughkeepsie, N. Y.; the Long monument, at Mansfield, Ohio; the Patterson monument, at Ashland, Pa.; the Meehan monument, at St. Joseph's Cemetery, Boston, and the Mead Chapel, at Lake Waccabuc, N. Y.

The last of the Quincy quarries is on the southeast side of the Blue Hills.

The Sartori quarry is on Pine Hill, in Quincy Township, close to the Braintree line. (See map, Pl. II, No. 12.) Operator, Angelo Sartori & Brothers, 66 West street, West Quincy, Mass.

The granite (specimen D, XXIX, 82, a) is an altered riebeckite-ægirite granite of very dark dull greenish-brownish gray, almost without contrasts, and of medium to coarse even-grained texture, with feldspars up to 0.5 inch and altered black silicates up to 0.3 inch. Its constituents, in descending order of abundance, are: A dark greenish-brownish gray nearly opaque potash feldspar (orthoclase, twinned), some of which is minutely intergrown with soda-lime feldspar. It is mostly much kaolinized and in places much micacized, and here and there is stained with hematite (no epidote or riebeckite crystals were detected in it); smoky quartz, in places pinkish from hematite stain, with intersecting streaks or sheets of cavities and minute black particles; riebeckite and ægirite particles completely altered to masses of greenish biotite, magnetite (mostly octahedral), carbonate, and quartz with some chlorite or delessite; very little soda-lime feldspar (oligoclase); magnetite, zircon, allanite, and fluorite. There are also (spherulites) brownish balls of radiating fibrous crystals, 0.02 to 0.1 millimeter in diameter, some of which polarize like zircon. Secondary: Biotite, a white mica, carbonate, chlorite or delessite, hematite, and magnetite.

This granite differs by its greenish-brownish color from all the other Quincy granites, although microscopically it approaches the pinkish of the Savo quarry (p. 114); but it differs from that by the different alterations of its feldspars and black silicates.

The quarry, opened in 1903, measures 50 by 30 feet, and 15 to 20 feet in depth.

This is a boulder quarry. Joints A strike N. 77° W., dip 45° NNW., and are spaced 3 to 10 feet. Joints C strike N. 10° W., dip 90° , and are spaced 3 to 20 feet. The rift is reported as parallel to A.

The product in 1906 had been found adapted only to bases, curbing, and paving.

ROCKPORT.

Topography.—The township of Rockport occupies the eastern and northern part of that insular mass on the Atlantic coast known as Cape Ann. (See Gloucester sheet of United States Geological Survey topographic atlas.) It is in the county of Essex, in north-eastern Massachusetts, in a region of low, roundish or oval, granitic or sandy hillocks, never exceeding 180 feet in height, and of marshes and boulder-strewn sand flats. The most conspicuous of these hillocks is Pigeon Hill, about a mile north of Rockport village, which is regarded as a drumlin. The quarries are in the northern part of the Cape, scattered along the shore or within three-quarters mile of it, from Rockport to Bay View. (See fig. 13.)

General geology.—The physiography and geology of Cape Ann have been interestingly described by Shaler and Tarr.^a

The entire Cape is represented in Shaler's map, Pl. LXXVII, as of granite but traversed at very frequent intervals by diabase dikes and at a few points by quartz porphyry dikes. According to Sears's geological map of Essex County, hornblende granite covers Halibut Point, Rockport, and the area half a mile east of Bay View, but a quarter of a mile east of Bay View there is a small area of "augite syenite."^b

The geological age of the granite is not yet fully determined. The basic dikes may be Triassic. They range from one-half inch to 40 feet in width. Of 361 observed by Shaler and Tarr 266 lie in the northwest quadrant and more than half in the 45 degrees between north and northwest. They conclude from numerous observations of dike and joint courses that the number of dikes does not appear to have been determined by the number of incipient fissures afforded by the joints; in other words "that the conditions which guided the direction of the dikes were probably due to some feature or condition not inherent in the joints themselves."

Description of Rockport granite.—The more recent scientific accounts of Rockport granite are those of Wadsworth, Merrill, Washington, and Sears.^c Cooke, Clarke, Penfield, and Forbes have described certain new or unusual minerals in Rockport granite.^d

The following epitomizes the descriptions of rough and polished specimens and thin sections of this granite from all the quarries as

^a See Shaler, N. S., The geology of Cape Ann, Mass.: Ninth Ann. Rept. U. S. Geol. Survey, 1889, pp. 529-611.

^b Sears, J. H., The physical geography, geology, mineralogy, and paleontology of Essex County, Mass.: Essex Institute, Salem, Mass., 1905.

^c Wadsworth, M. E., Notes on the petrography of Quincy and Rockport: Proc. Boston Soc. Nat. Hist., vol. 19, 1881; Merrill, G. P., Report Smithsonian Institution, 1885, 1889, pt. 2, p. 419; Washington, H. S., The petrographical province of Essex County, Mass.: Jour. Geol., vol. 6 (8), 1898, pp. 790-796; Sears, J. H., op. cit., pp. 150, 153.

^d Cooke, J. P., On cryophyllite, a new mineral species of the mica family with some associated minerals in the granite of Rockport, Mass.: Am. Jour. Sci. (2), vol. 43, 1867, pp. 217-230; also, On danalite from Rockport: Ibid., July, 1866 (p. 73); Clarke, F. W., On cryophyllite from Rockport: Ibid. (3), vol. 32, 1886, p. 358; Penfield, S. L., and Forbes, E. H., Fayalite from Rockport, Mass., etc.: Ibid. (4), vol. 1, 1896, pp. 129-131.

described on the following pages. Analyses, mineral percentages, and results of physical tests follow the rock description.

Rockport granite is of two sorts, the first and most abundant, known commercially as "gray granite," is a hornblende granite of

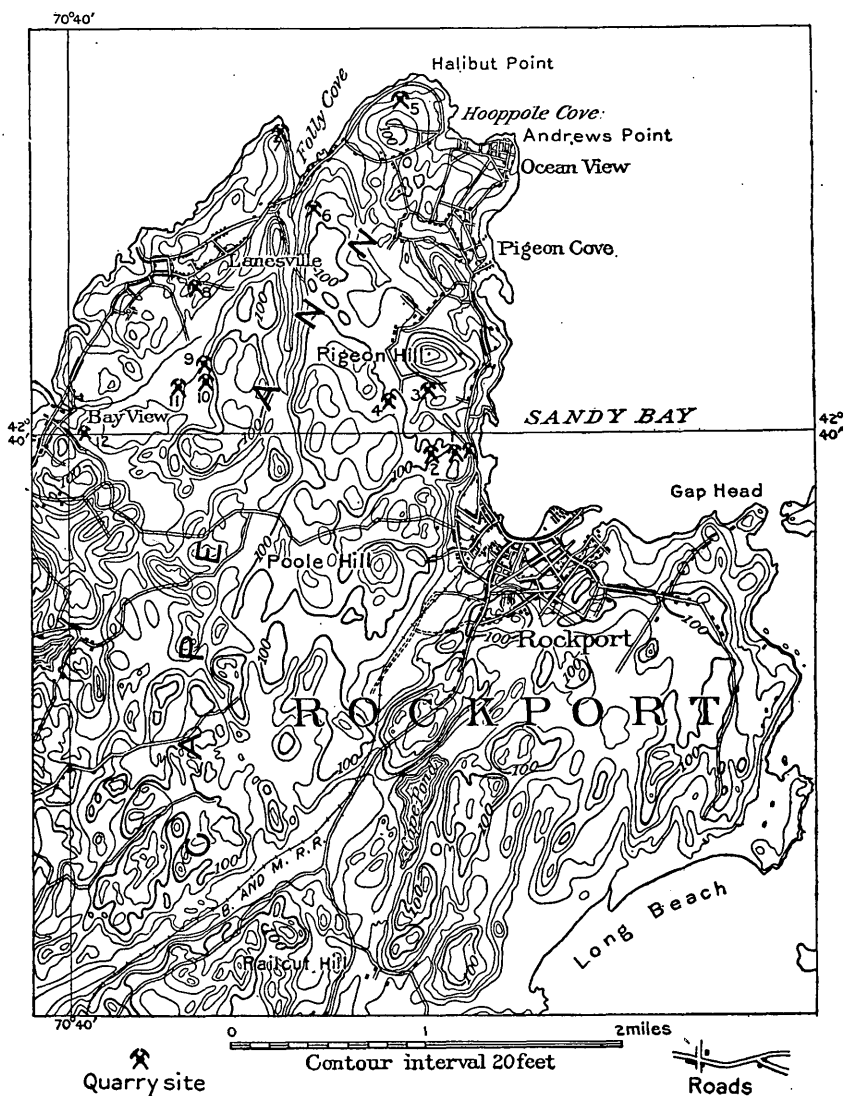


FIG. 13.—Map of part of Cape Ann, Mass., showing the locations of Rockport granite quarries. 1, Flat Ledge quarry, Rockport Granite Company. 2, Upper Pit, Rockport Granite Company. 3, Pigeon Hill quarry, Pigeon Hill Granite Company. 4, Upper quarry of Pigeon Hill Granite Company. 5, Babson Farm quarry, Rockport Granite Company. 6, Nickerson quarry, W. E. Nickerson. 7, Breakwater quarry, Breakwater Construction and Engineering Company. 8, Canney quarry, Edwin Canney. 9, Devils Rock quarry, William R. Cheves. 10, Cheves Green Granite quarry, William R. Cheves. 11, Blood Ledge quarry, Rockport Granite Company. 12, Deep Pit, Rockport Granite Company.

medium gray shade (in places with slight greenish or bluish tinge) spotted with black. Its texture is medium to coarse and even grained, with feldspars up to 0.3 or 0.5 inch, and hornblende up to 0.2

inch. Its constituents, in descending order of abundance, are a light gray potash feldspar (orthoclase with or without microcline) of a slightly greenish or bluish or buff tinge, generally twinned and minutely intergrown with soda-lime feldspar (albite to oligoclase-albite), more or less kaolinized; quite smoky quartz with abundant cavities (many with liquid and vacuoles), from 0.0043, or under, to 0.02 millimeter in diameter, mostly in sheets; black hornblende, in places with a little bluish-black riebeckite (p. 91); very little separate soda-lime feldspar like above; and very little black mica (biotite or lepidomelane).^a The accessory minerals are: Magnetite, pyrite, allanite, fluorite, zircon, and apatite. The secondary are: Hematite, limonite, kaolin, some black hornblende, and calcite.

Estimates of the mineral percentages by the Rosiwal method yield the following results:

Estimated mineral percentages in "Rockport Gray Granite."

| | Average. |
|--|----------|
| Feldspar, 55.50 to 59.60..... | 57.97 |
| Quartz, 33.88 to 38.90..... | 35.82 |
| Hornblende and mica, 5.60 to 7.26..... | 6.20 |

Rockport granite is said to be "hard." These estimates show quartz averaging 35.83 per cent, or if the green of Bay View, given beyond, be averaged with the gray, 34.85 per cent, whereas the average amount of quartz in five tests of Quincy granite is 30.60 per cent (p. 93), in Conway red granites 28.62 per cent (p. 180), and in the Redstone granite of Westerly, R. I. (p. 200), 29.87 per cent. This extra 6 per cent of quartz may be sufficient to account for the hardness.

H. S. Washington^b gives the following analysis of Rockport granite:

Analysis of Rockport granite.

[By H. S. Washington.]

| | |
|--|--------|
| SiO ₂ (silica)..... | 77.61 |
| TiO ₂ (titanium dioxide)..... | .25 |
| Al ₂ O ₃ (alumina)..... | 11.94 |
| Fe ₂ O ₃ (iron sesquioxide)..... | .55 |
| FeO (iron oxide)..... | .87 |
| MnO (manganese oxide)..... | Trace. |
| MgO (magnesia)..... | Trace. |
| CaO (lime)..... | .31 |
| Na ₂ O (soda)..... | 3.80 |
| K ₂ O (potash)..... | 4.98 |
| H ₂ O (water) 110—..... | Trace. |
| H ₂ O (water) 110+ignition..... | .23 |
| | 100.54 |

Specific gravity 2.618 at 18° C.

^aWashington, H. S., op. cit., p. 793, reports 2 varieties of biotite, one very pale green, probably cryophyllite of Cooke, the other darker greenish gray, lepidomelane (annite). Clarke, F. W., op. cit., shows that several varieties of biotite occur.

^bOp. cit., p. 793. On p. 794 he gives these estimates of the mineral percentages based partly on the analysis and partly on microscopic observation: Feldspars 50.2 per cent, quartz 35.5 per cent, hornblende and two biotites 3.8 per cent, accessory minerals 0.5 per cent. The figure for quartz agrees very closely with that obtained by the Rosiwal method.

Messrs. Steiger and Sullivan, chemists, of the United States Geological Survey, find that this granite contains from 0.14 to 0.20 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates the presence of from 0.25 to 0.35 per cent of CaCO₃ (lime carbonate), calcite. (See pp. 125, 129.)

Owing to the black silicate being almost entirely hornblende the stone takes a very high polish. The contrasts of shade between the gray feldspar, smoky quartz, and black hornblende are much more marked on the polished than on the rough face.

The other variety of Rockport granite, known as "green granite," is also a hornblende granite, but of somewhat dark olive-gray color spotted with black.

Its texture is medium to coarse, even grained, with feldspars up to 0.3 and 0.5 inch and hornblende up to 0.2 inch. Its constituents, in descending order of abundance, are: Medium olive-gray feldspars, like those of the gray variety, slightly yellow-greenish smoky quartz, black hornblende and biotite (black mica), together with accessory magnetite, zircon, and allanite, and secondary kaolin, limonite, and calcite. The feldspar varies in the same particle from an olive green to a scarcely greenish milk-white. Limonitic stain is visible in the rift and other cracks of both feldspar and quartz. This stain seems to originate in particles of allanite and magnetite, in the biotite and hornblende, and partly in minute ferruginous particles in the feldspars not distinguishable from kaolin. Quarrymen state that this stone, which when first quarried is a dark gray, becomes greenish after an exposure of three to four hours to rain. It is also stated that the green granite loses some of its color on continued exposure about the quarry. Specimens of this slightly faded green granite show that, while the feldspars have lost a little of their greenness, that color is preserved in the quartz.

An estimate of the mineral percentages in this granite by the Rosiwal method yields the following results:

Estimated mineral percentages in Rockport green granite.

| | |
|-----------------|--------|
| Feldspars..... | 58.45 |
| Quartz..... | 31.95 |
| Hornblende..... | 9.60 |
| | <hr/> |
| | 100.00 |

This granite takes as high a polish as the gray but its contrasts are less marked.

Besides these granites there is near Bay View a dark brownish-gray riebeckite-ægirite-biotite granite, which has only been prospected, and is described on page 139, and also near Pigeon Cove a beautiful diabase porphyry, which is as yet little worked. This is described on page 139. Finally there is the bright rust-colored "sap"

referred to on page 57, which is unusually abundant in some of the Rockport quarries. This has been used by architects in the basements of several private residences on the Cape. The office of the Rockport Granite Company and the Rockport Carnegie Library are made of it. In both buildings the fresh gray granite has been used for trimmings. The resulting contrast is pleasing.

Geology of Rockport quarries.—The conspicuous feature of the Rockport quarries is the large number of basic dikes which traverse them. Some of these are shown in Pl. V, *A* and *B*. Their courses are given in the quarry descriptions. One attains a thickness of 18 feet. They are mostly diabase (soda-lime feldspar, augite more or less altered to hornblende; magnetite, and biotite). One was found to contain both augite and hornblende but no mica. The dike matter was erupted through deeply parted joints. Contemporaneous with them was the irregular-shaped injection described on page 50 and also shown in Pl. V, *B*. The faulting of the large dike in the same quarry shows that a crustal movement affected the region after the crystallization of the dike material. The injection of molten matter into cold granite was not without effect, for the stone on either side of these dikes is apt to be darkened. A thin section of this darkened granite from the Flat Ledge quarry (p. 127) shows it traversed by minute parallel or converging fractures, 0.004 to 0.04 inch apart. The intervening material is broken into angular slivers, and the walls of the fractures are coated with chlorite, and the adjacent feldspars are partly altered to mica. The darker shade of the granite is thus due to the secondary minerals, the formation of which was made possible by the cracking of the quartz and feldspar.

Segregations (knots) are not uncommon in Rockport granite, but at Halibut Point, the extreme north end of the Cape, in the Babson Farm quarry, there is one of unusual character. It is 8 by 4 by 2½ feet, and consists mainly of feldspar and quartz. The feldspar is a somewhat kaolinized light-grayish potash feldspar (microcline) minutely intergrown with soda-lime feldspar (oligoclase-talbie) and containing a few particles of quartz. The cleavage of the feldspar has in places a marked curvature. The quartz is amethystine smoky, in particles up to 2 feet across, and has cavities from 0.00285 to 0.0285 millimeter in diameter. In the center of this knot is a mass, 6 by 2 inches, of a yellow-brownish mineral of the augite group, which Mr. Johannsen determines as bronzite, a silicate of magnesia with 60 per cent of silica and 40 per cent of magnesia.

The pegmatite dikes contain some bright green feldspar (amazon stone). A 4-inch dike of aplite is bordered by pegmatite 1 to 2 inches thick.

Although some of the data obtained from the quarrymen as to rift and grain appear to be incorrect, owing to their confounding rift

and grain or else to inaccurate observation, the course of the rift appears to be east-west and generally vertical and the grain horizontal. Rift and grain cracks can be detected in the quartz areas of polished surfaces.

Sheet structure is generally imperfect, owing either to the shortening of the lenses by increase in the curvature of the fractures or to the low-dipping joints which intersect them, or else to incomplete development. In some places the "toe-nail structure" enhances the difficulties.

The joints at the 11 quarries in operation have the following courses: About north, N. 25° E., N. 30°-40° E., N. 60°-75° E., about east-west, N. 15°-20° W., N. 30°-45° W., and N. 55°-70° W. The courses noted at the largest number of quarries were: N. 30°-40° E., N. 30°-40° W., N. 60°-75° E., and the east-west ones.

At the Upper Pigeon Hill quarry a compressive strain in all lateral directions results in undulating fractures and binds the chisels in channeling.

The Rockport quarries.—*The Flat Ledge quarry* is half a mile north-northwest of Rockport and 80 feet west of Sandy Bay. (See fig. 13.) Operator, Rockport Granite Company, Rockport, Mass.

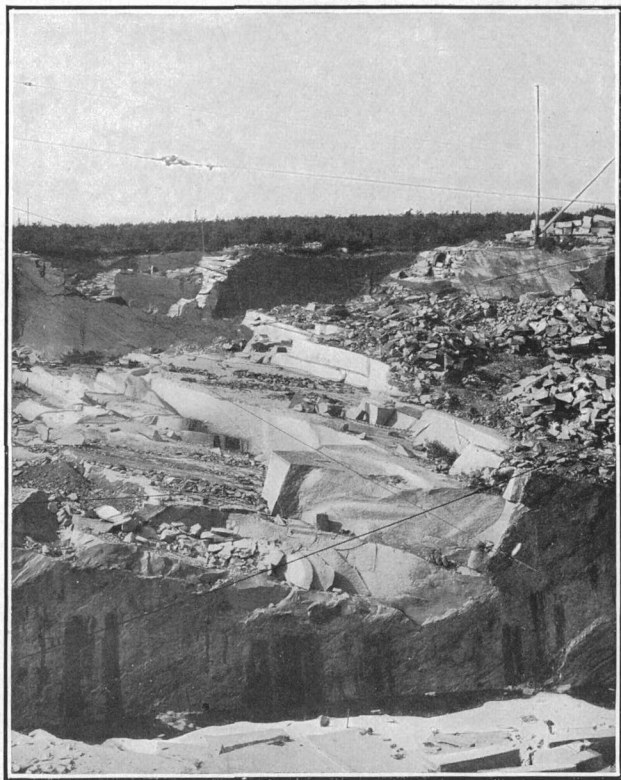
The granite (specimens D, XXVIII, 24, a, f), "Rockport gray," is a hornblende granite of medium-gray shade with a slight bluish-green tinge and inconspicuous black spots. In large masses its general color is bluish gray. Its texture is medium to coarse, even grained, with feldspars up to 0.5 and hornblende to 0.2 inch. Its constituents, in descending order of abundance, are: A light-gray, slightly blue-greenish potash feldspar (orthoclase, some of it twinned, and microcline), minutely intergrown with soda-lime feldspar and somewhat kaolinized; very smoky quartz; black hornblende; and very little separate soda-lime feldspar (oligoclase-albite); together with accessory magnetite, molybdenite, purple fluorite, and zircon; and secondary kaolin and calcite.

Mr. George Steiger, chemist, of the United States Geological Survey, finds that it contains 0.20 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates the presence of 0.35 per cent of CaCO₃ (lime carbonate) calcite.

The stone takes a very high polish and hammers somewhat light.

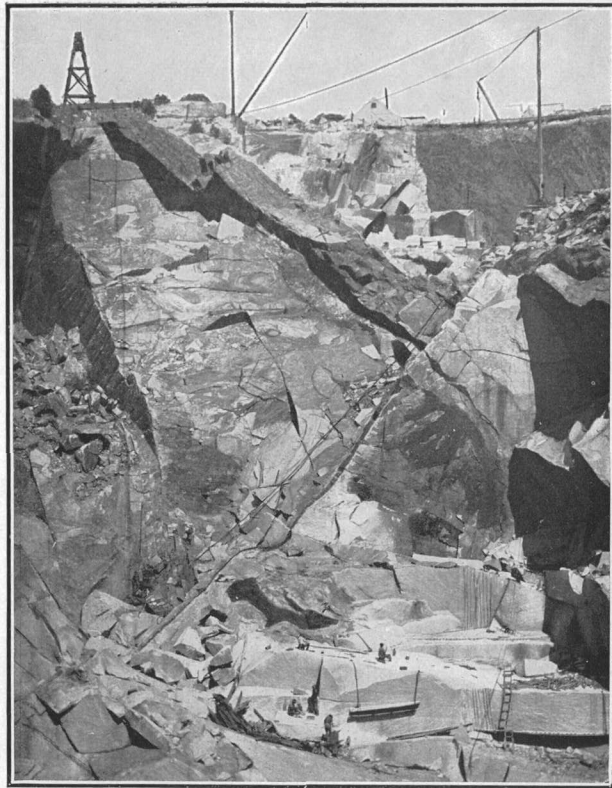
The quarry, opened about 1855, measures about 1,100 feet from northwest to southeast by 1,000 feet across and from 45 to 120 feet in depth, but it is only worked in its northern part.

The sheets, from 6 inches to 30 feet thick, are horizontal in the southern part, dip 25° NW. on the east side, and in the center dip about 20° S. One set of joints, striking N. 15° W. and dipping 65° WSW., is spaced 8 to 15 feet. Another set, striking N. 60° W. and dipping 80° NNE., is spaced 2 to 25 feet. The rift is reported as



A. UPPER QUARRY OF PIGEON HILL GRANITE COMPANY, ROCKPORT, MASS., LOOKING SOUTHWEST.

Showing thick granite sheets intersected by basic dikes. The black streaks in the front dike are underground water from sheet surfaces.



B. DEEP PIT QUARRY OF ROCKPORT GRANITE COMPANY, NEAR BAY VIEW, ON CAPE ANN, MASS., LOOKING NORTH.

Showing in upper part thick faulted dike of hornblende diabase, intersected by a thin dike of lamprophyre without biotite, reaching to bottom at left; also in center, below an irregular injection of hornblende diabase, joint planes, some of which are parallel to big dike.

dipping 20° about S. and the grain as vertical with a N. 15°–20° E. course. A medium-grained pegmatite dike 5 feet thick, striking N. 30° W. and dipping 25° E., consists of potash feldspar (microcline and orthoclase), smoky quartz, soda-lime feldspar (oligoclase to andesine), garnet, and zircon. A coarse-grained dike, not examined microscopically, consists of a cream-colored feldspar, in places bright green, smoky quartz, black and possibly other varieties of mica, and garnets. Basic dikes strike N. 10° E., N. 15° W., and N. 60° W., dipping 40°, 70°, and 90°. The discolored granite adjacent to one of these was examined and has been described on page 125. Rusty stain, from one-fourth to 2 inches thick, is very abundant and bright, particularly along the joint faces. (See pp. 57, 125.)

The equipment of the quarry, combined with that of the adjoining "upper pit" quarry of same firm, will be found on page 128.

Transportation is effected by means of an 800-foot track to cutting shed and wharf.

The lower story of the Providence, R. I., post-office is made of stone from this quarry. Paving and crushed stone and riprap form a considerable part of the product, in tons, of the several quarries operated by this company. In 1905, 32,000 tons of paving blocks and 30,000 tons of riprap were produced, as against 50,000 of rough stone and 12,000 of dressed stone.

The "upper pit" of Rockport Granite Company lies west-southwest of the Flat Ledge quarry, about half a mile northwest of Rockport. (See fig. 13.) Operator, Rockport Granite Company, Rockport, Mass.

The granite, "Rockport gray," is a hornblende granite identical with that of the Flat Ledge quarry. (See p. 126.)

An estimate of the mineral percentages in this stone, made by the Rosiwal method, with half-inch mesh and total linear length of 20 inches, yielded the following results:

Estimated mineral percentages in Rockport gray granite from "upper pit" of Rockport Granite Company.

| | |
|-----------------|--------------|
| Feldspars..... | 55.50 |
| Quartz..... | 38.90 |
| Hornblende..... | 5.60 |
| | <hr/> 100.00 |

The quarry measures about 625 feet from northwest to southeast by 325 feet across, and averages 100 feet in depth, but there is an intermediate opening, 150 by 125 feet, averaging 40 feet in depth.

The sheets, from 4 to 35 feet thick, dip 20° about east. One set of joints strikes N. 30° E., dips 50° W., and is spaced down to 10 feet; another strikes about N. 30° W., dips 30°–50° E., and is spaced down to 5 feet. A third set, in the intermediate opening, strikes

N. 70° E., dips steeply south-southeast, and is spaced 10 to 25 feet. A fourth set, "blind seams," strikes east-west, dips 50° S., recurs at very irregular intervals, and is not stained with limonite. The rift is reported as striking N. 80° W. and dipping 75°-80° S. The grain is probably like that in the Flat Ledge quarry. There are 4 basic dikes on the east and west sides striking N. 15° W. and dipping 70° E., and an 8-foot dike in the smaller opening striking N. 70° W. and dipping steeply north-northeast. A dike of aplite, 4 inches wide, with a border of pegmatite 1 to 2 inches thick with bright green feldspar, strikes N. 55° E. Gray knots measure up to 12 inches.

The combined plants of the "upper pit" and Flat Ledge quarry include 14 derricks, a hoisting engine, 7 large air drills, 25 air plug drills, and 6 steam pumps. Compressed air is furnished by the cutting plant on the wharf.

The cutting plants of the Rockport Granite Company are on the wharf near the Flat Ledge quarry and at Bay View near the other quarries of the company. They comprise 3 "stiff-legged" derricks, one of them with "bull wheel" and a three-drum engine, 3 locomotive cranes, 2 air compressors (capacity 1,400 and 350 cubic feet of air per minute), 10 air plug drills, 6 air hand tools, 6 surfacers, a McDonald surfacers for stones up to 8 feet wide, a set of 6 saws for blocks 20 feet long, 3 stone lathes (one for stones 30 by 3 feet, two for stones 12 feet by 20 inches), 3 polishing lathes for stones of above sizes, 6 vertical polishers, and 4 horizontal polishers; also a stone crusher with a capacity of 200 tons per day.

Transportation is effected by a track of 1,500 feet to wharf.

In 1906 this quarry was furnishing part of the granite for the piers and tower of the Cambridge-Boston bridge over the Charles River, and also for the anchorage of Manhattan Bridge No. 3 on the New York side.

The Pigeon Hill quarry ("lower quarry" of this company) is at the south foot of Pigeon Hill, one-third mile west of the shore and a mile north-northwest of Rockport. (See fig. 13.) Operator, Pigeon Hill Granite Company, Rockport, Mass.

The granite (specimens D, XXVIII, 34, a, b) is a hornblende granite of medium-gray shade with a slight bluish-green tinge and inconspicuous black spots. Its texture is medium to coarse and even grained. In texture, general color, and constituents this stone appears to be identical with that of the Flat Ledge and "upper pit" of the Rockport Granite Company. The only discernible difference is that the Pigeon Hill stone shows less quartz and a slightly lighter shade in the feldspar. The thin sections also show the presence along with the black hornblende of a little blue-black riebeckite (soda hornblende) and of a little biotite (black mica). Allanite, apatite, and pyrite appear also among the accessories. There is some sec-

ondary brown hornblende filling microscopic cracks in the feldspar, also a little secondary hematite and limonite stain. Some cavities of irregular outline in the quartz measure up to 0.02 millimeter, others of oval or roundish form, with liquid and vacuoles, measure up to 0.0043 millimeter.

An estimate of the mineral percentages in this granite, made by the Rosiwal method, with half-inch mesh and a total linear length of 30 inches yields the following results:

Estimated mineral percentages in gray Rockport granite from the Pigeon Hill quarry.

| | |
|-----------------|--------------|
| Feldspars..... | 58.86 |
| Quartz..... | 33.88 |
| Hornblende..... | 7.26 |
| | <hr/> 100.00 |

A chemical analysis of this stone by H. S. Washington is given on page 123. Mr. E. C. Sullivan, chemist, of the United States Geological Survey, finds that it contains 0.14 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates a content of 0.25 per cent of CaCO_3 (lime carbonate), calcite.

The following data as to the compressive, compressed elastic, shearing, and transverse strengths of this granite were obtained by tests made at the United States arsenal at Watertown, Mass., in 1894 from stone quarried during the previous month:

Compressive strength.—Tests Nos. 6871, 6872, 6870, cubes about 4 inches square. First crack at 79,000, 86,000, 94,000 pounds. Ultimate compressive strength in pounds per square inch, 20,716, 20,522, and 17,772. Direction of rift and grain in cubes not given.

Compressed elastic strength.—The block tested measured 24 by 4.01 by 6.06 inches. Weight, 54.5 pounds. Weight per cubic foot, 161.5 pounds. Sectional area, 24.3 inches square. Pressure applied endwise. Under a pressure of 1,000 pounds per square inch the compression in a gauged length of 20 inches was 0.0031 inch. Under 2,000 pounds it ranged from 0.0063 to 0.0078 inch. Under 4,000 pounds it ranged from 0.0116 to 0.0129 inch. Under 6,000 pounds it ranged from 0.0162 to 0.0175 inch. Under 8,000 pounds it ranged from 0.0208 to 0.0209 inch. Under 10,000 pounds from 0.0253 to 0.0258 inch; and under 12,000 pounds it was 0.0297 inch.

Shearing strength.—Dimensions of block 12 by 6 by 4 inches, distance apart of supports 6 inches, width of plunger 5 inches. Tests Nos. 6879, 6880. First tension fractures midway between supports at 45,400 and 38,600 pounds. Shearing fractures developed later near edge of one support. Shearing strength 2,047 and 1,052 pounds per square inch of shearing area.

Transverse strength.—Dimensions of block, length 24, width 6, breadth 4 inches (decimals omitted). Length between end supports 19 inches. Tests Nos. 6882, 6883. Ultimate strength 12,320 and 12,480 pounds per square inch, equaling a modulus of rupture of 2,404 and 2,416, respectively. This was computed by the formula:

$$R = \frac{3}{2} \frac{p}{b d^2}$$

It takes a very high polish and hammers rather light.

The quarry, opened about 1871, measures about 625 feet on the northeast side and 700 feet on the southwest side by 450 to 500 feet across and from 40 to 80 feet in depth.

The sheets, 6 to 10 feet thick, dip northeast about 10° in the northern part of the quarry, but 10° to 30° SE. in the southeastern part. The joint and dike courses are shown in fig. 14. Joints A dip 75° N., are spaced 3 to 10 feet, and abound in the southern part. Joints B dip 55° W., exceptionally 55° E., and are spaced 2 to 20 feet. In the southwestern part the closeness of these joints precludes the quarrying of large blocks. Joints C dip steeply west. The rift is reported as horizontal but feeble, and the grain as vertical with northwest course. Dike *a*, 10 to 12 inches thick, dipping 65° W. and forming the west side of quarry, is a fine-grained diabase consisting of soda-lime feldspar (andesine), hornblende from alteration of augite, magnetite, and black mica. Dike *b*, 18 inches thick,

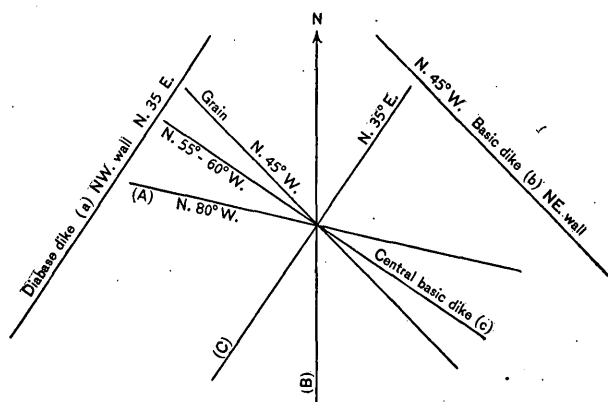


FIG. 14.—Structure at Pigeon Hill quarry, Rockport, Mass.

dipping 75° SW., forms the north wall; and dike *c*, 12 inches thick, dipping 75° WSW., crosses the center of quarry. Knots measure up to 10 by 7 inches and rusty stain up to 6 inches on sheet surfaces.

The plant consists of 3 derricks, a hoisting engine, a large air drill, 3 air plug drills, and a steam pump. The company's cutting plant, which receives material from both of its quarries, comprises 3 derricks, 3 hoisting engines, a locomotive crane, an air compressor (capacity 1,000 cubic feet of air per minute) which supplies both quarries, 5 surfacers, 2 air plug drills, 16 air hand tools, and a stone crusher with a capacity of 160 tons per day.

Transportation is effected by horsepower and an inclined track one-third mile long to wharf.

The product goes chiefly into buildings, but partly into paving and riprap for breakwater use. Specimen structures: The Charlestown, Mass., High School, entire; Bradford Memorial Chapel, at

Gloucester, Mass.; The Chelsea, Mass., viaduct over Boston and Maine Railroad at Mystic Wharf. In 1906 this quarry was furnishing stone for the Union National Bank at Pittsburg.

The *Upper Pigeon Hill quarry* is about a mile northwest of Rockport, and one-third mile southwest of Pigeon Hill. (See fig. 13.) Operator, Pigeon Hill Granite Company, Rockport, Mass.

The granite is a hornblende granite of medium gray shade, with slight bluish-green tinge and inconspicuous black spots. Its texture is medium to coarse and even grained. It is identical in composition with the stone of the lower quarry of this firm described on page 128.

The quarry, opened about 1876, measures about 800 feet in a N. 35° E. direction by 450 feet N. 65° W., and from 50 to 100 feet in depth.

The sheets, from 4 inches to 12 feet thick, dip mainly west as high as 10°. Thin sheets are confined to the upper 20 feet. The sheet

structure is generally regular, as shown in Pl. V, A. Joint and dike courses are given in fig. 15. Set A is vertical and spaced from 7 to 50 feet. Set B dips 20° south, and is spaced 50 feet. Its low inclination confuses the sheet structure in places. Set C dips 55° west, and is spaced 10 to 50 feet. Set D, exceptional and intermittent, dips 75° NE. Set E, also exceptional, dips 75° SSE. The rift is

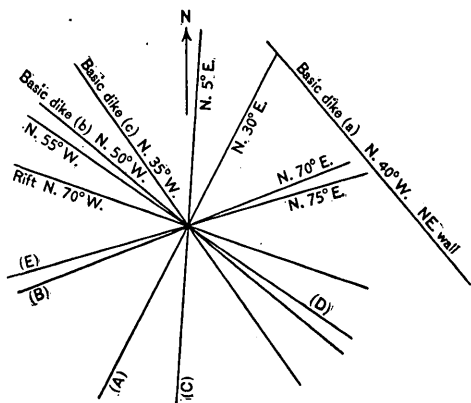


FIG. 15.—Structure at Upper Pigeon Hill quarry, Rockport, Mass.

reported as vertical with N. 70° W. course and the grain as horizontal. There are 3 or more basic dikes from 12 to 18 inches thick: Dike *a* forms the northeast wall; dike *b*, about 350 feet from *a*, dips 80° northeast, and dike *c*, 300 feet southwest of *a*, is vertical. The intersection of the sheets by the central dike is well shown in Pl. V, A. Knots are reported as not over 2 feet, but rarely up to 10 by 5 feet. Rusty stain is from one-half inch to 12 inches thick.

The plant consists of 3 derricks, 3 hoisting engines, 3 large air rock drills, 5 air plug drills, and 3 steam pumps. The cutting plant has been given on page 130.

Transportation is effected by an inclined track of half a mile to the wharf.

The product is used largely in construction. In 1906 some of it was being used, under a subcontract, in the tower on the southeast corner of the Cambridge and Boston bridge over the Charles River.

The Babson Farm quarry is at the north end of the cape, near Halibut Point, $2\frac{1}{2}$ miles north-northwest of Rockport. (See fig. 13.) Operator, Rockport Granite Company, Rockport, Mass.

The granite (specimen D, XXVIII, 25, d) is a hornblende granite of somewhat dark greenish-gray shade. It is markedly darker than the granite of the Flat Ledge and Pigeon Hill quarries. Its texture is medium to coarse, even grained, with feldspars up to 0.5 inch and hornblende up to 0.3 inch. Its constituents, in descending order of abundance, are: Medium greenish-gray potash feldspar (orthoclase) intergrown with soda-lime feldspar, and in places much kaolinized; very smoky quartz with parallel sheets of cavities and abounding in prismatic grayish crystals up to 0.02 millimeter; black hornblende and very little separate soda-lime feldspar (oligoclase-albite). Accessory minerals are: Magnetite, zircon, and apatite. Secondary: Kaolin, limonite, hematite, and chlorite, the last in cracks and isolated particles within the feldspar, also along the boundaries of particles. To this mineral and to the limonite the feldspar owes its greenish tinge.

The quarry, opened about 1897, measures about 350 feet in a north-east direction by 150 feet across and from 40 to 50 feet in depth.

Sheet structure is normal. The sheets, from 4 inches to 15 feet thick, increasing in thickness downward, are horizontal or dip 10° NW. There are 4 sets of joints. Set A, striking N. 40° E., dipping 75° SE. or 90° , spaced 10 to 40 feet, forms the northwest and southeast walls. Set B, striking N. 40° W. and dipping 45° – 50° SW., is spaced 100 to 200 feet. Set C, striking N. 65° W. and vertical, forms the northeast and southwest walls. Set D, striking N. 80° E., and vertical, forms a short heading near the north corner and recurs at rare intervals. The rift is reported as marked and vertical, with N. 50° E. course, and the grain as horizontal. A segregation of uncommon composition, measuring 8 by 4 by $2\frac{1}{2}$ feet, from this quarry is described on page 125. There is some pyrite on the joint faces. Rusty stain from 1 to 6 inches thick occurs along the sheet surfaces.

The plant consists of 5 derricks, 3 hoisting engines, an air compressor (capacity, 550 cubic feet of air per minute), 2 large drills, 10 air plug drills, and 2 steam pumps.

Transportation is effected by cartage of one-fourth mile to wharf, which affords 30 feet of water at low tide.

No buildings constructed of this granite are reported.

The Breakwater quarry is on Folly Point, west of Folly Cove, $2\frac{1}{2}$ miles northwest of Rockport. (See fig. 13.) Operator, Breakwater Construction and Engineering Company, 5 Nassau street, New York.

The granite is a gray hornblende granite, which, because of the use it was being put to, was not specially examined.

The quarry, opened in 1905, measures about 250 feet in a west-north-west direction by 100 feet across and from 5 to 30 feet in depth.

Sheet structure is scarcely perceptible, but the intersecting joints and headings are so numerous as to facilitate quarrying for the purpose in view.

The plant consists of 8 traveling cranes of 10 to 20 tons capacity, an air compressor (capacity, 150 cubic feet of air per minute), 10 steam drills, 1 "stiff-legged derrick," and a rotary engine for loading onto barges.

Transportation is effected by a track of 300 feet to wharf.

The product is riprap for the Rockport breakwater, for the construction of a section of which, measuring 165 feet in length by 150 in width at low-water level, the company had a contract in 1906. The average weight of each block was to be 4,000 pounds and the minimum 200.

The Nickerson quarries are one-fourth mile southeast of Folly Cove, and 2 miles N. 30° W. of Rockport. (See fig. 13.) Operator, W. E. Nickerson, Lanesville, Mass.

The granite, like specimen D, XXVIII, 29, a, from the Devils Rock quarry, described on page 134, is a hornblende granite of medium-gray shade with a slight buff tinge and weak contrasts.

The main quarry, opened in 1896, is triangular, measuring about 350 feet N. 40° W. by 350 feet E. and 400 feet N. 40° E., and up to 25 feet in depth. The other opening measures about 100 by 60 feet and 60 feet in depth.

The sheets from 9 inches to 6 feet thick undulate horizontally. There are 4 sets of joints: Set A, striking nearly east-west and vertical, is spaced 10 to 100 feet. Set B, striking N. 40° E., occurs but exceptionally. Set C, in the smaller pit, striking north and vertical, is spaced 10 to 20 feet. Set D, in the smaller pit, striking N. 30° W. and dipping 70° E., is spaced from 10 feet up. The rift is reported as vertical with east-west course and the grain as horizontal. A vertical diabase dike 6 feet thick, weathering spheroidally, strikes N. 40° W. and forms the northeast wall of the main quarry near the smaller one. Another east of the quarry has a like course. Knots are reported as not exceeding 1 foot in diameter. Rusty stain is 2 inches thick on lower sheets and 9 on the upper ones.

The plant consists of 4 derricks, 3 hoisting engines, a steam drill, and 3 steam pumps.

Transportation involves cartage of one-half mile to Lanesville wharf.

The product consists largely of paving stone, with some "random" stone, and finds a market mostly through the Rockport Granite Company.

The Canney quarry is on the east side of Lanesville, about 2 miles N. 50° W. from Rockport. (See fig. 13.) Operator, Edwin Canney, Pigeon Cove, Mass.

The granite is a hornblende granite of medium gray, not bluish, shade and of medium texture, like that of the "deep pit" of the Rockport Granite Company. (See p. 137.)

The quarry, opened about 1861, measures about 500 feet in a N. 40° E. direction by 400 feet across, and averages 65 feet in depth.

The sheets, from 6 inches to 25 feet thick, increasing in thickness downward, dip about 10° in a general S. 45° W. direction. Joints, striking N. 60° E. and vertical, are spaced 3 to 30 feet. The rift is reported as vertical with N. 25° E. course and the grain as horizontal. Three vertical basic dikes, from 18 to 24 inches thick, strike N. 40° W. One forms the west wall; another is 100 feet east of it, and another 75 feet east of that. Knots up to 5 inches are reported.

The plant consists of 5 derricks, 3 hoisting engines, an air compressor (capacity 470 cubic feet of air per minute), 4 steam pumps, and a stone crusher with a capacity of 100 tons per day.

Transportation is effected by an inclined track of 2,500 feet to wharf when water is smooth, but by cartage to Lanes Cove in rough weather.

The product is mostly paving, with some curbing, flagging, crushed stone, and foundation stones. It goes to Boston, New York, and Philadelphia.

The Devils Rock quarry is about half a mile southeast of Lanesville and about 1½ miles N. 58° W. of Rockport. (See fig. 13.) Operator, William R. Cheves, Lanesville, Mass.

The granite (specimen D, XXVIII, 29, a) is a hornblende granite of general medium gray, not bluish, shade and of medium to coarse, even-grained texture, with feldspars up to 0.4 inch and black hornblende up to 0.3 inch. It consists, in descending order of abundance, of: Light-gray potash feldspar (microcline and orthoclase), from slightly greenish to cream-colored, minutely intergrown with soda-lime feldspar (albite to oligoclase-albite) and somewhat kaolinized; very smoky quartz with cavities; and black hornblende. Accessory: Magnetite, pyrite, zircon, and allanite. Secondary: Kaolin.

The quarry, opened in 1876, measures about 400 by 200 feet and averages about 50 feet in depth.

The sheets, from 1 to 18 feet thick, dip 10° N. There are 3 sets of joints. Set A, striking N. 25° E., dipping 70° E. to 90°, is spaced 3 to 90 feet and forms a heading on the west side. Set B, striking N. 70° W. and dipping 45° to steeply north, is spaced from 1 to 50 and 100 feet and forms a heading on the south side and the wall on the north. Set C, diagonal, striking N. 25° E. and dipping about 65° NW., is spaced 20 feet at the south end, but does not recur. The rift is reported as good, vertical, and with east-west course. There is a 6-inch basic dike on the east side. Gray knots are reported up to 14 by 6 inches. Rusty stain is from 1 to 6 inches thick.

The plant, including that at the green granite quarry of the same firm, comprises 9 derricks, 2 hoisting engines, an air compressor (capacity 560 cubic feet of air per minute), 2 steam drills, 6 air plug drills, and 3 steam pumps.

Transportation involves cartage of a mile to Lanesville wharf, which affords 13 feet of water at high tide.

The product is used for building and paving. In 1906 this firm had a subcontract for material for the naval dry dock at Kittery, Me.

The Cheves Green Granite quarry is about 250 feet south of the Devils Rock quarry and $1\frac{1}{4}$ miles N. 60° W. from Rockport. (See fig. 13.) Operator, William R. Cheves, Lanesville, Mass.

The granite (specimen D, XXVIII, 30, a), "green granite," is a hornblende granite of somewhat dark olive-gray color, spotted with black, and of medium to coarse even-grained texture, with feldspars up to 0.5 inch and hornblende up to 0.3 inch. When first quarried the yellowish-green tint is scarcely perceptible, but after a few hours exposure to rain it becomes marked. Its constituents, in descending order of abundance, are: A medium olive-gray potash feldspar (orthoclase and microcline, much of it twinned), minutely intergrown with soda-lime feldspar (many of the feldspars are much kaolinized and contain minute particles, possibly of an oxide of iron); very smoky quartz with cavities and black particles; some separate soda-lime feldspar (albite to oligoclase-albite); and black hornblende. Accessory: Magnetite, allanite (most of it within hornblende particles), and zircon. Secondary: Calcite, and limonite stain, some of it proceeding radially from allanite particles, also in cracks and along boundaries of particles.

The contrast in this stone, owing to the dark shade of the quartz, is mostly between the feldspar and the combined quartz and hornblende.

The quarry is somewhat triangular in outline, measuring about 200 feet N. 70° W. by 100 to 200 feet across and from 30 to 90 feet in depth.

The sheets are up to 35 feet thick. The joints correspond to sets A and B of the Devil's Rock quarry, and the rift is said to be like the rift of that quarry, but less marked.

The Blood Ledge quarry is three-fifths mile east-northeast of Bay View and 2 miles N. 62° W. of Rockport. (See fig. 13.) Operator, Rockport Granite Company, Rockport, Mass.

The granite (specimens D, XXVIII, 28, b, e), "Bay View green," is a hornblende granite of general somewhat dark olive-gray color, with black spots, and of medium to coarse, even-grained texture, with feldspar up to 0.5 inch and hornblende up to 0.2 inch. Its constituents, in descending order of abundance, are: A more or less kaolinized medium olive-gray potash feldspar (orthoclase and micro-

dips 50° west. Set C dips 30° north. Set D, dipping 90° or steeply south, forms the short south wall and recurs intersecting the north wall. The rift is reported as vertical with a N. 85° W. course, and the grain as also vertical and about north-south. The stone is said to split most readily from the ends of the blocks, both along rift and grain. The basic dike, shown in fig. 16, is 2 feet thick and dips 70° southwest. Dark knots a few inches in diameter were collected, but they are reported as occurring up to the size of half a barrel. Rusty stain is up to 3 inches thick on sheet faces.

The plant consists of 6 derricks, 4 hoisting engines, 3 steam drills, and 2 steam pumps.

Transportation is effected by a locomotive (p. 139) and track about 1 mile long to the wharf at Bay View.

The product is used for buildings, monuments, docks, and paving. Specimen structures: Of gray granite, the first story (outside) of Suffolk County court-house, Boston. Six polished columns and two pilasters in the Madison Square Presbyterian Church, New York. Of green granite, the base of the General Logan monument in Chicago.

The "Deep Pit" is about one-fifth mile from tidewater at Bay View, on the west side of the Cape, 2½ miles N. 73° W. of Rockport. (See fig. 13.) Operator, Rockport Granite Company, Rockport, Mass.

The granite (specimens D, XXVIII, 27, a, b), "Bay View gray," is a hornblende granite of medium-gray shade (lighter than 25, d, Babson quarry, p. 132, and darker than 24, a, 34, a, and 29, a, Flat Ledge, Pigeon Hill, and Cheves quarries, pp. 126, 128, 134), with a slight cream and greenish tinge, spotted with black. Its texture is medium even grained, with feldspars up to 0.4 and hornblende up to 0.3 inch. Its constituents, in descending order of abundance, are a cream-colored and pale-greenish, more or less kaolinized potash feldspar (orthoclase and microcline, mostly twinned) minutely intergrown with soda-lime feldspar; very smoky quartz with cavities; a little separate soda-lime feldspar (oligoclase-albite), and black hornblende. Accessory: Magnetite, zircon, and allanite. Secondary: Kaolin, chlorite, calcite, and hematite and limonite stain. The colors of feldspar are evidently due to the chlorite and limonite.

An estimate of the mineral percentages in this granite, by the Rosiwal method, with half-inch mesh and total linear length of 20 inches, yields the following results:

Estimated mineral percentages in Bay View gray granite, Rockport, Mass.

| | |
|-----------------|--------------|
| Feldspar..... | 59.60 |
| Quartz..... | 34.70 |
| Hornblende..... | 5.70 |
| | <hr/> 100.00 |

This granite takes a very high polish. In the rough its contrasts are less marked than those of the Flat Ledge and Pigeon Hill stone, and the color of the feldspar is different, but the contrasts are more marked on the polished face owing to the lighter shade of the feldspar.

The quarry, opened about 1848, measures about 800 feet N. 20° W. by 500 feet across, but owing to a recess its actual area is about 750 by 500 feet. Its depth is from 60 to 150 feet. A diagonal view of this quarry is given in Pl. V, *B*, and a rough plan of it in fig. 17.

The sheet structure is hardly perceptible, but at the south end seems to dip 20° E., and at the northeast corner to undulate horizontally. In the absence of sheets horizontal channeling has to be resorted to. Steeply downward curving partings, "toe nails," are conspicuous in the central part. Joint and dike courses are shown in fig. 17.

There are 5 sets of joints: Set A is vertical. Set B dips 60° E.

Set C dips 55° northeast.

Set D is vertical. The rift

is reported as vertical with

N. 85° W. course, and the

grain as horizontal. The

stone is said to split read-

ily from the top. There

are 5 basic dikes. The

central one, *a*, of horn-

blende diabase (soda-lime

feldspar—andesine—

micacized, augite, horn-

blende, magnetite, and

black mica—biotite), from

12 to 18 feet thick, and dip-

ping 55°–60° NE., crosses

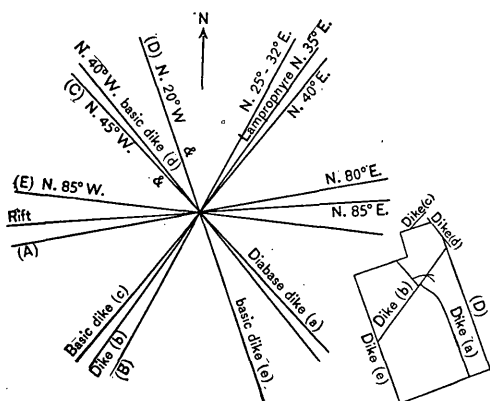


FIG. 17.—Structure and plan of Deep Pit quarry, near Bay View, Mass.

the quarry diagonally, but with marked curvature, from N. 20°–45° W., and is also faulted along dike *b* with a lateral displacement of about 15 feet. Both of these dikes and the fault are shown in Pl. V, *B*. Dike *b*, a lamprophyre without biotite (soda-lime feldspar—andesine—altered to white mica, zoisite, and epidote, also with hornblende, augite, and magnetite) is 18 inches thick and dips 55° WNW. Dikes *c*, *d*, and *e* are vertical. In the northern part a small branching and curved basic dike intersects and branches off from dike *a*. The relations of these dikes are shown in fig. 17. In about the center of the quarry at a depth of 125 feet is an irregular mass of injected hornblende diabase, more fully described on page 50, and also shown in Pl. V, *B*, and fig. 2, which is probably connected more or less remotely with dike *a*. Rusty stain along sheet surfaces measures up to 6 inches in thickness.

The plant comprises 4 derricks, 4 hoisting engines, a Blondin carrier, a locomotive, an air compressor (capacity 1,750 cubic feet of air per minute), which supplies this and the Blood Ledge quarry, 2 steam drills, and 2 steam pumps.

Transportation is effected by a half-mile track to the wharf at Bay View, which affords 15½ feet of water at low tide.

Specimen structures: The Boston and Baltimore post-offices.

The Bay View dark-granite prospect is between the Blood Ledge quarry and the "Deep Pit" near Bay View, and was opened by the Rockport Granite Company, of Rockport, Mass. It may be in the small area of augite syenite shown on Sears's geologic map of Essex County.^a

The granite (specimens D., XXVIII, 28½, a, b) is a riebeckite-ægirite-biotite granite of dark brownish gray color and medium to coarse, even-grained texture, with feldspars up to 0.5 inch in diameter. It consists, in descending order of abundance, of a brownish gray potash feldspar (orthoclase and microcline), somewhat kaolinized, mostly in twins and minutely intergrown with soda-lime feldspar; slightly smoky quartz; brownish gray soda-lime feldspar (albite to oligoclase-albite); blue-black riebeckite (soda-hornblende) and green-black ægirite (soda-augite), and black mica. The accessory minerals are: Magnetite, allanite, zircon, fluorite, and apatite; the first three are somewhat abundant. Secondary calcite is present in small amount and a little limonite stain occurs to which the feldspars owe their brownish tinge. They also contain minute particles of all the black silicates.

This rock takes a very high polish and hammers rather light. The quartz and feldspar being of about one shade, the only contrast on the polished face is between these and the black silicates. On the rough face the contrast is slight.

Rockport porphyry.—The Pigeon Cove diabase porphyry prospect is on a dike of altered diabase porphyry, 18 feet wide, which was represented by Shaler^b and Tarr as exposed for half a mile on the hillock west of Pigeon Cove, with a N. 21° W. course, also as reappearing in Rockport three-fourths mile west of Gap Head with a N. 9° W. course. Washington^c refers to this dike as cutting the quarry pit at Pigeon Cove, and describes it microscopically as a labradorite porphyry.

Fuller, Foley & Co., of West Quincy, Mass., have quarried a few carloads of this rock and have made a polished ball of it, 2 feet 7 inches in diameter, mounted on a cubical base. Fig. 18 was prepared from a photograph of it taken by the writer.

This diabase porphyry (specimens D, XXIX, 89, a, b) has a very dark green or black fine-grained groundmass, with porphyritic feld-

^a Sears, J. H., The physical geography, geology, mineralogy, and paleontology of Essex County, Mass., Essex Institute, Salem, Mass., 1905.

^b Shaler, N. S., The geology of Cape Ann, Mass.: Ninth Ann. Rept. U. S. Geol. Survey, 1889, p. 609, Pl. 77.

^c Washington, H. S., The petrographical province of Essex County, Mass.: Jour. Geol., vol. 7 (3) p. 200.

spars of medium greenish gray color, measuring from 0.2 to 4.42 inches in length by about 0.78 inch in width. Many of the crystals are from 1 to 2 inches long. Their striation shows plainly. Fig. 18 shows the general character of the rock. The groundmass consists of the following minerals, in descending order of abundance: Lime-soda feldspar (andesine-labradorite) partly micacized, augite largely altered to a green hornblende and chlorite, biotite (black mica), magnetite, and apatite. Rarely a little secondary calcite.

This rock takes a very high polish and the contrast between the black groundmass and the large pale-greenish crystals is most striking.

BECKET (CHESTER).

Topography.—The town of Becket is on the southern continuation of the Green Mountain range in the east-central part of Berkshire County, Mass. The range attains thereabouts elevations of 1,750 and 1,845 feet, but is deeply cut by south-southeasterly valleys, through which flow the branches of Westfield River, and by minor north-south and east-west hollows tributary to those valleys.

General geology.—The geology of the region has been described by Emerson,^a and will appear in a revised form in the forthcoming Housatonic folio of the United States Geological Survey. There is a long north-south area of so-called Becket gneiss, which is of pre-Cambrian age. In some places,

as at the quarry, to be described, it is a true granite, which has undergone only a very slight textural change. East of it lies a belt of marine sediments, now called Ordovician by Emerson, once clayey but afterwards metamorphosed into mica schist. The granite at the quarry contains a large inclusion of somewhat coarse muscovite-biotite garnetiferous gneiss. It is also overlain by or incloses a considerable mass of a black schistose quartz-mica diorite, containing both potash and soda-lime feldspar, along the contact with which the granite has a banded flow structure. It is, therefore, evident that the granite of Becket is more recent than these two rocks; in other words there were gneisses (probably of granitic origin) and schists (originally quartz-mica

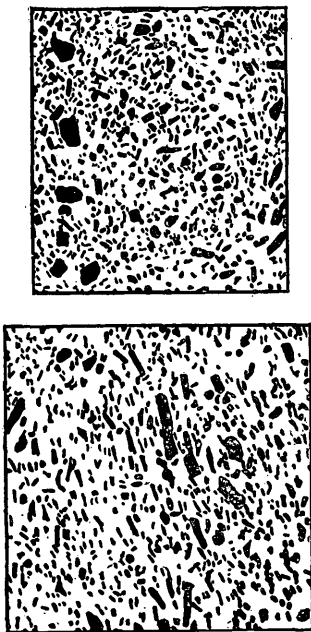


FIG. 18.—Labradorite feldspars in polished surfaces of diabase porphyry from the dike at Pigeon Cove on Cape Ann, Mass., one-thirteenth natural size. The largest crystal is 4.4 inches long.

^a Emerson, B. K., Geology of eastern Berkshire County, Mass: Bull. U. S. Geol. Survey No. 159, 1899, Pl. IX, pp. 75, 99.

diorite) in this region before the intrusion of the Becket granite. The diorite schist once overlay the surface of the granite and, either alone or with other rocks, possessed a considerable thickness. The granite of the Becket quarry has been described by Kemp and Emerson.^a

The quarry.—The Hudson and Chester Granite quarry is in the town of Becket, 1,400 feet above sea level, $6\frac{3}{4}$ miles southeast of Becket village, in Berkshire County, Mass., and $2\frac{3}{4}$ miles ($3\frac{1}{2}$ by road) southwest of the village of Chester, on the Boston and Albany Railroad, in the town of Chester in Hampden County. (See the Becket, Chesterfield and Housatonic topographic sheets of the Geological Survey.) Operator, Hudson & Chester Granite Company, Chester, Mass.

The granite (specimens D, XXIX, 91, f, g, k), "Chester dark" and "Chester light," is a muscovite-biotite granite of medium inclining to dark bluish gray, to medium bluish gray color and of fine texture with feldspars up to 0.15 inch and mica in very fine particles. The texture of this granite is neither exactly gneissoid, porphyritic, nor even grained. In thin section the coarser particles of quartz and feldspar are seen to lie in a somewhat micaceous matrix of very fine texture, and there is not a little granulation about the feldspars. The average diameter of the particles of this matrix, estimated by the Rosiwal method, is less than 0.005 inch, which is finer than the finest Westerly granite (p. 192), although the stone as a whole is coarser textured than that. Its constituents, in descending order of abundance, are: Light bluish-gray potash feldspar (microcline, rarely orthoclase); slightly bluish quartz, with sheets of cavities (up to 0.02 millimeter in diameter) in two rectangular directions with brightly polarizing rift and grain cracks parallel to them; light bluish gray soda-lime feldspar (oligoclase-albite); white mica (muscovite); and black mica (biotite). The only difference between the dark and light varieties is in the percentage of the black mica. The accessory minerals are: Titanite, pyrite, ilmenite, allanite, fluorite, apatite, and zircon. The secondary: Muscovite, carbonate, and epidote (as rim about allanite). The amount of titanite is relatively large.

An estimate of the mineral percentages in this granite, by the application of the Rosiwal method to a camera lucida drawing of a thin section enlarged 37 diameters, with a mesh of 1.2 inch and a total linear length of 25.85 inches, yields the following results:

Estimated mineral percentages in Becket, Mass., granite.

| | |
|--|--------------|
| Quartz | 49.35 |
| Potash feldspar (orthoclase 17.05, microcline 11.50) | 28.55 |
| Soda-lime feldspar (oligoclase-albite) | 15.37 |
| Mica (muscovite, 4.10, biotite, 2.47) | 6.57 |
| Titanite | .16 |
| | <hr/> 100.00 |

^a Kemp, J. F., On the granite quarried at Chester, Mass.: Trans. N. Y. Acad. Sci. vol. 11, 1891-2, pp. 129-130. Emerson, B. K., Geology of Old Hampden County, Mass.: Mon. U. S. Geol. Survey, vol. 29, 1898, pp. 33, 34, 36-38; and Bulletin No. 159, pp. 75, 99.

The following analysis, by Prof. L. M. Dennis of Cornell University, is quoted by Kemp.^a

Analysis of Becket, Mass., granite.

| | |
|--|--------|
| SiO ₂ (silica)..... | 69.465 |
| Al ₂ O ₃ (alumina)..... | 17.50 |
| Fe ₂ O ₃ (iron sesquioxide)..... | 2.30 |
| CaO (lime)..... | 2.57 |
| MgO (magnesia)..... | .305 |
| K ₂ O (potash)..... | 4.07 |
| Na ₂ O (soda by difference)..... | 2.93 |
| H ₂ O (water at 110°)..... | .08 |
| Loss on ignition..... | .74 |

99.960

Specific gravity 2.684 to 2.688.

Mr. George Steiger, chemist of the United States Geological Survey, finds that this granite contains 0.53 per cent of CaO (lime), soluble in hot dilute acetic acid, which indicates a content of 0.94 per cent of CaCO₃ (lime carbonate), the presence of which carbonate is also shown by the microscope and by a slight effervescence with cold dilute muriatic acid.

Professor Kemp^a states that a cube of this stone was tested at Columbia University by boiling in dilute muriatic acid (1 part of HCl of specific gravity 1.20 to 20 parts of H₂O) for 5 hours, when it was found to have lost 0.59 per cent in weight. Another boiled for the same length of time in dilute sulphuric acid (1 part of H₂SO₄ of specific gravity 1.84 to 20 parts of H₂O) gave a loss of 0.48 per cent.

Absorption and crushing tests, made at the same time and place, yielded the following results: Four cubes of specific gravities, 2.688, 2.687, 2.684, and 2.688, after 3 weeks' soaking, absorbed 0.0021, 0.0021, 0.00224 and 0.0026 per cent. The crushing test was applied to five cubes, which showed a crushing strength per square inch ranging from 25,350 to 28,841 pounds.

The stone takes a fair polish and hammers somewhat light. The fineness of the particles precludes any marked contrast. Feldspar and quartz appear light gray, and the mica, black, producing a fine mottling.

The quarry, opened in 1886, measures about 600 feet east-west by 100 feet across and from 50 to 100 in depth.

The sheets are normal lenticular and horizontal, becoming thicker downward and measuring 6 inches to 30 feet in thickness, but there is some irregularity in this increase in different parts of the quarry. There are two sets of joints. Those of set A strike N. 10° E., dip 30° to 35° W., and are spaced from 18 inches to 20 feet. They are intermittent and have a thin coat of discoloration, the microscopic character of which is described on page 61. Those of set B strike N. 80°

^a Loc. cit.

W., are vertical, and are spaced 10 to 25 feet, exceptionally curved so as to dip as low as 55° W. On the north side a mass of fine-grained, heavy, hard, black schist, 40 feet thick, overlies the granite. It is traversed by horizontal and vertical quartz veins, the latter taking their rise at the contact with granite and tapering upward. Emerson^a represents this mass as also overlain by the granite at one end, but that part had probably been quarried away before the writer's visit in 1906. A thin section of this rock, crossing also a tortuous white veinlet, is found to consist, in descending order of abundance, of: Quartz, with sheets of cavities and rift cracks parallel to them polarizing brightly; black mica; potash feldspar (microcline); soda-lime feldspar (oligoclase); muscovite, and hornblende. The accessory minerals are: Ilmenite, titanite, pyrite, apatite, and zircon. The secondary: Epidote, carbonate, and limonite. The white veinlets are mainly quartz and soda-lime feldspar. This rock thus appears to be a quartz-mica diorite schist, but with potash feldspar apparently exceeding the soda-lime. It is an eruptive rock made schistose by pressure before the intrusion of the granite, and probably formed part of the original cover into which granite was intruded. That the granite is the later rock is evident because of the marked flow structure which, for a space of 2 feet below the diorite schist, runs parallel to the contact surface, as has been observed in some New Hampshire quarries (p. 62). This flow structure consists of parallel white bands from 0.1 to 0.3 inch wide, recurring at intervals of 1 inch. The gray granite between these light bands is darker than that beyond them. A thin section of one of these bands shows it to consist of quartz and feldspar, the quartz with many sheets of cavities up to 0.03 inch, and with rift cracks parallel to them. In the darker bands biotite, epidote, titanite, and muscovite are very abundant. At the northeast corner the flowage bands have very sinuous courses, the rock taking on the appearance of a true gneiss. On the west side the flow structure, shown by a band of lighter granite 2 feet thick, strikes N. 55° E., and dips 40° SE. At the northwest corner, several feet below the granite surface, is an inclusion, 10 by 8 feet, of coarse garnetiferous muscovite-biotite gneiss with accessory magnetite, apatite, and zircon. It is a very different rock from either the granite or the diorite schist, and was evidently broken off from some overlying or adjacent formation during the granite intrusion and inclosed by the molten matter.

The rift is reported as dipping about 20° W. and the grain as vertical with a N. 10° E. course.

At the northwest corner there is a pegmatite dike (feldspar and quartz, coarse) up to 2 feet thick, with a northwest course. In thin section the feldspar is orthoclase with fissures from 0.37 to 1.85

^a Bull. U. S. Geol. Survey No. 159, fig. 16, p. 75.

millimeters wide, filled with fragments of microcline and quartz and stringers of white mica. It has evidently been subjected to pressure and some metamorphism.

Rusty stain along the sheet surfaces is from 3 to 12 inches thick.

The plant, including the cutting machinery at Chester, comprises 7 derricks, 6 hoisting engines, a Blondin carrier and engine, 2 overhead cranes (capacity 4 tons), 2 air compressors (capacity 500 and 150 cubic feet of air per minute), 4 large drills, 14 air plug drills, 8 air hand tools, a surfacer, 4 vertical polishers, and a steam pump.

Transportation is effected by the Chester and Becket Railroad, a branch of the Boston and Albany, which connects the quarry through Walker Brook hollow with the main line at Chester, a distance of $3\frac{1}{2}$ miles. The rough stone is shipped direct from the quarry; the rest is taken to the cutting shed at Chester and reshipped there. The granite thus comes to be known as Chester granite although the quarry is in Becket.

The product is used mostly for monuments and finds its chief markets in Pennsylvania, New York, and Michigan. Specimens: Doctor Hoover monument at Chambersburg, and the McCormack monument at Pittsburg, Pa., and the W. A. Harder monument at Hudson, N. Y.

NEW HAMPSHIRE.

GENERAL STATEMENT.

Some of the New Hampshire granite quarries to be described are near Concord, in Merrimac County, and Milford, in Hillsboro County, which are both in the Merrimac River basin in the southern part of the State. The rest are near Conway, on the south side of the White Mountain region, in the east-central part of the State. (See map, Pl. I.) The Concord and Milford quarries are in an area designated by Prof. C. H. Hitchcock "Lake Winnepesaukee gneiss," which on his geological map has a northeast to southwest trend, and is dovetailed both on the northeast and the southwest into a schist formation designated "Rockingham schists," which he regarded as forming the base of the Cambrian. Both the Concord and the Milford granite carry inclusions of gneiss, but the relations of these to the Rockingham schists is as yet undetermined. Some gneisses which cap the Milford granite are evidently of igneous origin, so can not be the Rockingham schists. The Conway quarries are in an area of granite designated on the same map "Conway granite," which measures about 35 by 20 miles and extends from the Franconia Mountains on the west to Conway on the east, and from the foot of Mount Washington on the north to Mount Chocorua on the south.^a

^a See Hitchcock, C. H., *The geology of New Hampshire*, Concord, 1878, Atlas. Also *The geology of northern New England*, printed by the author, apparently between 1885 and 1892. New Hampshire map is dated 1877.

The Auburn and Sunapee quarries were not visited, but the granite from these localities will be found described on pages 186, 187.

CONCORD.

Topography.—The Concord quarries are on the east side and top of a north-south ridge known as Rattlesnake Hill, which is said to attain an elevation of 580 feet above the high-water mark of Merri-mac River; and they lie within a radius of $1\frac{1}{2}$ to 2 miles from about N. 25° W. to N. 50° W. of the statehouse. Some of them are at the foot of the ridge on North State street at about the level of the city; others are from 70 to 360 feet above it.

Geology of the quarries.—The salient geological feature is the occurrence here and there within the granite of inclusions of coarse and fine banded gneisses measuring from a few inches to 30 feet in diameter. The largest of these (see page 153) is a bright, dark biotite-muscovite gneiss with fine bands of varying shades, according to the proportions of the micas or of the quartz and feldspar. Its feldspar is a soda-lime (oligoclase-albite to oligoclase), and the accessory minerals are garnet, zircon, apatite, etc. Others again are biotite gneisses and consist of alternating bands of very light feldspathic quartzose rock and of dark, coarse, very fine micaceous schist, the particles of the latter not exceeding 0.02 inch. The geological age of these gneisses is uncertain. The pegmatite dike which traverses this large inclusion seems, from its relation to the granite, to have been formed before the block was surrounded by granite. Of general interest is also the occurrence of fluorite on joint faces, referred to on page 61, which implies deep-seated origin of the solutions out of which it crystallized, and raises the question as to whether the associated calcite and quartz may not have come from the same source.

Joint planes at the Concord quarries divide themselves into 8 sets, of which those occurring at the largest number of quarries strike N. 15° E., N. 20° – 30° E., N. 60° – 65° E., and N. 60° – 75° W. Of less frequent occurrence are those striking N. 10° W., N. 45° W., N. 80° E. and E.-W. The number and variety of fractures within one of the headings at the Granite Railway quarry indicate the localization and sharpness of the strain which produced the heading.

Flow structure appears at only one quarry, where it is vertical with a N. 60° W. course. The rift is reported as either horizontal or inclined from 5° to 15° (N. 65° , 75° W., S. 45° W.), and the grain as vertical with east-west course, but exceptionally N. 45° E., N. 70° E., N. 80° W. The effect of heat and cold on the quality of rift and grain is recognized, and also the fact that the degree of dip of rift is affected by the direction in which the sheet is split. If the splitting is done from the north or south the rift will prove horizontal, but if

from the west it will be inclined. Whether the east-west compressive strain which affects Rattlesnake Hill has anything to do with this deflection is uncertain.

There are pegmatite dikes with courses of N. 30° E., N. 45° E., N. 45° W., and N. 85° W. and segregations of very fine porphyritic granite. (See p. 155.)

Description of Concord granite.—The following combines all the more detailed descriptions of rough and polished specimens and thin sections given on pages 147–156.

“Concord granite” is a muscovite-biotite granite of medium bluish gray color. The significance of the term “medium gray” becomes apparent upon comparing the terms applied to the principal light granites of New England. Hallowell, Me., granite is *light gray*; the “white granite” of North Jay, Me., is *very light gray*; and the granite of Bethel, Vt., is *white mottled with gray*. The general shades of these light or whitish granites forms a descending series in which Concord granite stands fourth, the granite of Bethel, Vt., being the lightest. The texture of Concord granite is fine to medium, somewhat porphyritic, with sparse, slender, isolated feldspars up to 0.5 inch. Although the micas occur in very minute particles, especially the biotite, they measure up to 0.2 inch and exceptionally 0.4 inch. Its constituents, in descending order of abundance, are: Slightly bluish, translucent potash feldspar (microcline, usually in longish twins, and some orthoclase), inclosing particles of quartz and of soda-lime feldspar (in some specimens these minerals with biotite are zonally arranged within a crystal of feldspar); clear to pale amethystine quartz with hairlike crystals, probably of rutile, and with cavities in sheets which in some sections are parallel; milk-white, striated soda-lime feldspar (oligoclase-albite) more or less kaolinized and centrally micacized; white potash mica (muscovite); and black mica (biotite) some of it chloritized, generally in smaller scales than the muscovite. In some cases the mica plates have their flat sides parallel to the rift direction; in some the biotite appears to predominate over the muscovite, possibly owing to the different alignment of its scales. The accessory minerals are: Magnetite, apatite, zircon (some in doubly terminated slender prisms), and rutile. Purple and white fluorite occurs here and there on and near joint planes. Calcite and quartz are associated with it on these joints. The secondary minerals are: Kaolin, muscovite, in veinlets, a white mica without potash, chlorite, and calcite.^a

There is so much irregularity in the dimensions of the particles of this granite that the Rosiwal method of determining the mineral percentages was not practicable.

^a A microscopic description of Concord granite by G. W. Hawes will be found in his *Mineralogy and lithology of New Hampshire*, which forms vol. 3, pt. 4, of C. H. Hitchcock's *Geology of New Hampshire*, 1878.

But one chemical analysis of Concord granite is available. That is given on page 150. The specific gravity of the stone was determined by Crosby as 2.64 and 2.65, averaging 2.65, or 155.6 pounds per cubic foot.

Messrs. Steiger and Schaller, chemists, of the United States Geological Survey, find as the result of two tests that Concord granite contains from 0.15 to 0.17 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates a content of from 0.26 to 0.30 per cent of CaCO_3 (lime carbonate), and the microscope also shows the presence of carbonate.

Two tests of compressive strength, made at the United States arsenal at Watertown, Mass., show a compressive strength of 30,830 pounds per square inch with pressure applied at right angles to rift, and of 23,860 pounds when applied parallel to it. There is thus a loss of $12\frac{1}{2}$ per cent of compressive strength in the rift direction. A more recent test made at the same place gave this stone a compressive strength of 23,670 pounds, direction of rift and grain not stated.

The polish of Concord granite is fair, but the abundant mica plates and the size of some of them do not favor the durability of the polish under long-continued outdoor exposure. The muscovite appears much darker when polished. No pyrite was detected in the polished specimens or thin sections, although the chemical analysis indicates its probable presence. There is considerable contrast between the rough and hammered faces. Its general bluish cast is marked particularly on the polished face, but the rough face becomes lighter on continued exposure. There is some variation in the amount of mica apparent on the different faces of a block, as well as a difference in the actual amount of black mica and in the sparseness of the large feldspars in the stone from different quarries. Only on close inspection do strong contrasts appear between the bright muscovite plates, the fine black biotite scales, and the glassy feldspar.

The Concord quarries.—*The New England Granite Works quarry* is in the upper part of Rattlesnake Hill, roughly northwest of Concord. Operator, The New England Granite Works, 20 Ferry street, Concord, N. H.

The granite (specimens D, XXVIII, 39, a, b, f, g), "Concord granite," is a muscovite-biotite granite of medium bluish-gray color, and fine to medium, somewhat porphyritic texture, with sparsely disseminated larger feldspars up to 0.4 inch (exceptionally 0.5 inch), and micas, from very minute size up to 0.2 inch (exceptionally 0.4 inch). It consists, in descending order of abundance, of a slightly bluish translucent potash feldspar (microcline, mostly in long twins, less orthoclase), inclosing quartz and soda-lime feldspar particles; clear to faintly amethystine quartz with abundant hairlike crystals, probably of rutile, also with sheets of cavities; milk-white more or

less kaolinized and micacized soda-lime feldspar (oligoclase-albite) containing rare particles of carbonate, probably calcite; white potash mica (muscovite); and black mica (biotite), mostly in smaller scales than the muscovite or with their flat sides at right angles to the muscovite scales. The accessory minerals are: Magnetite (some within biotite); apatite, zircon, and rutile. The secondary are: Kaolin, muscovite in veinlets, white mica without potash, and calcite.

Mr. George Steiger, chemist, of the United States Geological Survey, finds that this granite contains 0.15 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates a content of 0.26 per cent of CaCO_3 (lime carbonate), the presence of which carbonate is also indicated by the microscope.

A test of the compressive strength of this granite, made at the United States arsenal at Watertown in 1907, gave the following results: A cube of approximately 2-inch edge showed the first crack at 86,000 pounds and was crushed at 94,200 pounds, thus having an ultimate compressive strength of 23,670 pounds per square inch. It does not appear whether the pressure was applied in the rift or grain direction.

The granite of this quarry appears to be more biotitic and to have its larger feldspars more sparse than the stone of the other Concord quarries.

The quarry, opened in 1812, is about 350 feet from northeast to southwest by 300 feet across and has a working face on the southwest 130 feet in height.

The sheets range from 6 inches thick in the upper 30 feet of the working face to 40 feet at the bottom, and dip from 10° to 15° SE. Some of the sheets, owing to their freedom from rusty discoloration, are regarded by the foremen as of recent origin and are called "strain sheets;" and even now a northwest-southeast compressive strain occasionally extends these sheets.^a

There are two sets of joints: Set A, striking N. 62° E. and vertical, forms headings on the northwest and southeast sides and recurs in the middle, but is apt to be discontinuous. Set B, striking N. 45° W. and dipping 35° NE., is represented by only two on the northwest wall which are 5 feet apart. The rift is reported as horizontal and the grain as vertical and exactly east-west. Two 6-inch pegmatite dikes, 20 feet apart, and several an inch thick, traverse the quarry vertically with a N. 30° E. course. The thick ones are banded, consisting of a central $1\frac{1}{2}$ - to 2-inch band of aplitic material with a half-inch border on one or both sides made up of coarse pegmatite, milk-white oligoclase and microcline, and smoky quartz. Very fine garnets occur throughout these dikes, some in bands, and here and

^a See p. 28.

there a small beryl. There are also half-inch muscovitic veins, "sand streaks" (p. 51), striking N. 45° W., and consisting of a central band of muscovite and quartz, with borders of quartz and feldspar. Gray and black knots of the micas measure up to 6 by 5 inches. Light rusty stain measures from 6 inches to 2 feet on the sheet surfaces, but for 100 feet vertically in the center of the quarry the sheets have little or none of it.

The plant, including the cutting machinery at the company's sheds in Concord, comprises 6 derricks, 6 hoisting engines, 4 overhead electric traveling cranes (capacity 15 and 20 tons), 4 air compressors (capacity three of 750, one of 500, cubic feet of air per minute), belt driven from a dynamo, 4 large rock drills, 15 air plug drills, 24 air hand tools, 8 surfacers, a stone saw (Lincoln patent with Hawley sand feed) for blocks 15 feet long, 4 stone lathes (2 for stones 20 and 23 feet long, and 2 for balusters), and 3 steam pumps.

Transportation is effected by cartage of about five-eighths mile to a siding of the Boston and Maine Railroad, but the laying of a gravity track was in contemplation in 1906.

The product consists mainly of building stone. Thin sheets and waste furnish about 100,000 paving blocks per annum as a by-product. Specimen structures: The four outer walls and the covered driveway of the Congressional Library, the outside and inner court walls of the basement of the United States Senate Office Building; Blackstone Library, Chicago; German Savings Bank and Christian Science Church in New York; Camden County court-house, at Camden, N. J.; German-American Savings Bank, at Pittsburg, Pa.; Manufacturers and Traders' Bank, at Buffalo, N. Y.; Assabet River bridge, Northboro, Mass., and Early Settlers monument, at Galveston, Tex.

The Granite Railway quarry (of Concord) or Upper Swenson quarry^a is on Rattlesnake Hill, about N. 40° W. from the statehouse at Concord and 260 feet above it. Operator, John Swenson, Concord, N. H.

The granite (specimens D, XXVIII, 40, c, e), "Concord granite," is a muscovite-biotite granite of medium bluish gray color and fine to medium somewhat porphyritic texture, with feldspars up to 0.5 and mica plates to 0.2 inch. Feldspar appears to be relatively more abundant and biotite less so than in the stone of the New England Granite Works quarry (p. 147). In other respects the two granites are identical. A section cut at right angles to the rift shows that the mica plates, both black and white, lie with their flat sides parallel to the rift.

The following analysis of this granite was made by Sherman and Edwards, chemists, from a "thoroughly composite sample carefully

^aThis quarry owes its first name to the fact that it was originally operated by the Granite Railway Company of Quincy, Mass., referred to on p. 109.

selected" by Prof. W. O. Crosby, of the Massachusetts Institute of Technology. This analysis forms part of a report made by him for the firm in 1907, and is published here merely for reference.

Analysis of Concord granite from Swenson quarries.

| | |
|--|--------------|
| SiO ₂ (silica)..... | 74.47 |
| Al ₂ O ₃ (alumina)..... | 14.15 |
| Fe ₂ O ₃ (iron sesquioxide)..... | 1.16 |
| FeO (iron oxide)..... | 1.21 |
| MgO (magnesia)..... | .63 |
| CaO (lime)..... | 1.70 |
| Na ₂ O (soda)..... | 1.97 |
| K ₂ O (potash)..... | 4.14 |
| S (sulphur)..... | .27 |
| CO ₂ (carbonic dioxide)..... | .25 |
| H ₂ O (water not combined)..... | .06 |
| H ₂ O (water combined)..... | .20 |
| | <hr/> 100.21 |

Professor Crosby, in the same report, gives two determinations of specific gravity: 2.64 and 2.66, average 2.65, which is equivalent to 155.6 pounds per cubic foot.

Mr. W. T. Schaller, chemist, of the United States Geological Survey, finds that this granite contains 0.17 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates the presence of 0.30 per cent of CaCO₃ (lime carbonate).

Compression tests made at the United States arsenal at Watertown, Mass., in 1906 show it to have an ultimate compressive strength of 30,830 pounds per square inch with pressure applied at right angles to rift, but of 23,860 pounds with pressure applied in the direction of the rift, the rift thus weakening the stone 12½ per cent when pressure is applied parallel to it.

The quarry, opened in 1863, measures about 500 feet north-northeast to south-southwest by 400 and 200 feet in width, and from 10 to 100 feet in depth.

The sheets are irregular, lenticular, and from 4 inches to 14 feet thick, but mostly from 2 to 7 feet, and dip northwest at a low angle. There are two sets of joints: Set A, striking N. 20° E. and dipping 70°-75° E., is spaced 10 to 100 feet and forms the west wall and a heading 50 feet wide on the east side. Set B, striking N. 65° W. and vertical or dipping 75° S, is spaced 10 to 300 feet, and forms the north wall and a heading 6 to 15 feet wide on that side. The rift is reported as dipping 15° W., with a strike of N. 5°-10° E., and the grain as vertical east-west. In summer time it is not necessary to follow the grain closely in splitting. There are pegmatite dikes up to 1½ inches wide. Segregations of the micas are said to be very rare and to measure only 4 inches. Rusty stain is up to 8 inches wide, but is confined to the proximity of headings. A little com-

pressive strain in an east-west direction is reported. The joint faces of headings B are dull greenish in color, owing to chloritization of biotite and the formation of fibrous muscovite in the feldspar and between the particles. The soda-lime feldspars also contain chlorite and carbonate. Other joint faces of the same set carry secondary quartz and calcite crystals and apparently also fluorite, deep purple and white. (See p. 61.)

The plant, including that of the lower quarry of same firm, described on this page, and that of the firm's cutting shed on North State street, comprises: 7 derricks, 4 hoisting engines, an electric overhead crane (capacity 15 tons), a Rand air compressor (capacity 750 cubic feet of air per minute), 4 large drills, 12 air-plug drills, 55 air hand tools, 3 surfacers, 3 "Jenny Lind" polishers, a vertical polisher, 5 pendulum polishers, and 2 steam pumps.

Transportation involves cartage of one-third mile to cutting sheds, which are on a siding of the Boston and Maine Railroad.

The product is used for buildings and monuments, and finds a market mostly in the West. Specimen structures: City hall and Christian Science Church, Boston; Northampton County Savings Bank, Easton, Pa.; Post-offices at Lincoln, Nebr., Adrian, Mich., and Hammond, Ind.; pedestal of the Monaghan monument, Spokane, Wash.; New Hampshire soldiers' monument, Vicksburg, Miss.; pedestal and exedra of McKinley Memorial, McKinley Park, Chicago. In 1906 the firm was filling contracts for the Citizens' National Bank, St. Clair, Pa.; Medico-Chirurgical Hospital, Eighteenth and Cherry streets, Philadelphia; and the electric station of the New York Edison Company, East Thirty-ninth street, New York.

The Hollis quarry (Lower Swenson) is about 600 feet northeast of the last and 70 feet below it. It is also operated by John Swenson, Concord, N. H.

The granite is identical with that of the upper quarry just described.

The quarry, opened about 1864, measures about 450 feet north-south by 300 feet across and from 40 to 50 feet in depth.

The sheets are irregular lenticular and horizontal or dip 15° W. They are from 6 inches to 35 feet thick. There are two sets of joints. Set A, striking N. 25° E. and dipping 65° - 70° E., is spaced 10 to 50 feet, and forms headings on the west and east sides and another 50 feet east of west wall. Set B, striking N. 65° W. to east-west and about vertical, is spaced 20 to 75 feet and forms the northeast wall. There are several inclusions of banded gneiss, one 3 feet 6 inches by 2 feet, another, originally much larger, now measures 4 feet 6 inches in diameter and is roughly quadrangular. Part of this is pegmatitic and part a biotite gneiss, with soda-lime feldspar (oligoclase-andesine) and garnets. In the finer parts the particles do not exceed 0.37 millimeter in diameter. The rift and grain are

reported as the same as at the upper quarry. One-inch pegmatite dikes cross the quarry diagonally. Rusty stain on the upper sheets is up to 8 inches thick. The granite along heading A on the west wall is much kaolinized and in places very limonitic. The surfaces have frostlike crystallizations (dendrites), probably of limonite also.

The plant and product of this quarry have been combined with those of the Granite Railway quarry on page 151.

The *Anderson quarry* is about 2 miles, roughly, N. 25° W. of the statehouse and 300 feet west of North State street, opposite Park street. This is the most northerly of the Concord quarries. Operator, Ola Anderson, Concord, N. H.

The granite, "Concord granite," is a muscovite-biotite granite of medium bluish-gray color and fine to medium, somewhat porphyritic texture, like that of the Granite Railway or Lower Swenson quarry, described on page 149.

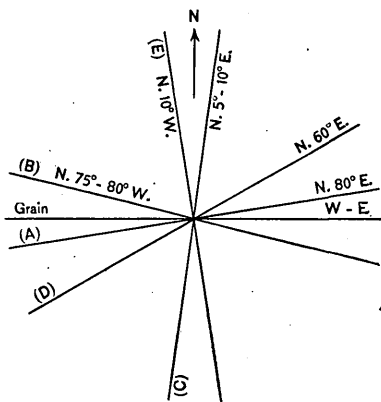


FIG. 19.—Structure at Anderson quarry, Concord, N. H.

The quarry, opened between 1860 and 1870, measures about 200 feet northwest-southeast by 175 feet across and 35 feet in depth. A second adjacent opening is 50 feet square and 10 to 15 feet deep.

The sheets, from 6 inches to 6 feet thick, are irregular lenticular and dip low west. There are five sets of joints, whose courses are shown in fig. 19.

Set A, vertical, is spaced 3 to 10 feet and forms the west wall. Set B, vertical, is spaced 10 to 30 feet and forms the northwest wall. Set C dips 55°-75° E., is spaced 200 feet, and occurs at north and southwest corners. Set D dips 50° SE. and forms heading on the southeast side. Set E dips 70° E. and forms a heading on the same side, intersecting Set D. The rift is reported as about horizontal and the grain as vertical with east-west course. Knots are reported up to 2 inches in diameter and rusty stain from one-fourth to 10 inches thick.

The plant consists of 5 derricks, 2 hoisting engines, an air compressor (capacity 237 cubic feet of air per minute), a large drill, 4 air plug drills, 8 air hand tools, and 3 surfacers.

Transportation is effected by a siding from the Boston and Maine Railroad.

The product is used chiefly for buildings and the waste for paving blocks. Specimens: Soldiers and sailors' memorial arch in front of statehouse, Concord; post-offices at Kankakee, Ill., and Gloversville,

N. Y.; base course and first story of post-office at Jamestown, N. Y.; sarcophagus monument to Mrs. Gilbert, Goodland, Ind.; Gerhardt mausoleum at Bushwick Junction, Long Island.

The Crowley quarry is about 300 feet south of the Anderson quarry, near North State street. Operator, P. Crowley, 434 North State street, Concord, N. H.

The granite, "Concord granite," is a muscovite-biotite, medium-gray granite, presenting no special variations from the general type described on page 146.

The quarry, opened in 1865, is about 240 feet northeast-southwest by 100 feet across, and from 35 to 50 feet deep.

The sheets, from 6 inches to 25 feet thick, are horizontal or dip gently southwest. There are four sets of joints. Set A strikes N. 30° E., dips 65°-70° E., and is spaced 3 to 25 feet. Set B strikes N. 60°-65° W., is vertical, and is spaced 50 feet. Set C strikes north, is vertical and diagonal, and occurs on the northwest wall. Set D strikes N. 10° E., dips 50° E., and is spaced 100 feet. In the center of the quarry is an inclusion of dark banded biotite-muscovite-oligoclase gneiss of slight purplish hue. It was originally 30 feet high and pointed at the top. It measures 30 feet in diameter at the base, which is nearly round on one side, but rectangular on the other. A 2-inch pegmatite dike crosses the schistosity of the gneiss, but ends abruptly at the granite contact. Another part of this inclusion consists of porphyritic granite with feldspars an inch long. The rift is reported as horizontal or dipping N. 65° W. In splitting sheets from the west the rift is said to be inclined, but in splitting from the east horizontal. The grain is said to be vertical with east-west course when frozen, but in summer to be very feeble. A 1 to 2 inch pegmatite dike with a N. 45° E. course branches irregularly. There are geodes of coarse feldspar, smoky quartz, and muscovite of half-bushel size. Rusty stain measures from 6 to 18 inches thick, but less on the lower sheets.

The plant consists of 2 derricks, a hoisting engine, and a steam drill.

Transportation is by a siding from the Boston and Maine Railroad, but by cartage to local cutters.

The product is used for buildings, monuments, curbing, and paving. Specimen: The trimmings on the new high school at Concord.

The Henneberry & Halligan quarry is on Rattlesnake Hill, one-fourth mile west of North State street and 70 feet above it, at a point one-fourth mile north of the State prison. Operators, Henneberry & Halligan, Concord, N. H.

The granite (specimens D, XXVIII, 49, a, c), "Concord granite," is a muscovite-biotite granite of medium bluish gray color, and fine to medium, somewhat porphyritic texture, with feldspars up to 0.5

and white mica scales up to 0.2 inch. This stone resembles more closely that of the New England Granite Works quarry than that of the Swenson quarries, being more micaceous and less feldspathic than the latter, but the black mica scales are generally finer than in the former, so that it has a larger number of fine particles. The firm regards the stone as harder than that of the other Concord granites. The constituents are the same as in the sections already described on pages 147, 148. The soda-lime feldspar is oligoclase and contains some secondary calcite.

The quarry, opened in 1900, is about 200 feet N. 25° E., by 100 feet across, and from 50 to 65 feet deep.

The sheets, from 2 to 15 feet thick, are somewhat irregular and horizontal or dip 17°–30° NE. There are 2 sets of joints. Set A, discontinuous, strikes N. 25° E., is spaced 3 to 15 feet, and forms a heading at the northeast end. Set B, strikes about northeast, diagonal, and is spaced 12 to 25 feet. The rift is reported as horizontal or nearly so, and the grain as vertical with a northeast course. Three garnetiferous pegmatite dikes, 1 to 4 inches thick, in a space of 2½ feet, strike about N. 45° W. and dips 60° SE. Rusty stain is about 4 inches thick on sheet surfaces.

The plant, at the quarry, includes 3 derricks, a hoisting engine, a steam drill, and a steam pump. At the cutting shed in Concord it comprises 2 derricks, 2 air compressors (capacity 135 and 78 cubic feet of air per minute), 2 electric motors, an air plug drill, a surfacers, and an air hand tool.

Transportation involves cartage of one-eighth mile to Boston and Maine Railroad, or 1¼ miles to cutting shed on Prospect street.

The product is used entirely for monuments. Specimens: Fay sarcophagus, Dewitt, Iowa; Sielaff sarcophagus, Milwaukee, Wis.; Raines sarcophagus, Memphis, Tenn.; McElwee sarcophagus, Homer, Ill.; Alten cross, Elyria, Ohio. In 1906 an elaborately carved sarcophagus (Crippen) was being cut for the Blossom Hill Cemetery, Concord, and several for Syracuse, N. Y.

The Fox quarry is on Rattlesnake Hill, 110 feet above North State street, N. 43° W. from the statehouse, and about half a mile N. 40° E. from the New England Granite Works quarry. Operator, Thomas Fox, 272 North State street, Concord, N. H.

The granite, "Concord granite," is a muscovite-biotite granite of medium bluish gray color and fine to medium somewhat porphyritic texture, resembling that of the Granite Railway quarry more than that of the New England Granite Works quarry. (See p. 149.)

The quarry, opened in 1884–5, a plan of which is given in fig. 20, measures about 200 and 300 feet by 175 feet across and from 40 to 70 feet deep.

The sheets are, for this region, exceptionally regular, dip 10° SW., and from 2 to 20 feet thick. There are 3 sets of joints. (See fig. 20.)

Set A, vertical to steep east-southeast, is spaced 3 to 30 feet and forms east and west walls and the headings on the east side and center. Set B, vertical to steep east, is spaced 10 feet and over. Set C, spaced 10 to 70 feet, is apt to be discontinuous. The rift is reported as dipping 5° – 7° SW. and the grain as vertical with a N. 70° E. course. The stone splits more easily along the rift in winter than in summer. In the northern part a 10-foot band of granite, without the bluish tint of the rest, strikes N. 60° W. and dips 90° . The cause of the difference is not clear, unless it be the micacization of the potash feldspar. It contains zonally arranged particles of quartz and oligoclase. The course of this band presumably indicates the flow direction of the granite. On one or both sides of it is an inch vein of muscovite. Pegmatite dikes measure up to $1\frac{1}{2}$ inches in thickness. There are spheroidal segregations, from 6 inches to 3 feet by 2 feet 6 inches, of a porphyritic granite of bluish gray shade, darker than any Concord granite. The matrix is fine-textured (particles 0.18 to 0.74 millimeter); the feldspars measure up to .4 inches, and the mica to 0.2 inches. The constituents are the same as those of Concord granite. The sheet surfaces are mostly free from rusty stain, and it is said never to exceed 4 inches in thickness. One of the joint faces carries chlorite, calcite, and pyrite.

The plant, including that of the cutting shed on North State street, comprises 3 derricks (one with a 95-foot mast and a 75-foot boom), 2 hoisting engines, an air compressor (capacity 140 cubic feet of air per minute), 2 steam drills, an air plug drill, 15 air hand tools, a surfer, 3 "Jenny Lind" polishers, and a steam pump.

Transportation involves cartage of one-fourth mile to a siding of the Boston and Maine Railroad, or of three-fourths mile to the cutting shed.

The product is used for buildings and monuments. Specimens: Church of Christ, Scientist, Concord, N. H.; Sheldon Library, St. Paul's School, Concord; entrance to Forest Lawn Cemetery, Buffalo; Soldiers' monument, Warner, and Carpenter tomb, Manchester, N. H.

The Perry quarry is on Rattlesnake Hill, N. 50° W. from the state-house and 360 feet above North State street. This is the most southerly of the Concord quarries. Operator, W. H. Perry & Co., Concord, N. H.

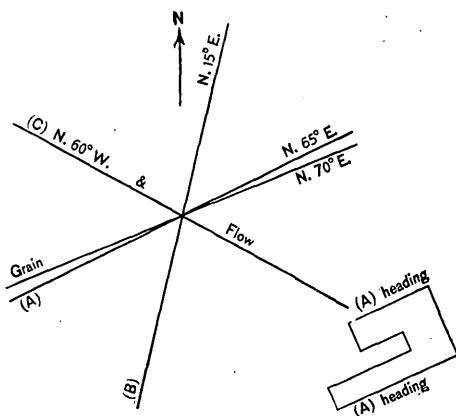


FIG. 20.—Structure and plan of Fox quarry, Concord, N. H.

The granite, "Concord granite," is a medium bluish gray muscovite-biotite granite of fine to medium somewhat porphyritic texture, closely resembling that of the New England Granite Works quarry described on page 147.

The quarry, opened in 1873, measures 250 feet N. 75° W. by 125 to 250 feet N. 10° E., and from 60 to 100 feet in depth.

The sheets, from 1 to 18 feet thick, are about horizontal. There are 4 sets of joints. Set A, striking N. 10° E. and dipping steeply east, is spaced 5 to 20 feet. Set B, striking N. 75° W. and vertical, is spaced 18 to 35 feet. Set C, striking N. 30° E. and dipping 50° E., is spaced 200 feet. Joint D, striking N. 45° W. and dipping 75° S. 45° W., occurs only at the northeast corner. That corner is much jointed and some of the joints are exceptional. The rift is reported as horizontal, and the grain as vertical with N. 80° W. course. A 4 to 5 inch pegmatite dike occurs with a N. 85° W. course and a vertical dip. Rusty stain does not exceed 4 inches and is absent from some sheets.

The plant, including that of the cutting shed in Concord, comprises 4 derricks, a hoisting engine, an air compressor, 7 air hand tools, 2 surfacers, a steam drill, 3 "Jenny Lind" polishers, a polishing lathe for stones 8 by 4 feet, an electric motor, and 2 steam pumps.

Transportation involves 3 miles' cartage from the quarry to the cutting shed, which is on the Boston and Maine Railroad.

The product is used mostly for monuments. Specimen: George Fogg monument, in Blossom Hill Cemetery, Concord, N. H.

The Duffy prospect is on Rattlesnake Hill, N. 50° W. from the state-house and 40 feet lower than the Perry quarry. Operator, N. J. Duffy, Concord, N. H.

The granite, "Concord granite," corresponds to that of the New England Granite Works quarry described on page 147.

The quarry, opened in 1906, measures about 50 feet east-west by 25 feet across and but a few feet in depth.

The sheets are thick. Joints will probably be found to be similar to those at the Perry quarry. Knots, 2 inches in diameter, and a 2-inch pegmatite dike were noted.

The plant consists of 2 derricks and 1 engine.

Transportation is by cartage of a mile to the cutting shed, which is on the Boston and Maine Railroad.

MILFORD, N. H.

Topography.—The Milford quarries lie within a radius of 4 miles of Milford village and between southwest, south, and southeast directions from it. A few lie northwest of it. The region about Milford, as shown on the Milford, N. H., topographic sheet of the United States Geological Survey, is marked by hills and short ridges, from 440 to 760 feet above sea level, trending north to south or north-

northeast to south-southwest. The highest of these hills are, Burns Hill (720 feet) and Badger Hill (760 feet), southwest of the village, and Federal Hill (700 feet) southeast of it. This hilly surface is, however, bisected east and west by the valley of Souhegan River,

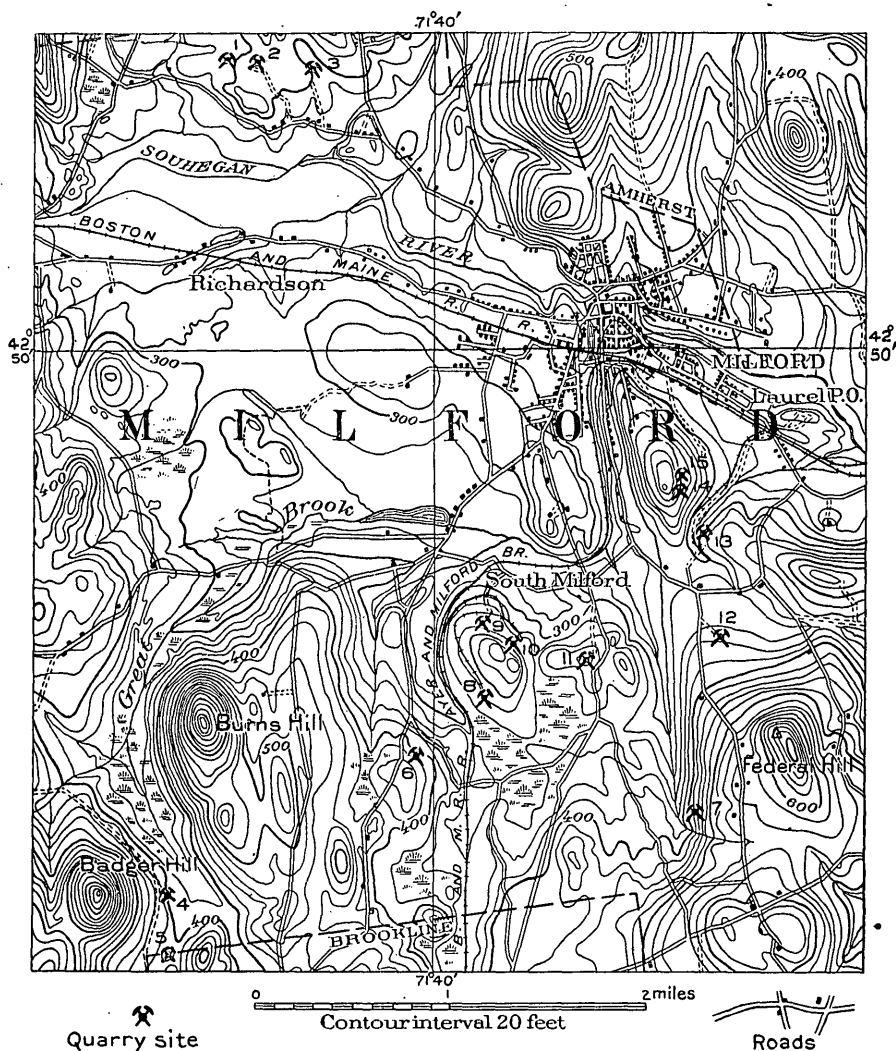
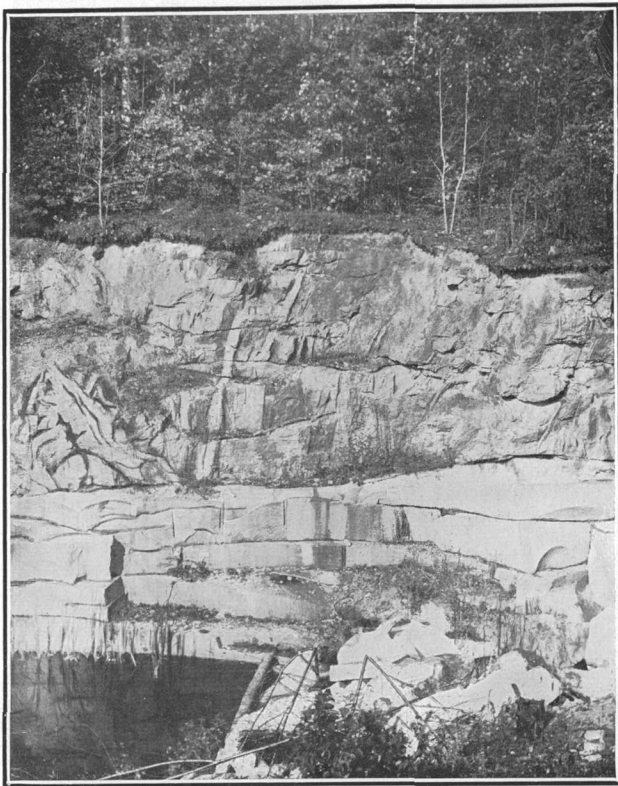


FIG. 21.—Map of vicinity of Milford, N. H., showing locations of granite quarries. 1, New Westerly quarry, New Westerly Granite Company. 2, Carlton quarry, A. E. Carlton. 3, Bishop quarry, John B. Bishop. 4, Comolli quarry, Comolli Bros. & Co. 5, Paradise quarry, Milford, Nashua Lake Street Granite Company. 6, Tonella New quarry, Tonella & Sons. 7, Souhegan quarry, Daniels Granite Company. 8, Lovejoy quarry, Lovejoy Granite Company. 9, Pease quarry, Milford Quarry and Construction Company. 10, Kittredge quarry, Edward L. Kittredge. 11, Tonella Old quarry, Tonella & Sons. 12, Hayden quarry, Henry W. Hayden. 13, Young quarry, Young's Sons & Co. 14, Milford Granite Company, south opening. 15, Milford Granite Company, north opening.

which hereabouts flows between the 206 and 240 foot levels. The locations of the quarries, shown on the map (fig. 21), are not governed by the topography. None of them are above the 400-foot level or 130 feet above the bench mark at Milford village.

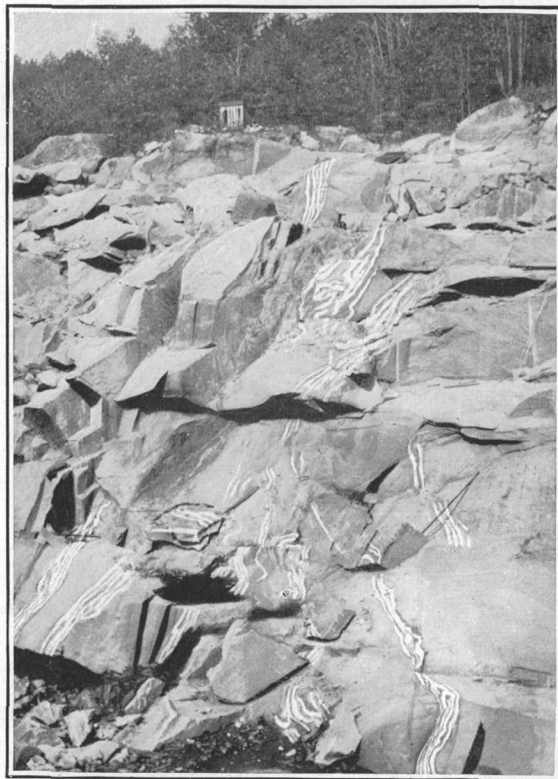
Geology of Milford, N. H., quarries.—The most interesting geological features of the Milford granite quarries are the contact phenomena and inclusions. The former have been fully described on page 62 and are illustrated in fig. 5 and Pl. VI, A. At these places remnants of the gneisses which once probably overlay the granite mass of the entire region are preserved. As these gneisses are evidently themselves granitic rocks which under powerful compression have undergone chemical and textural changes and become schistose, we are led to conclude that the Milford region has been the scene of two intrusions of rock material in molten condition, with an intervening period of metamorphism. The gneiss now capping the granite at the quarries of the Milford Granite Company (p. 173) represents the earlier granitic rock metamorphosed, the presence of which supplied part of the pressure which made possible as granite the stone which is now quarried.^a The strike of the gneiss foliation is N. 75° W., which furnishes a clue to the direction from which came the compression which metamorphosed the earlier granite. It is assumed, of course, that these few feet of gneiss are but the shreds of a mass which originally measured many hundred feet in thickness, but which was eroded mainly in preglacial time. The pegmatite dikes, which, apparently starting at the contact, run up into the gneiss, as shown in Pl. VI, A, were probably formed at the time of the intrusion of the underlying granite. This original gneiss of the region is also exposed at the Tonella quarries. (See pp. 164, 165.) At two quarries fragments of coarse biotite gneiss occur as inclusions in the granite. (See pp. 169, 176.) These probably formed part of the same overlying gneiss, which indeed they closely resemble. This was fractured by the vertical and lateral strain accompanying the intrusion, and fragments fell into the rising semiliquid fused mass. There is also at several quarries a marked banding in the granite, with courses of N., N. 15°, 20°, 50°, 70° E., and N. 75°–80° W., which must have been caused by the granite current (flow structure). At the Daniels quarry (p. 169) a roughly diamond-shaped inclusion of gneiss, over 3 feet in diameter, has a flow structure about it parallel to its surface, showing that while the plastic material was adjusting itself to the foreign body a zonal rearrangement of the mineral constituents of the granite took place. The occurrence of pegmatite dikes in groups of parallel courses in Milford granite has already been discussed (p. 48), and is shown in Pl. VI, B. The courses of pegmatite dikes at the quarries are N. 20°, 25°, 30°, 75° E. and N. 20°, 25°, 50°, 65° W. These must be attributed to a secondary intrusion in the granite in openings possibly due to contraction. The pegmatites thus represent a third access of heated matter to this portion of the crust. Finally the basic dikes, noted on pages 162, 163, 167,

^aSee Bull. U. S. Geol. Survey No. 313, pp. 14–16.



A. CONTACT OF GRANITE AND OVERLYING GNEISS AT MILFORD GRANITE COMPANY'S QUARRY, MILFORD, N. H., LOOKING WEST-NORTHWEST.

Pegmatite dikes in gneiss. Sheet structure in both rocks, but disconnected.



B. PEGMATITE DIKES IN GROUPS AT THE YOUNG GRANITE QUARRY, MILFORD, N. H., LOOKING NORTH-NORTHWEST.

A typical heading at the left: freshly cleared hummocky surface at top.

represent a fourth and probably much later injection of rock material in molten condition. The effect, direct or indirect, of these dikes in reddening the adjacent granite is very noticeable (see pp. 163, 167), and appears to be due to the hematitization of the feldspars either by the oxidation of magnetite by water or by the deoxidation of limonite by heat. The most abundant set of joints strikes N. 70° – 85° W., its complementary set striking N. 10° – 30° E. Others strike N., N. 35° – 40° , 45° – 50° , 60° E. and N. 30° , 50° , 60° W. The rift is reported at all the quarries as either horizontal or inclined at a very low angle south or S. 70° W. or west. The grain is reported as vertical or dipping 70° north with a course of N. 60° – 90° W., in one place N. 80° E. The sheets are from 3 inches to 30 feet thick.

Description of Milford, N. H., granite.—The following combines all the more detailed descriptions of specimens and thin sections given on pages 160–176.

Milford, N. H., granites are quartz monzonites ^a of light, medium, and dark-gray shade, in places of a slight bluish, pinkish, or buff tinge, and always spangled with black mica. Their texture is, with one exception, even grained, and very fine to fine, with feldspars and mica in the very fine up to 0.1 inch and in the fine to 0.2 inch. The constituents of these monzonites, in descending order of abundance, are: Clear to slightly smoky quartz with cavities (in sheets) up to 0.008, 0.017, 0.03 millimeter, and in some quarries with hair-like crystals, probably of rutile; clear, colorless to milk white, or bluish, greenish, or pinkish soda-lime feldspar (oligoclase), somewhat kaolinized and micacized; clear, colorless to milk white, or bluish, greenish, pinkish, or cream-colored potash feldspar (microcline with or without orthoclase), in places slightly kaolinized and mica-cized; black mica (biotite), some of it chloritized or bleached. Both feldspars are intergrown with quartz circular in cross section. The accessory minerals are: Magnetite, pyrite, apatite, zircon, allanite, and rutile; the secondary: Chlorite, two white micas, carbonate, kaolin, limonite, and hematite.

Estimates of the mineral percentages by the application of the Rosiwal method to camera lucida drawings of 3 thin sections of the very fine Milford granite from 3 widely separated quarries (pp. 164, 170, 173) yield the following results:

Average estimates of mineral percentages in Milford, N. H., monumental granite.

| | |
|---|-------|
| Quartz..... | 27.09 |
| Soda-lime feldspar (oligoclase) | 34.03 |
| Potash feldspars (microcline 14.15; orthoclase 15.57) | 29.72 |
| Black mica..... | 8.58 |
| Magnetite..... | .25 |
| Minor accessories..... | .33 |

100.00

^a See Glossary, p. 219.

As the percentages of quartz, soda-lime feldspar, and mica varied considerably in the separate estimates, the averages for these minerals are more dependable.

The average diameter of the particles in these three granites, as determined by the same method, is 0.0095 inch, which is about the same as the average of three Westerly, R. I., "blue granites," given on page 192 as 0.0099 inch.

Messrs. Sullivan, Schaller, and Steiger, chemists, of the United States Geological Survey, found that granite from 5 Milford, N. H., quarries contained from 0.11 to 0.26 per cent of CaO (lime) soluble in hot dilute acetic acid, or an average of 0.16 per cent, which indicates a content of from 0.19 to 0.46 per cent, or an average of 0.29 per cent, of CaCO_3 (lime carbonate). The presence of this carbonate is also shown by the microscope and by effervescence with cold dilute muriatic acid.

The finer Milford granites, which are properly monumental granites, take a high polish; to which the fineness of the mica contributes. The hammered face of these quartz monzonites offers quite a little contrast to the polished face, owing to their large percentage of soda-lime feldspar. The particles are so fine that the only contrast, that between the mica and the other particles, is only visible at a short distance. In the coarser Milford granites, in which the mica measures 0.2 inch in two of its diameters, this contrast is more marked. The chief characteristics of all these finer granites are the uniformity and delicacy of their shade or tint, the variety of tints obtainable at the different quarries, and the adaptability of the stone for fine carving. The coarser Milford granites are entirely constructional.

The Milford, N. H., quarries.—*The Lovejoy quarry* is in South Milford, about 2 miles S. 25° W. of Milford village, on the 380-foot level, on the southwest side of an oblong hill 440 feet high. (See fig. 21.) Operator, Lovejoy Granite Company, Milford, N. H.

The granite (specimen D, XXVIII, 51, b) is a quartz monzonite of light-gray shade spangled with black mica. Its texture is even grained, fine, inclining to medium, with feldspars and mica up to 0.2 inch. It consists, in descending order of abundance, of a milk-white potash feldspar (microcline and orthoclase); in almost equal amount a clear to milk-white soda-lime feldspar (oligoclase), partly kaolinized and micacized; light smoky quartz; biotite (black mica), some of it chloritized. Accessory minerals are: Allanite, zircon, apatite. Secondary: Chlorite, two white micas, kaolin, carbonate, and hematite.

Mr. George Steiger, chemist, of the United States Geological Survey, finds that this granite contains 0.14 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates the content of 0.25 per cent

of CaCO_3 (lime carbonate); the microscope also shows the presence of a carbonate, and the stone effervesces slightly with dilute muriatic acid.

The quarry, opened about 1886, measures 477 feet N. 35° E. by 150 feet across and from 5 to 20 feet in depth.

The sheets, from 3 inches to 10 feet thick, but mostly up to 5 feet 6 inches, dip 5° to 10° east and southeast. There is but one set of joints, which is vertical, striking N. 85° W., recurs at intervals of 40, 100, and 330 feet, and forms a 4 to 10 foot heading 140 feet from the north end. The rift is reported as horizontal but tending to incline with the sheets, the grain as vertical with N. 85° W. course. In summer the rock splits without reference to rift and grain. A flow structure, shown by more micaceous bands alternating with some 2-inch white ones, strikes N. 40° W. and dips 25° NE. Pegmatite dikes, up to 2 inches thick, strike N. 65° W., exceptionally N. 25° E. They consist of half-inch particles of clear to milky striated soda-lime feldspar (oligoclase), light smoky quartz, and black mica with magnetite and pyrite. There are no knots. Rusty stain is light, and up to 6 and 18 inches thick, but is not present on all sheets.

The plant consists of 3 derricks, 2 hoisting engines, an air compressor (capacity 935 cubic feet of air per minute), 2 large drills, 12 air plug drills, 2 surfacers, and a steam pump.

Transportation, as shown on the map (fig. 21), is by siding from the Boston and Maine Railroad.

Specimen structures: Pier 4 of Haverhill bridge, Essex County, Mass.; piers 4 and 6 of the railroad bridge at the same place; trimmings of Majestic Theater, Chicago; and Ferguson mausoleum at Kenrico Cemetery, New York.

The Kittredge quarry is in South Milford, about $1\frac{1}{2}$ miles S. 15° W. of Milford village, on the 360-foot level, on the opposite side of the same hill the Lovejoy quarry is on. (See fig. 21.) Operator, Edward L. Kittredge, Milford, N. H.

The granite (specimen D, XXVIII, 50, b) is a quartz monzonite of light-gray shade (with very slight bluish tinge apparent when the stone is in large masses) spangled with black mica. Its texture is even grained, fine, inclining to medium, with feldspars up to 0.2 and mica to 0.1 inch. In 4 thin sections the particles do not exceed 2.96 millimeters, or 0.012 inch, and most of them are not 2.2 millimeters or 0.08 inch. At very rare intervals porphyritic feldspars occur up to $1\frac{1}{2}$ inches in diameter. Its constituents, in descending order of abundance, are: Very slightly bluish milk-white potash feldspar (microcline intergrown with quartz, and orthoclase); in almost if not quite equal amount clear, colorless to milk-white soda-lime feldspar (oligoclase), partly micacized and kaolinized; light smoky quartz with sheets of cavities and rift or grain cracks parallel to them; and biotite (black mica), some of it chloritized. Accessory minerals are:

Magnetite, allanite, zircon, and apatite. Secondary: Kaolin, chlorite, white mica, and limonite. In the upper sheets the stone is of light cream color owing to limonite proceeding from magnetite and allanite particles.

A very fine monumental granite (specimen D, XXVIII, 50, a), forming a band 20 feet wide at the south end of the quarry, is also a quartz monzonite of light-gray shade with very slight bluish tinge and spangled with fine black mica. Its texture is very fine, with feldspars rarely over 0.1 and mica not over that. In thin section the feldspars measure up to 1.85 millimeters and the mica 0.74 millimeter. The constituents are like those of the coarser stone but the potash feldspars appear to predominate. The quartz contains hair-like crystals, probably rutile, and sheets of cavities intersecting at right angles, with cracks parallel to at least one of the sets of sheets.

The main product (specimen 50, b) is a constructional granite closely resembling that of the Lovejoy quarry on the other side of the hill but with slightly finer mica scales and a more bluish tinge in large masses. It effervesces very slightly with dilute muriatic acid.

The quarry, opened about 1890, measures 800 feet north-south by 200 feet across and from 5 to 40 feet in depth. The working face is on the southwest.

The sheets are lenticular, from 4 inches to 2 feet 10 inches thick, and dip at a low angle north and east. There are 3 sets of joints: Set A striking N. 22° E. and vertical, forms a heading 5 to 7 feet wide on each side of a basic dike. Set B, striking N. 70° and vertical, is spaced 200 feet. Set C, striking N. 45° E. and dipping 55° N. 45° W., is exceptional. The rift is reported as horizontal and the grain as vertical with a N. 80° E. course. A flow structure marked by parallel bands of abundant black mica strikes N. 20° E. also N. 50° E., with a dip of 20° NNW. and NW. A basic dike, a foot thick, striking N. 22° E. and vertical forms the east wall. This is intimately related to joint system A. Pegmatite dikes, 1½ to 3 inches thick, strike N. 20° and 50° W., forming in one place a network with meshes 15 feet square. An obscure whitish vein, 1 inch thick, probably quartz, strikes N. 10°-15° W. Rusty stain, 4 to 8 inches thick, occurs on some of the sheet surfaces. The top sheets are cream colored from a slight general discoloration. (See p. 56.)

The plant consists of 7 derricks, 3 hoisting engines, an air compressor (capacity 210 cubic feet of air per minute), 2 large drills, and 12 air plug drills.

Transportation is by a siding from the Boston and Maine Railroad, as shown on map (fig. 21). Seven-eighths of the product consists of paving, curbing, flagging, and crossings, the remainder being dimension stone and bases for monuments. Its markets are chiefly Boston, Albany, and their vicinities.

The Pease quarry is in South Milford, about $1\frac{1}{2}$ miles S. 25° W. of Milford village, on the 350 feet level, on the same hill the Lovejoy and Kittredge quarries are on. (See fig. 21.) Operator, Milford Quarry and Construction Company, Milford, N. H.

The granite in the east half of the quarry is a quartz monzonite of light-gray shade (with very slight bluish tinge apparent only in large masses of the stone) and spangled with black mica. Its texture is fine, inclining to medium, with feldspar and mica up to 0.2 inch. Its constituents are identical with those of specimen 50, b, from the Kittredge quarry, page 161.

The granite from the west half of the quarry (specimen D, XXVIII, 64, a), "pink stock," is a quartz monzonite of light buff-gray color spangled with black mica. Its texture is even grained, fine, inclining to medium, with feldspar and mica up to 0.2 inch. Its constituents, in descending order of abundance, are: Light smoky quartz with cavities in sheets, many parallel; colorless, transparent to milk-white soda-lime feldspar (oligoclase); light buff-gray potash feldspar (microcline); both feldspars are somewhat kaolinized and micacized; and biotite (black mica), some of it chloritized. Accessory minerals are: Magnetite, apatite, and zircon. Secondary: Kaolin, white micas, chlorite, and carbonate. It effervesces slightly with cold dilute muriatic acid.

This is a constructional granite of warm tint with conspicuous small black micas.

The quarry, opened in 1886, measures about 600 feet east-west by 400 and 300 feet from north to south, and from 35 to 60 feet in depth.

The sheets are lenticular, from 2 to 22 feet thick, and have a slight northerly dip. There are 2 sets of joints: Set A, striking N. 15° E., vertical, and spaced 50 to 200 feet, forms headings on west wall and 200 feet east of it next to the dikes. Set B, striking N. 80° W. and dipping 75° south, is spaced 5 to 50 feet and occurs on north and south walls. The rift is reported as horizontal and the grain as vertical with N. 65° W. course. A flow structure, shown by biotitic bands, alternating with more feldspathic and quartzose ones, strikes N. 70° – 75° W., and dips 25° south. This is conspicuous on the south side but at the southwest corner, where the granite is overlain by a gneiss as shown in fig. 5 (p. 63), the flow structure has a N. 70° – 75° E. course and dips 20° – 25° S. The strike of the gneiss is N. 75° W. and the dip 20° S. This gneiss consists of light-gray to milk-white soda-lime feldspar (oligoclase), smoky quartz, biotite, with magnetite, apatite, and zircon. It is thus a mica diorite gneiss. There are 2 basic dikes striking N. 15° E. and vertical, one, 4 feet thick, makes the west wall; the other, 12 to 18 inches thick, forms a jog 200 feet east of it. Within 50 feet of the thicker dike the granite passes from a light buff gray to a medium pinkish gray, owing to the darkening of the feldspars and to hematitic stain. These dikes are

also the probable cause of the difference between the color of the granite in the western and eastern halves of the quarry, the amount of hematitic stain increasing with the nearness of the dikes. (See pp. 36, 55.) A 4-inch pegmatite dike strikes N. 65° W. and consists of quartz, white feldspar, and biotite, the particles being up to 2 inches in diameter. Limonitic stain up to 2 inches thick occurs on some sheets only.

The plant consists of 4 derricks (2 with a capacity of 25 tons), 3 hoisting engines, an air compressor (capacity 345 cubic feet of air per minute), a large drill, 12 air plug drills, 2 surfacers, and a steam pump.

Transportation is effected, as shown on the map (fig. 21), by a siding from the Boston and Maine Railroad.

The product is used for bridges and buildings and the waste for paving. Specimen building of "pink stock:" Thayer Memorial Library at Franklin, Mass. Contracts in 1906: Neponset, Mass., railroad bridge; piers 12, 25, 26, and 32 on the Prison Point Street bridge (Boston and Maine Railroad), East Cambridge, Mass.; and east side coping of the Atlantic Avenue Bridge, Boston.

The Tonella old quarry is in South Milford, 1½ miles south of Milford village. (See fig. 21.) Operators, Tonella & Sons, Milford, N. H.

The granite (specimens D, XXVIII, 54, a, b) is a quartz monzonite of light-gray shade (without either bluish or greenish tinge), with very minute black spangles.

Its texture is fine, even grained, with feldspars up to 0.15 inch, and black mica in slender scales but exceptionally over 0.1 inch. Its constituents, in descending order of abundance, are: Very light smoky quartz with hairlike crystals, probably of rutile, and cavities in sheets; colorless clear to milk-white soda-lime feldspar (oligoclase) slightly kaolinized and micacized; very light gray potash feldspar (microcline and orthoclase), mostly intergrown with quartz circular in cross section, and in some cases very slightly kaolinized; and biotite (black mica), some of it chloritized. Accessory minerals are: Magnetite, zircon, allanite, apatite, and rutile. No pyrite detected. Secondary: Kaolin, chlorite, and 2 white micas.

An estimate of the mineral percentages, made by applying the Rosiwal method to a camera lucida drawing of a thin section enlarged 40 diameters, yields the following results with a mesh of 1.7 inches and a total linear length of 42 inches.

Estimated mineral percentages in Milford, N. H., granite from the old Tonella quarry.

| | |
|--|--------------|
| Quartz..... | 36.76 |
| Soda-lime feldspar (oligoclase)..... | 29.16 |
| Potash feldspars (microcline 14.00, orthoclase 13.58)..... | 27.58 |
| Black mica..... | 6.50 |
| | <hr/> 100.00 |

The average diameter of the particles obtained by the same method is 0.011 inch.

This is a fine-grained monumental granite, in shade a trifle lighter than Hallowell, Me., granite, but not as light as that of North Jay, Me. It takes a high polish. The only contrast, visible but a few feet off, is between the black mica and the combined quartz and feldspars. The polished face shows many minute particles of magnetite.

The quarry, opened in 1900, measures about 300 feet north-south by 100 feet across and from 20 to 35 feet in depth.

The sheets, from 2 to 14 feet thick, are lenticular horizontal and regular. There are 2 sets of joints: Set A, striking N. 85° W. and vertical or dipping steep south, is spaced 20 to 50 feet, and forms a heading 3 feet wide, 125 feet from the south end. Set B, striking N. 35-40° E. and vertical, is intermittent and confined to upper sheets. It forms a heading on the east wall, and recurs 30 feet from west wall. From the large blocks of gneiss attached to granite lying on the dumps and from the occurrence of this gneiss in a much weathered condition in or under the drift on the edge of the quarry, it is evident that the rock surface originally included a mass of gneiss which either capped the granite or formed a large inclusion in its upper part. This gneiss is coarse, biotitic, with lenses of pinkish potash feldspar (microcline) bordered with clear to milk white-soda-lime feldspar (oligoclase). Its quartz is smoky. Its accessory minerals are: Pyrite, magnetite, allanite, and zircon. The rift is reported as horizontal, and the grain as vertical with N. 85° W. course. There are no dikes, veins, or knots. Rusty stain occurs only along the headings, where it is 6 inches thick. The original rock surface was covered with 10 to 20 feet of till. This quarry is remarkably free from the common structural difficulties.

The plant, including cutting machinery at the village, comprises a derrick (with a mast of Georgia pine 105 feet high), a smaller derrick, 2 hoisting engines, an air compressor (capacity 108 cubic feet of air per minute), a large drill, an air plug drill, 18 air hand tools, a surfacer, and a steam pump.

Transportation is effected by cartage of one-half mile to railroad for rough stock, but of 2 miles to the cutting shed for blocks to be finished.

The product is used principally for monuments and the waste for paving. The firm makes a specialty of fine carved work, most of which finds a market in the West. Specimen: The Morgenthaler monument in Greenwood Cemetery, Hamilton, Ohio. This is a 5-ton block, 6 feet high, with a delicately carved branching ivy vine entwined about a cross, all in high relief on a roughly chipped face. As only ordinary hand tools were used the outlines in this are sharper than they would have been with the use of pneumatic tools.

The Tonella new quarry is 2¼ miles S. 25° W. of Milford village. (See fig. 21.) Operator, Tonella & Sons, Milford, N. H.

The granite (specimen D, XXVIII, 55, a) is a quartz monzonite of medium buff-gray shade, spangled with fine black mica. Its texture is generally even-grained and fine, with feldspar up to 0.2 and mica to 0.1 inch, but with rare porphyritic light pinkish feldspars an inch in diameter. Its constituents, in descending order of abundance, are: Light amethystine to pale smoky quartz; colorless, clear to milk-white soda-lime feldspar (oligoclase), partly kaolinized and micacized; light-buff to cream-colored potash feldspar (microcline much intergrown with quartz circular in cross section); and black mica, some of it chloritized. Accessory minerals are: Magnetite, allanite, apatite, and zircon. Secondary: Kaolin, a white mica, chlorite, hematite from magnetite, and limonite from allanite.

In general color this rock resembles specimen 64, a, of the Pease quarry (p. 163), but its mica scales are finer. It may become pinkish as the excavation deepens.

A finer granite (specimen D, XXVIII, 55, c) from the upper part of the quarry is also a quartz monzonite of medium buff-gray color, spangled with extremely fine mica. Its texture is even grained, very fine, with feldspars up to 0.1 and mica rarely over 0.05 inch. Its constituents and stain are the same as the other.

A pinkish granite (specimen D, XXVIII, 55, d) occurring next to the dike described beyond, is of pinkish medium-gray color, like that adjoining the dike in the Pease quarry (p. 163), but its general texture is fine, with feldspars and mica up to 0.15 inch, and with sparse porphyritic feldspars from 0.02 to 0.04 inch. Its constituents, in descending order of abundance, are: Pale amethystine to light smoky quartz with hairlike crystals, probably of rutile, and cavities in two sets of sheets intersecting at right angles with rift and grain cracks parallel to them; a translucent to opaque pinkish soda-lime feldspar (oligoclase) partly kaolinized and micacized, the kaolinized parts showing hematite by incident light; pinkish potash feldspar (microcline and orthoclase, in twins), intergrown with quartz circular in cross section; biotite (black mica), some of it chloritized. Accessory minerals are: Magnetite, allanite, zircon, apatite, and rutile. Secondary: Kaolin, a white mica, carbonate, and hematite. It effervesces slightly with dilute muriatic acid.

The quarry, opened in 1905, measures 100 feet north-south by 80 feet across and has an average depth of 20 feet.

The sheets, from 18 inches to 6 feet thick, are lenticular and horizontal, or dip as high as 20° E. Only one set of joints occurs, striking N. 30° W., dipping 35° W., and spaced 5 to 20 feet. The granite is capped on the east and west sides by about 5 feet of coarse biotite gneiss, but on the west this is overlapped by 2 to 3 feet of granite, and hence the gneiss may be merely a large inclusion. This gneiss (specimen D, XXVIII, 55, b) consists of pinkish potash feldspar (micro-

cline), and milk-white soda-lime feldspar, both intergrown with quartz; smoky quartz with cavities in sheets; and biotite. The accessory minerals are magnetite, zircon, apatite, and allanite. The foliation of the gneiss strikes about N. 45° W. The rift is reported as horizontal and grain as vertical, with N. 80° W. course. A flow structure shown by more biotitic streaks and planes strikes north and dips 20° W. At the top there is a band of fine-grained granite, 2 feet thick, in the flow direction. On the south side a vertical dike 2 feet 6 inches thick of augite camptonite strikes N. 10° E. This consists of soda-lime feldspar (andesine), augite, brown hornblende, magnetite in octahedra and skeleton crystals, apatite in slender prisms all through the feldspar, and pyrite, together with secondary chlorite and carbonate from alteration of augite. The granite for a thickness of 8 feet on the south side of this dike has a marked pinkish color, already shown under specimen 55, d (p. 166), as due to the presence of a very small amount of hematite.

The plant consists of 2 derricks and a hoisting engine.

Transportation involves cartage of one-fourth mile to a railroad siding, but of 2½ miles to cutting shed.

The product in 1906 had not yet been put upon the market pending further excavations.

The Comolli quarry is 3½ miles southwest of Milford village, at the east foot of Badger Hill, S. 10° W. of Burns Hill. (See fig. 21.) Operator, Comolli Brothers & Co., Milford, N. H.

The granite (specimen D, XXVIII, 58, a) is a quartz monzonite of light, inclining to medium, bluish gray color, and of very fine, even-grained texture, with feldspars and mica up to 0.1 inch. Its constituents, in descending order of abundance, are: Light smoky quartz with hairlike crystals, probably of rutile, and with cavities; bluish milk-white soda-lime feldspar (oligoclase), partly kaolinized; colorless clear potash feldspar (microcline and orthoclase) much intergrown with quartz circular in cross section; and biotite (black mica), some of it chloritized. Accessory minerals are: Magnetite, zircon, apatite, and rutile. Secondary: Kaolin and chlorite. It effervesces slightly with dilute muriatic acid.

This stone is so fine grained as to afford no contrasts except under close inspection, when only that between the mica and the general bluish gray of the rest appears. It is a monumental granite.

The quarry, opened in 1905, is about 70 by 50 feet and 5 to 15 feet deep.

The sheets, from 6 inches to 6 feet 6 inches thick, are lenticular and irregular. There are 2 sets of joints: Set A strikes N. 10° E. and dips 45° E. Set B strikes N. 80° W., is about vertical, and occurs at the south end. At the southeast corner the granite is overlain by 6 feet of coarse biotite gneiss. The rift is reported as horizontal and the

grain as vertical with N. 80° W. course. A pegmatite dike strikes N. 75° E. The amount of rusty stain on sheets is insignificant.

The plant consists of 2 horse derricks and 12 air hand tools at the cutting shed at Milford, where compressed air is obtained from another plant.

Transportation involves cartage of about 4½ miles to the cutting shed.

The product is used entirely for monuments.

The Paradis quarry is on the Milford and Brookline township line, 3¼ miles S. 35° W. of Milford village and about one-half mile southeast of Badger Hill. (See fig. 21.) Operator, Milford Nashua Lake Street Granite Company, Milford, N. H.

The granite is a quartz monzonite of light inclining to medium bluish gray color, and very fine, even-grained texture, identical with that of the Comolli quarry, three-tenths mile north of it, described on page 167.

The quarry, opened in 1905, is about 150 by 72 feet and is 4 feet deep.

The sheets, from 2 to 7 feet thick, are lenticular and undulating. There are 2 sets of joints: Set A, striking N. 60° E. and vertical or dipping steeply south, is spaced 4 to 30 feet. Set B, striking north and vertical, forms the east wall only. The rift is reported as horizontal and the grain as vertical north-south. Pegmatite dikes, from 1 to 12 inches thick, strike N. 20° E. and dip 40° W., also N. 25° W. and vertical, but turning to N. 50° W. Rusty stain is 6 inches thick.

The plant consists of 2 horse derricks and 1 hand derrick.

The product is used for monuments and curbing, the former in Boston, the latter in Nashua, N. H.

The Souhegan quarry is 2½ miles S. 12° E. from Milford village and three-fifths mile southwest of Federal Hill. (See fig. 21.) Operator, The Daniels Granite Company, Milford, N. H.

The granite (specimens D, XXVIII, 53, a, b, c) is a quartz monzonite of dark gray shade with very slight pinkish tinge and very fine scales of black mica. Its texture is even grained and fine, with feldspar and mica not over 0.1 inch. Its constituents, in descending order of abundance, are: Light smoky quartz with few cavities, some in sheets; milk-white soda-lime feldspar (oligoclase), slightly kaolinized and micacized; colorless to dull greenish gray potash feldspar (microcline), intergrown with quartz circular in cross section, and biotite (black mica), some of it chloritized. Accessory minerals are: Magnetite, pyrite, apatite, allanite, and zircon. Secondary: Kaolin, a white mica, chlorite, carbonate, and some irregularly disseminated hematite stain which gives the pinkish hue.

Mr. George Steiger, of the United States Geological Survey chemical laboratory, finds that this granite contains 0.26 percent of CaO (lime)

soluble in hot dilute acetic acid, which indicates a content of 0.46 per cent of CaCO_3 (lime carbonate), the presence of which carbonate is also shown by the microscope and by a slight effervescence in cold dilute muriatic acid.

The stone takes a high polish and offers quite a contrast of shade between its hammered and polished faces. The polished surface shows rare particles of pyrite along with the usual abundance of magnetite particles. The only contrast between its minerals, that between the black mica and the general color of quartz and feldspar, is visible but a few feet off.

The quarry, opened in 1896, measures 150 by 50 feet and is 10 to 25 feet in depth.

The sheets, generally normal and from 6 inches to 5 feet thick, dip low west and south, but are intersected by sharply curved planes, "toe nails." There are two sets of joints: Set A, striking N. 80° W. and vertical, occurs only in the southern part. Set B, striking N. 22° E. and vertical, forms headings on the east and west walls, and recurs discontinuously at intervals of 10 feet. There is a rhomb-shaped inclusion at the south end, about 3 feet 6 inches across, of very coarse biotite gneiss, consisting of milk-white soda-lime feldspar (oligoclase-andesine), smoky quartz, and biotite, with a little copper pyrite. There is some banding in the granite parallel to the surface of the inclusion. (See p. 19.) The rift is reported as in places horizontal but generally dipping south at a very low angle, and the grain as vertical with N. 70° W. course. A pegmatite dike, up to 2 inches thick, with a little magnetite, strikes N. 30° E. and dips 50° W. Rusty stain on the sheet surfaces measures up to 6 inches.

The plant, including that of the cutting shed at Milford, comprises 5 derricks, a hoisting engine, a 12-ton traveling crane, an air compressor (capacity 100 cubic feet of air per minute), several air hand tools, 2 polishers, a steam drill, and a steam pump.

Transportation is by cartage of 3 miles to cutting shed on siding of Boston and Maine Railroad.

The product is used for monuments. Specimens: Seaver monument in cemetery at Brookline, N. H.; Captain Randall monument in Riverside Cemetery, Milford, N. H.

The Hayden quarry is $1\frac{1}{4}$ miles S. 25° E. of Milford village, over one-half mile N. 35° W. from Federal Hill. (See fig. 21.) Operator, Henry W. Hayden, Milford, N. H.

The granite (specimens D, XXVIII, 57, a, c) is a quartz monzonite of dark medium-bluish gray color with very fine black mica. Its texture is even grained, fine, with feldspar and mica up to 0.1 inch, but with rare porphyritic feldspars 0.2 inch. Its constituents, in descending order of abundance, are: Very light smoky quartz, some of it with cavities up to 0.03 millimeter in sheets; milk-white soda-

lime feldspar (oligoclase), partly kaolinized and micacized; bluish translucent potash feldspar (microcline); and biotite (black mica), some of it chloritized. Accessory minerals are: Magnetite, pyrite, apatite, allanite, and zircon. Secondary: Kaolin, white micas, chlorite, and carbonate. Both feldspars are intergrown with quartz circular in cross section.

The stone takes a good polish. The polished face shows many fine particles of magnetite and rare ones of pyrite. The only contrast, that between the mica and the rest of the stone, is not visible at a distance.

The quarry measures about 150 feet N. 30° E. by 60 feet across and 15 to 20 feet in depth.

The sheets, from 4 inches to 5 feet thick, dip 10° S. 70° W. There are two sets of joints: Set A, striking N. 30° E. and vertical, is spaced 15 to 40 feet, and forms three 5-foot headings near the middle and on east and west sides. Set B, striking N. 60° W. and vertical, is spaced 20 to 30 feet. The rift is reported as dipping like the sheets and the grain as vertical with N. 60° W. course. In a part of the quarry the lower sheets are affected by short parallel fractures one-half to 1 inch apart. This resembles "shake" structure, but is much coarser. These incipient sheets seem to be due to some local strain. About 200 feet east of the quarry the granite is in contact with a coarse gneiss with a foliation striking east-west. Meandering pegmatite dikes, from one-fourth inch to 2 inches thick, in groups numbering up to 12, strike N. 50° W., with vertical or steep southeast dip, and recur at intervals of 20 to 30 feet. Another set of these dikes strikes nearly at right angles to the first. The pegmatite consists of cream-colored oligoclase, light smoky quartz with cavities in sheets, a little microcline, black mica, and magnetite, together with accessory pyrite, apatite, allanite, and zircon. Muscovite veins ("sand streaks") strike N. 60° W. at intervals of 1 to 12 inches near the pegmatite dikes. The granite contains here and there porphyritic crystals of biotite (black mica) up to 2 inches by 0.4 inch, with their flat and very thin sides parallel to the rift. (See p. 57.) Rusty stain on the sheet surfaces is from 2 to 6 inches thick. Pyrite occurs on the joint faces.

The plant comprises 2 derricks, a hoisting engine, and a steam pump.

Transportation is by cartage of 1 $\frac{3}{4}$ miles to Milford.

The product is dimension stone, blocks for monuments, and paving. The quarry is worked only from April to December of each year.

The Young quarry is 1 $\frac{1}{4}$ miles southeast of Milford village and three-fourths mile southwest of East Milford, or Laurel post-office. (See fig. 21.) Operators, Youngs Sons & Co., Milford, N. H.

The granite (specimens D, XXVIII, 52, aa, c), "dark-blue New Westerly," is a quartz monzonite of general dark-gray shade (neither bluish, greenish, nor pinkish, but of smoke color) with very fine black spangles. Its texture is even-grained and fine, with feldspar up to 0.1—rarely 0.15—inch, and mica to 0.1 inch. Its constituents are, in descending order of abundance: Very light smoky quartz with cavities; slightly greenish-gray soda-lime feldspar (oligoclase), somewhat kaolinized and micacized; clear, colorless to grayish potash feldspar (microcline and orthoclase), very slightly kaolinized; and black mica, some of it chloritized. Accessory minerals are: Magnetite, pyrite, apatite, allanite, and zircon; secondary: White mica, kaolin, chlorite, carbonate, and a little hematite and limonite stain, the latter about the allanite.

An estimate of the mineral percentages obtained by applying the Rosiwal method to a camera lucida drawing of part of a thin section enlarged 40 diameters yields these results with a mesh of 2 inches and a total linear length of 34 inches.

Estimated mineral percentages in Milford, N. H., granite from the Young quarry.

| | |
|--|--------------|
| Quartz..... | 27.40 |
| Soda-lime feldspar (oligoclase)..... | 27.70 |
| Potash feldspars (microcline 12.87, orthoclase 17.41)..... | 29.28 |
| Black mica (biotite)..... | 13.51 |
| Magnetite..... | .11 |
| Allanite..... | 1.00 |
| (Accessory, 1.11.) | |
| | <hr/> 100.00 |

The percentages of magnetite and allanite are not perfectly reliable, for a slight shifting of the mesh would have changed the figures for one or both, but as representing together the accessories they are not far from the truth. The average diameter of all the particles, by the same method, is 0.0084 inch.

Mr. W. T. Schaller, of the United States Geological Survey chemical laboratory, finds that this granite contains 0.18 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates a content of 0.32 per cent of CaCO_3 (lime carbonate), the presence of which carbonate is also shown by the microscope and by a very slight effervescence with cold dilute muriatic acid.

A crushing test, made for the firm by Professor Ricketts, of the Rensselaer Polytechnic Institute, at Troy, N. Y., is reported as showing an ultimate crushing strength of 24,950 pounds to the square inch.

The stone takes a fine polish. The polished face shows some magnetite and a little pyrite. There is much contrast of shade between the hammered and the rough or polished face, the hammered

face being light, slightly bluish gray. The contrast between the minerals, only visible near to them, is that between the black mica and the general color of the others.

The quarry, opened in 1886, a plan of which is shown in fig. 22, has a length of 370 feet, a width of 75 to 100 feet, and an average depth of 50 feet. Only the northwest bend was being worked in 1906.

The sheets, from 2 to 10 feet thick, are lenticular and generally horizontal. Joint courses are given in fig. 22. Set A is vertical, forms a heading at the west end, shown in Pl. VI, *B*, and recurs 70 feet east only. Set B dips 40° north, is spaced 5 to 10 feet, and occurs only at the northwest corner. The rift is reported as horizontal, but with a slight inclination to the west. There is no perceptible grain. Flow structure, shown by biotitic streaks, strikes N. 15° E. and dips 45° west. The marked feature of this quarry is the recurrence, at intervals of 20 feet, of dikes of pegmatite and aplite, already described on page 48 and shown in Pl. VI, *B*. These dikes are from one-fourth inch to 3 inches thick, occur in sets of three to eight, with a N. 25° W. course and a vertical dip. A few strike N. 25° E. and dip 40° ESE. They consist of cream-colored oligoclase, smoky quartz, cream-colored or pink

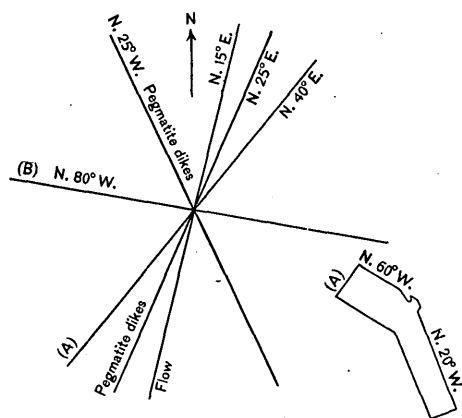


FIG. 22.—Structure and plan of Young quarry, Milford, N. H.

microcline, and biotite, with magnetite, allanite, and zircon. The biotite crystals measure up to 2 inches in length. Rusty stain measures up to 8 inches on sheet surfaces. Joints A are coated with pyrite, which has mostly passed into limonite.

The plant, including that of the cutting shed, comprises 4 derricks, a hoisting engine, an air compressor run by a 22-horsepower gasoline engine, 2 steam drills, 12 air hand tools, and a steam pump.

Transportation is by cartage of three-fourths mile to the cutting shed, on the Boston and Maine Railroad, although a siding extends to within a few hundred feet of the quarry.

The product is used for monuments, the stained and veined parts and small sheets for paving. The monuments go mostly to Troy, N. Y. Specimens: The Senator E. Murphy and W. Fitzpatrick monuments at St. Mary's Cemetery; the Mrs. R. J. Stark monument at Oakwood Cemetery, Troy, N. Y.; the Mrs. J. Craig monument at Rural Cemetery, Albany, N. Y.

The *Milford Granite Company's* quarries are a mile southeast of Milford village and 130 feet above it, on the east side of a hill. (See fig. 21.) The quarries were idle in 1906. Address, H. H. Barber, Milford, N. H.

The granite generally is like that of the Young quarry, described on page 171.

The quarries comprise 2 openings, along a N. 20° E. line. The southern opening is about 120 feet N. 20° E. by 60 feet across and is 40 feet deep. The northern opening, separated from the other by an interval of 150 feet, is about 900 feet N. 20° E. by 50 to 75 feet across and from 10 to 30 feet deep.

The sheets, from 1 to 5 feet thick, are lenticular and horizontal. Joints, striking N. 10° to 30° E. and vertical, are spaced 1 to 5 feet and form headings on the east and west walls of both quarries and also in the middle of southern one. Some of the joints of these headings are "sand seams," or veins up to one-half inch thick of a central band of quartz crystals with borders of muscovite. (See p. 51.) The granite of the west wall of both quarries is overlain by a mass of many-colored banded gneiss, 12 to 16 feet thick, with a foliation striking about N. 75° W. and dipping 75° south, with injections of pegmatite starting at the contact and tapering out within the gneiss. (See Pl. VI, A.) There is much variety in the composition and texture of the gneiss. The quartz of the finer augite-diorite gneiss has cavities, up to 0.047 millimeter, which are in sheets intersecting at right angles. The granite on either side of the muscovite veins in the heading is much reddened for half an inch; the biotite is mostly chloritized, the oligoclase is much kaolinized and micacized, and much limonite and hematite stain proceeds from particles of magnetite and pyrite.

The plant comprises, at the quarries, 4 derricks (6 to 20 tons), 2 hoisting engines, a steam drill, and a steam pump. At the cutting shed are a 45-horsepower engine, an air compressor (capacity, 212 cubic feet air per minute), a crane (capacity, 20 tons), a surfacer, and 2 polishers.

Transportation involves cartage of half a mile to a cutting shed on the Boston and Maine Railroad.

The *New Westerly quarry* is 2½ miles northwest of Milford village. (See fig. 21.) Operator, New Westerly Granite Company, Milford, N. H.

The granite (specimens D, XXVIII, 60, a, b), "New Westerly blue," is a quartz monzonite of medium slightly bluish-gray color, spangled with fine black mica. Its texture is even-grained, fine, inclining to medium, with feldspar and mica up to 0.2 inch and a marked parallelism in the mica scales. Its constituents, in descending order of abundance, are: Light smoky quartz with cavities up to 0.008 millimeter in sheets; slightly greenish-blue soda-lime feldspar

(oligoclase), partly kaolinized and micacized; slightly pinkish-gray potash feldspar (microcline, some twinned); biotite (black mica) some of it chloritized. Both feldspars are intergrown with quartz. Accessory minerals are: Magnetite, pyrite, allanite, apatite, and zircon; secondary: Kaolin, 2 white micas, chlorite, hematite, and carbonate.

An estimate of the mineral percentages, obtained by applying the Rosiwal method to a camera lucida drawing of part of a thin section, enlarged 40 diameters, yields the following results with a mesh of $1\frac{1}{2}$ inches and a total linear length of 34.5 inches:

Estimated mineral percentages in Milford, N. H., granite from the New Westerly quarry.

| | |
|--|--------|
| Quartz..... | 17.10 |
| Soda-lime feldspar (oligoclase)..... | 45.22 |
| Potash feldspars (microcline 15.59; orthoclase 15.71)..... | 31.30 |
| Black mica (biotite)..... | 5.74 |
| Magnetite..... | .64 |
| | <hr/> |
| | 100.00 |

The average diameter of all the particles, obtained by the same method is 0.009 inch.

Mr. George Steiger, chemist, of the United States Geological Survey, finds that this granite contains 0.12 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates a content of 0.21 per cent of CaCO_3 (lime carbonate), the presence of which carbonate is shown by the microscope and by a slight effervescence with cold dilute muriatic acid.

The stone takes a high polish, which brings out the greenish and reddish tints and darkens the shade so that the general color becomes a medium greenish gray. The polished face shows a few grains of magnetite and rare ones of pyrite.

The quarry, opened in 1876, is about 150 feet from east to west by 100 feet across and from 15 to 65 feet in depth.

The sheets, from 6 inches to 30 feet thick, increasing in thickness downward, dip south at a low angle. There are 2 sets of joints: Set A, striking N. 10° E., dipping 60° E. and 90° , is spaced 3 to 50 feet and forms a heading on east side. Set B, striking N. 75° – 80° W. and vertical, is spaced 30 to 40 feet and forms a heading on the south side. The rift is reported as horizontal and the grain as vertical with a N. 80° W. course, but it is so feeble that the stone can be split almost as well across it.

The plant, including that of the cutting shed, comprises 3 derricks, 3 hoisting engines, 3 air compressors (capacity of two being 140 and 177 cubic feet of air per minute, the third one requires a 22-horsepower engine to run it), 2 large drills, 5 air plug drills, a sur-facer, 16 air hand tools, a polisher, and 2 steam pumps.

Transportation requires cartage of about $2\frac{1}{2}$ miles to the cutting shed and railroad at Milford.

The product is used for monuments.

The Carlton quarry is 2 miles northwest of Milford village. (See fig. 21.) Operator, A. E. Carlton, Milford, N. H.

The granite (specimen D, XXVIII, 61, a) appears to be also a quartz monzonite, but probably with more of the potash feldspar. Its shade is medium pinkish gray, spangled with black. Its texture is porphyritic; the groundmass is fine, with feldspar and mica up to 0.1 inch and the isolated feldspars up to 0.4 and exceptionally 1 inch. Its constituents, in descending order of abundance, are: Light smoky quartz with hairlike crystals, probably of rutile, and cavities in sheets, with rift cracks parallel to them; light pinkish-gray potash feldspar (microcline), intergrown with quartz circular in cross section, inclosing particles of soda-lime feldspar, and somewhat kaolinized and micacized, making up part of the groundmass and also the porphyritic crystals; in almost equal amount a milk-white soda-lime feldspar (oligoclase), somewhat kaolinized, micacized, and intergrown with quartz; and biotite (black mica), some of it chloritized. Accessory minerals are: Magnetite, apatite, allanite, and rutile; secondary: Kaolin, 2 white micas, chlorite, and hematite.

At the north corner of the quarry there is a band of quartz monzonite of medium slightly bluish-gray color, with fine black mica, like the stone of the New Westerly quarry described on page 173.

The chief product of this quarry differs from all the other Milford, N. H., granites by its marked porphyritic texture. It is a constructional granite.

The quarry, opened in 1881, is about 110 by 100 feet and averages 30 feet in depth.

The sheets, from 1 to 16 feet thick, dip west at a low angle. There are 2 sets of joints: Set A, striking N. 50° W. and about vertical, is spaced 20 to 60 feet and forms a heading on the west side and the east wall. Set B, diagonal, striking north, and dipping 75° east, forms but one joint. The rift is reported as slightly inclined to the west and the grain as dipping 70° N. Flow structure, shown by streaks of black mica, also by the band of fine granite, strikes N. 70° E. and dips 40° to 50° N. 20° W. Rusty stain is up to 8 inches thick.

The plant consists of a horse derrick and a hand derrick, a steam drill, and an air compressor with a capacity of 50 cubic feet of air per minute.

Transportation is by cartage of 2 miles to Milford.

The product is mostly for street work in Boston and Cambridge. Specimen monument: The Abbie H. Patten monument, North Cemetery, Milford, N. H.

The Bishop quarry is about $1\frac{1}{4}$ miles northwest of Milford village. (See fig. 21.) Operator, John B. Bishop, Milford, N. H.

The granite (specimen D, XXVIII, 62, a) is a quartz monzonite of light-gray shade and faintly cream colored, with exceedingly minute black spangles. Its texture is even grained, fine, with feldspars and micas very rarely exceeding 0.1 inch. The mica plates measure much less than this in width. Its constituents, in descending order of abundance, are: Clear to pale smoky quartz with hairlike crystals, probably of rutile, and cavities in sheets; milk-white to cream-colored soda-lime feldspar (oligoclase) somewhat kaolinized and micacized; clear, colorless potash feldspar (microcline), in places very slightly kaolinized; biotite (black mica), some of it chloritized and either partially bleached or interleaved with muscovite. Both feldspars are intergrown with quartz. Accessory minerals are: Magnetite, apatite, and zircon. Secondary: Kaolin, 2 white micas, chlorite, and carbonate.

This stone resembles most closely in fineness that (specimen 54, a, b) of old Tonella quarry (p. 164), and that (specimen 50, a) of the small band in Kittredge quarry (p. 162), but differs from both in tint. It ought, from the fineness of its mica, to take a high polish.

The quarry, opened about 1831, measures about 250 feet by 100 or 200 feet in width, and has an average depth of 25 feet.

The sheets, from 6 inches to 3 feet thick, are somewhat irregular and dip west and north at low angles. There are 2 sets of joints: Set A, striking N. 50° E. and vertical, is spaced 10 to 20 feet and forms a heading on the east side and west wall. Set B, striking N. 75° – 80° W., seems to be consequent on the flow structure and is spaced very irregularly. Flow structure, shown by biotitic bands up to one-half inch wide and light bands up to 2 inches wide, strikes N. 75° – 80° W., and dips 50° N. 10° – 15° E., also 90° . There are angular inclusions, 3 inches in diameter, of very coarse gneiss, consisting of a pinkish and a cream-colored feldspar, smoky quartz, and biotite. In the eastern part of the quarry pegmatite dikes, up to 2 inches wide, strike N. 20° E. across the flow structure and dip about 90° . Their feldspars resemble those of the gneiss in color, and the quartz is smoky.

The plant consists of 5 horse derricks, an air compressor (capacity 69 cubic feet of air per minute), a large drill, 2 air plug drills, and a steam pump.

Transportation is by cartage of $1\frac{1}{4}$ miles to Milford.

The product is mostly curbing.

CONWAY.

Topography.—The Conway quarries are in Carroll County, N. H., near North Conway, some of them on the east and west sides of the Saco Valley. The Redstone quarries, on the east, are at the south foot of a series of summits ranging from 1,550 to 2,375 feet above sea

level (Black Cap, Middle Mountain, and Rattlesnake Mountain), known collectively as the Green Hills, and the White Mountain quarry on the west is on a 765-foot lenticular granite mass lying about 2 miles S. 25°-45° E. of the granite domes known as White Horse and Cathedral ledges. Also belonging to this group of quarries is the Fletcher & Lahey quarry, in the town of Madison, which adjoins Conway on the south. This quarry lies southeast of Moat Mountain and about 2½ miles southwest of Conway Corners.

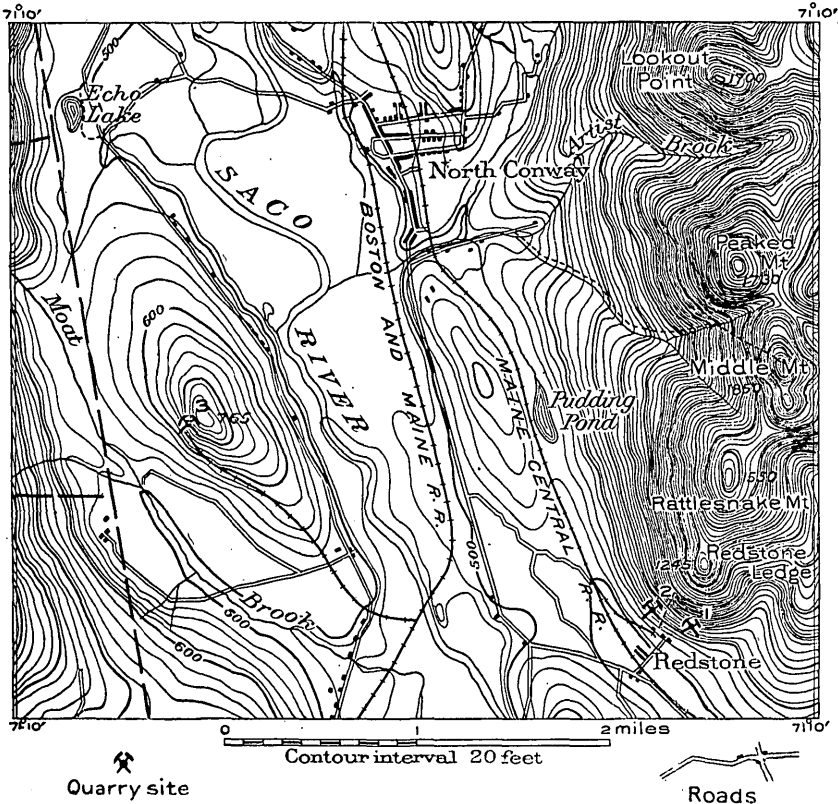


FIG. 23.—Map of part of Conway, N. H., showing locations of granite quarries. 1, Redstone red, granite quarry, Maine and New Hampshire Granite Corporation. 2, Redstone green granite quarry of the same firm. 3, White Mountain quarry, Henry A. Hitner's Son's Company, 1907. The boundary between pink and green granite is shown by dotted line.

Geology of the quarries.—The geological feature of general interest in Conway granites is their marked rift and grain and the manifest relation of these to the sheets of microscopic cavities, as shown in fig. 1 and described on page 42. The rift is reported as uniformly horizontal and the grain as vertical with N. 80°-90° W. course. Another feature is the contiguity of a yellowish-green biotite-hornblende granite to the pink biotite granite at Redstone (Pl. VII, A, and fig. 23). The writer attempted to trace the boundary between these two granites above the quarries, but found it impracticable

without using much time, owing to the reddening of both granites at the surface by forest fires. However, between the 500 and 800 foot levels the boundary has a N. 23° E. course and is said to continue in that direction toward Rattlesnake Mountain. Although the feldspars of both these granites are equally kaolinized, their original colors probably differed as greatly as do their present ones. The feldspar of the green stone seems to have been a bluish gray and that of the pink probably clear and colorless or slightly pinkish. Their present colors are due to the formation of limonite in the green and hematite in the pink. This limonite is largely traceable to somewhat abundant allanite and to the hornblende, while the hematite may be attributed to the oxidation of magnetite or of ferrite in infinitesimal particles in the feldspars. These two granites side by side represent originally different materials, and the line of their contact indicates the direction of their flow. A 20- by 30-foot segregation or dike of porphyritic biotite-hornblende granite, and geodes, coated internally with calcite rhombs and chlorite, should also be noted as occurring at the red quarry. The joint systems at the four quarries have courses of N. 70° – 90° W., N. 35° W., N. 15° E., and N. 30° E. As shown in Pl. VII, A, the sheets dip gently east and west from the axis of the ridge.

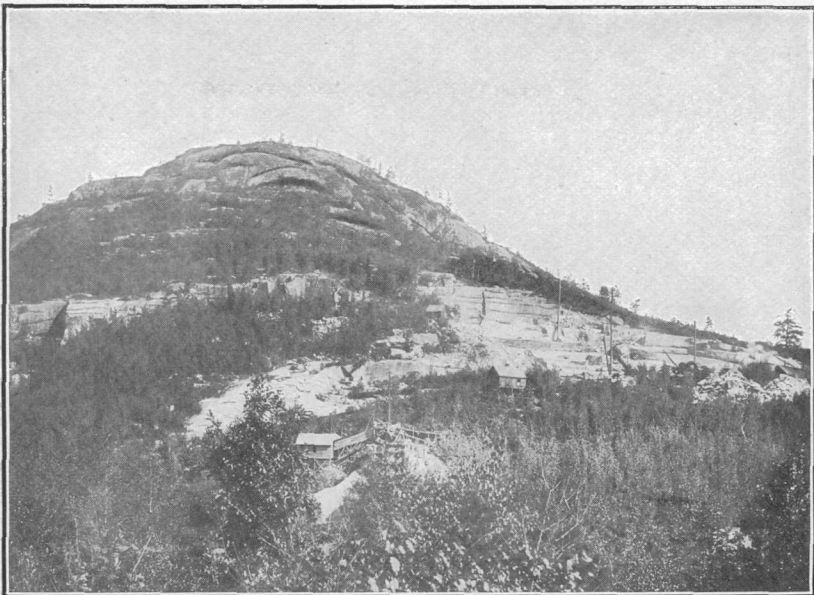
Description of Conway granites.—Conway granites are all coarse constructional granites, mostly of pinkish color mottled with amethystine gray and spotted with black; but one is dark yellow-greenish gray spotted with black. They are biotite or biotite-hornblende granites, and consist, in descending order of abundance, of: More or less pinkish potash feldspar (orthoclase), always minutely intergrown with soda-lime feldspar (oligoclase-albite); amethystine-smoky quartz; a little separate oligoclase-albite; and biotite (black mica) with or without a little hornblende. The accessory minerals are: Magnetite, (ilmenite?), pyrite, apatite, fluorite, zircon, and allanite (abundant in the green granite). The secondary are: Kaolin, chlorite, titanite (leucoxene), calcite, hematite, and limonite stain (the latter abundant in the green granite from which hematite is absent), and epidote.

Estimates of the mineral percentages, obtained by applying the Rosiwal method to 4 specimens from 3 quarries, yields the following results (see pp. 179, 180, 183, 185):

Estimated mineral percentages in Conway granites.

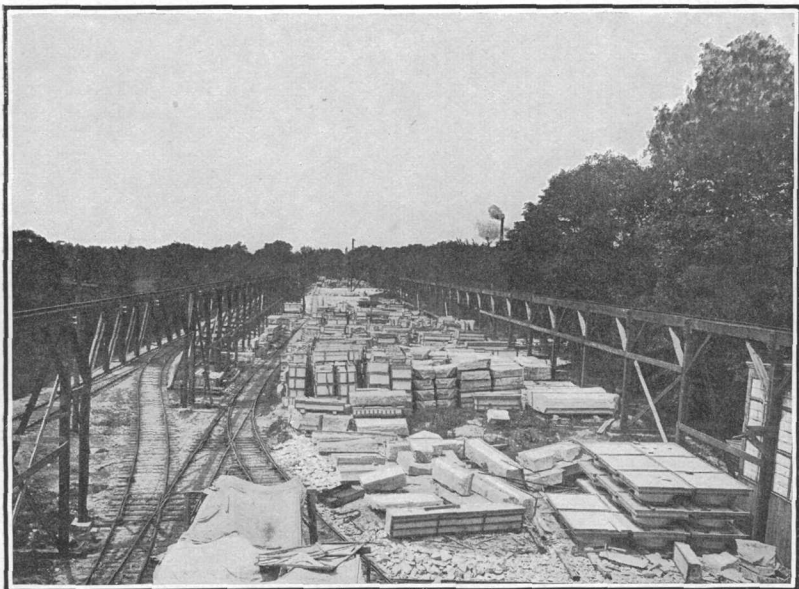
| | Average. |
|-------------------------------|----------|
| Feldspar, 54.79 to 68.00..... | 63.15 |
| Quartz, 26.00 to 38.26..... | 31.04 |
| Mica, 4.20 to 6.95..... | 5.81 |

Analyses of the red and green granites are quoted on pages 180, 183. They show 1 per cent more of iron oxides in the green. The estimates show 9.61 per cent more quartz in the green.



A. REDSTONE LEDGE, CONWAY, N. H., LOOKING N. 30° E.

Showing, on the left, quarry in green granite and, on the right, one in pink granite; also the sheets dipping away from axis of hill. Boundary between the two granites runs diagonally up the hill. In foreground is stone crusher for waste.



B. STORAGE YARD AT MILFORD, MASS., WITH FINISHED BLOCKS OF MILFORD PINK GRANITE FOR THE PENNSYLVANIA RAILROAD TERMINAL AT NEW YORK.

Elevated rails are for traveling crane.

The percentage of CaO (lime) soluble in hot dilute acetic acid in granites from two quarries was found by Messrs. Schaller and Steiger, chemists, of the United States Geological Survey, to average 0.205 per cent, and the CaCO_3 (lime carbonate) thus indicated to average 0.353 per cent.

A compression test of the Redstone pink shows it to have a compressive strength of 22,370 pounds per square inch. This test does not bear out the damaging judgment passed on Conway granites by Hawes in Hitchcock's *Geology of New Hampshire*,^a although all very coarse granites weather more easily than those of finer grain.

The Conway quarries.—*The Redstone red quarry* is in the town of Conway, about 3 miles S. 35° E. of North Conway, on the base of Redstone Ledge, one-third mile N. 50° E. of Redstone station on the Maine Central Railroad, and 180 feet above it. (See North Conway, N. H., topographic sheet of the United States Geological Survey; also fig. 23 and Pl. VII, A.) Operator, Maine and New Hampshire Granite Corporation, Portland, Me.

The granite (specimens D, XXVIII, 35, a, b, j, k), "red granite," is a biotite granite of light pink color with large dark gray and small black spots. Its texture is even grained, coarse, and with feldspars up to 0.75 inch, exceptionally 1.25, and black mica up to 0.3 inch. Its constituents, in descending order of abundance, are: A light pink nearly opaque potash feldspar (orthoclase, mostly twinned) minutely intergrown with soda-lime feldspar; smoky-amethystine quartz with cavities, up to 0.012 millimeter, in sheets, intersecting at right angles and parallel to rift and grain cracks (see fig. 1 and p. 42); translucent, very light gray to milk-white striated soda-lime feldspar (oligoclase-albite); and biotite (black mica) with but little of it chloritized. The orthoclase is much kaolinized, the oligoclase less so. The orthoclase in places surrounds oligoclase; in one specimen a small crystal of orthoclase is inclosed by oligoclase and that has a zone of orthoclase about it. The accessory minerals are: Magnetite (ilmenite?), pyrite, apatite, fluorite, and zircon. The secondary: Kaolin, chlorite, titanite (leucoxene), calcite, and hematite stain mostly combined with the kaolin and only visible under incident light.

Estimates of the mineral percentages by the Rosiwal method yield the following results:

Estimated mineral percentages in Redstone, N. H., "red granite."

[Specimen cut at right angles to both rift and grain; mesh 0.8 inch, total linear length 39.2 inches.]

| | |
|---------------------|--------------|
| Feldspars..... | 62.60 |
| Quartz..... | 31.00 |
| Mica (biotite)..... | 6.40 |
| | <hr/> 100.00 |

^a Vol. 3, pt. 4, p. 195.

Estimated mineral percentages in Redstone, N. H., "red granite."

[Specimen cut parallel to rift showing larger feldspars; mesh 1.2 inches, total linear length 28.8 inches.]

| | |
|---------------------|--------|
| Feldspars..... | 68.00 |
| Quartz..... | 26.30 |
| Mica (biotite)..... | 5.70 |
| | <hr/> |
| | 100.00 |

Average of both above estimates.

| | |
|---------------------|-------|
| Feldspars..... | 65.30 |
| Quartz..... | 28.65 |
| Mica (biotite)..... | 5.55 |

An analysis of this granite, made for the firm in 1898 by Franklin C. Robinson, State assayer of Maine, is here given merely for reference.

Analysis of "red granite" from Redstone, N. H.

| | |
|--|---------|
| SiO ₂ (silica)..... | 71.44 |
| Al ₂ O ₃ (alumina)..... | 14.72 |
| Fe ₂ O ₃ (iron sesquioxide)..... | 2.39 |
| FeO (iron oxide)..... | .46 |
| (Total iron oxides, 2.85.) | |
| MgO (magnesia)..... | .96 |
| Na ₂ O (soda)..... | 7.66 |
| K ₂ O (potash)..... | .89 |
| Rare elements, mostly TiO ₂ and ZrO ₂ (titanium and zirconium dioxides)..... | .78 |
| Manganese, sulphur, calcium, phosphates..... | Traces. |
| Loss at red heat (mostly water)..... | .61 |
| | <hr/> |
| | 99.91 |

Specific gravity 2.635.

Mr. W. T. Schaller, of the United States Geological Survey's chemical laboratory, finds that this granite contains 0.16 per cent of CaO (lime), soluble in hot dilute acetic acid, which indicates a content of 0.267 per cent of CaCO₃ (lime carbonate), the presence of which carbonate is also shown by the microscope.

A test made at the United States arsenal at Watertown, Mass., in 1887, gives this granite a compressive strength of 22,370 pounds per square inch.

The stone takes a high polish, but the large size of its mica scales is not favorable to the durability of the polish under long-continued outdoor exposure. Polished faces show some magnetite. As the relative amount of gray to pink feldspar is small the contrast is mostly between the pink feldspar and the smoky amethystine quartz, which is very pleasing. The minor spots of black mica give it still more character. This is a constructional granite, but is also, by its polish and contrasts, adapted to internal decorative uses.

The quarry, opened about 1887, is about 500 feet from east to west by 300 feet across and from 30 to 80 feet deep, with a working face 80 feet high on the north. (See Pl. VII, A.)

The sheets, from 4 to 30 feet thick, are normal and arch across the axis of the hill, dipping 15° to the east in this quarry. There are 3 sets of joints: Set A, striking east-west and vertical, is spaced 5 to 40 feet, and not everywhere continuous. Set B, striking N. 35° W. and dipping 80° S., forms a heading in the west part but does not recur. Set C, striking N. 15° E. and vertical, recurs at 160 feet. The rift is reported as horizontal and the grain as vertical with east-west course. Both are marked and appear as delicate cracks in the quartz particles on polished surfaces parallel to the "hard-way." This interesting textural feature is fully discussed on page 42 and is illustrated in fig. 1. There are small dikes of deep pinkish aplite (fine textured, particles 0.185–0.555 millimeter) consisting of pinkish orthoclase, clear quartz, clear oligoclase, and very little biotite, with secondary muscovite and hematite stain. In the eastern part of quarry is a mass about 30 feet north to south by 20 feet east to west and with an exposed depth of 10 feet, which may be a very large knot or quite possibly the upper part of a dike oval in cross section. Streaks of black mica 10 feet long radiate from its upper surface; also irregular pegmatitic bands with small dark-gray knots. Its matrix (particles 0.074 to 0.59 millimeter) is of medium purplish-gray color with porphyritic, light-pinkish feldspars up to 0.7 inch, light smoky quartz to 0.03 inch, and black silicate to 0.2 inch. The matrix consists of orthoclase, quartz, oligoclase-albite, hornblende, and biotite, with accessory magnetite, apatite, fluorite, titanite, and zircon. The large feldspars are orthoclase with intergrown oligoclase and quartz. There are elliptical and spherical knots from one-half inch to 14 inches in diameter of exceedingly fine-grained, very dark gray, largely biotitic material with sparse porphyritic feldspars. Lenses of pegmatite up to 2 feet by 6 inches also occur, and lenticular geodes, mainly of intergrown quartz and feldspar surrounded by a half-inch band of aplite. These geodes are lined with crystals of smoky amethystine quartz and orthoclase incrustated with chlorite and calcite. Some obtuse rhombs of calcite are one-half inch wide. Joint C is coated with epidote and chlorite, and the granite for one-half inch back of it is much altered to kaolin and mica, and stained by hematite and limonite. (See p. 62.) Rusty stain is an inch thick along sheet surfaces, but up to 4 inches along the joints.

The plant, including also that of the adjacent quarry (p. 182) and of the cutting shed, comprises 12 derricks, 6 hoisting engines, 2 locomotive cranes, 2 air compressors (capacity 690 and 80 cubic feet of air per minute), a large drill, 8 air plug drills, 29 air hand tools, 2 surfacers, a lathe for stones 12 feet by 2 feet 6 inches, 2 polishing lathes for stones 22 feet by 4 feet and 15 feet by 2 feet 6 inches, 3 polishers, 2 stone crushers, and 3 stationary engines for crushers, lathes, and polishers.

Transportation is by a gravity track 1,100 feet long from quarry to shed and by siding from there.

The product is used mainly for buildings. Specimens: First National Bank, Chicago; First and Fourth National banks, Cincinnati, with polished columns; Franklin Savings Bank, New York; Temple Bar Building, Brooklyn; Union station, Pittsburg; City hall, Lowell; High school, Springfield, Mass.; base of Longfellow monument, Portland, Me.; State Library, Concord, N. H. The pilasters and trimmings of this library are of Concord granite, the columns, at the entrance, are of polished green granite from the next quarry, and the rest is of the "red granite."

The Redstone green quarry is in the town of Conway, about 3 miles S. 25° E. of North Conway, on the base of Redstone Ledge, about 800 feet west-northwest of the red quarry, described above, less than one-half mile N. 15° E. from Redstone station and about 140 feet above it. (See fig. 23 and Pl. VII, A.) Operator, Maine and New Hampshire Granite Corporation, Portland, Me.

The granite (specimens D, XXVIII, 36, a, b, c), "green granite," is a biotite-hornblende granite of dark-yellow greenish-gray color with black spots. Its texture is even grained, coarse, with feldspars up to 0.8 inch and mica to 0.3 inch. Its constituents, in descending order of abundance, are: Medium-gray potash feldspar (orthoclase) with some yellow-green stained cleavage faces. (This feldspar is always minutely intergrown with lime-soda feldspar, oligoclase-albite, some of it is twinned and it is all much kaolinized); dark yellow-green smoky quartz with cavities in 2 or 3 sets of intersecting sheets with rift and grain cracks parallel to two of them and in places coinciding with them (see p. 42); very little separate soda-lime feldspar (oligoclase-albite), slightly micacized; biotite (black mica) and hornblende, some of it corroded. Accessory minerals are: Magnetite (ilmenite?), fluorite, allanite (mostly in biotite), and zircon. Secondary: Kaolin, a white mica, calcite, epidote in veinlets, chlorite, and limonite. There is a faint yellowish limonitic stain along the rift and grain cracks of the quartz, and along these and the cleavage planes of the feldspar, and along borders of all particles. This stain is deeper in the quartz because there are more cracks in it, and this, in combination with its original slightly amethystine hue, gives the quartz a greenish tint; and this yellow stain also, in connection with the original slightly bluish gray of the feldspars, gives them in places a greenish color. Much of this limonite stain comes from allanite particles, as shown in fig. 3, some also from the hornblende, biotite, and magnetite. (See p. 52.)

An estimate of the mineral percentages, obtained by the Rosiwal method, yields the following results with one-half inch mesh and total linear length of 71 inches:

Estimated mineral percentages in "green granite" from Redstone, N. H.

| | |
|---------------------|--------------|
| Feldspar..... | 54.79 |
| Quartz..... | 38.26 |
| Mica (biotite)..... | 6.95 |
| | <hr/> 100.00 |

An analysis made for the firm by Franklin C. Robinson, State assayer of Maine, in 1899, is given here merely for reference:

Analysis of "green granite" from Redstone, N. H.

| | |
|--|-------------|
| SiO ₂ (silica)..... | 70.42 |
| Al ₂ O ₃ (alumina)..... | 14.64 |
| Fe ₂ O ₃ (iron sesquioxide)..... | 1.54 |
| FeO (iron oxide)..... | 2.34 |
| (Total iron oxides, 3.88.) | |
| MgO (magnesia)..... | 1.20 |
| Na ₂ O (soda)..... | 7.80 |
| K ₂ O (potash)..... | .71 |
| Rare elements, mostly TiO ₂ and ZrO ₂ (titanium and zirconium dioxides)..... | .48 |
| Manganese, sulphur, calcium, and phosphates..... | Traces. |
| Loss at red heat, mostly water..... | .61 |
| | <hr/> 99.74 |

Specific gravity 2.634.

It will be noticed, on comparing the amounts of iron oxides in this and the red granite (p. 180), that this exceeds the other by 1 per cent, which is attributable to its larger content of hornblende and allanite and of the limonite proceeding therefrom.

When first quarried this stone is more greenish than after a few years' exposure, when its feldspars become more grayish, but its general color is even then still markedly greenish. The cause of this change is not apparent, for organic acids do not reach the quarried blocks. It takes a high polish, but its large-sized mica plates furnish vulnerable points of attack by the weather under prolonged exposure. The polished face shows a little magnetite. The contrasts are weaker than in the red granite, owing to the darker shade of its feldspar. Whether in the rough or polished, its color is striking. Though not unsuitable for purposes of construction, it is a coarse decorative granite well adapted for sheltered positions.

The quarry, opened about 1887, is about 150 feet north to south by 100 feet across and up to 50 feet in depth, which is the height of the working face on the north. It is worked at intervals only.

The sheets, from 11 inches to 14 feet thick, dip about 15° W. (See Pl. VII, A.) The joint sets are the same as in the red quarry, and the rift and grain are likewise the same.

The plant has been included in that of the red quarry.

Transportation is by cartage of 500 feet to the cutting shed.

The product has been used for buildings and polished columns. Specimens: Front of the first three stories of Fidelity Mutual Life Insurance Building, Philadelphia; polished columns in the Northwestern Guarantee Loan Company's Building, Minneapolis; in the Baxter Building, on Congress street, Portland, Me., and in the upper and lower vestibules of the State Library, Concord, N. H.

The White Mountain quarry is in the town of Conway, $1\frac{1}{4}$ miles southwest of North Conway, on the west side of a hill between Saco River and Moat Brook, southeast of White Horse Ledge. (See fig. 23.) Owner, Henry A. Hitner's Sons Company, Pennsylvania Building, Philadelphia.

The granite (specimens D, XXVIII, 38, a, b) is a biotite granite of medium pinkish buff gray color with black spots. Its texture is even grained, coarse, with feldspars up to 0.8 inch and mica to 0.3 inch. Its constituents, in descending order of abundance, are: Pinkish buff potash feldspar (orthoclase) in twins and minutely intergrown with soda-lime feldspar (oligoclase-albite), also intergrown with quartz and kaolinized; amethystine quartz with cavities in sheets intersecting at right angles, those in the rift direction being very close together; slightly greenish gray soda-lime feldspar (oligoclase), also intergrown with quartz, kaolinized, and partly micacized, in cases inclosed in orthoclase; biotite (black mica), some of it chloritized. Accessory minerals are: Fluorite, allanite, zircon. Secondary: Kaolin, a white mica, chlorite, and limonite and hematite stain.

This is a coarse constructional granite with good rift.

The quarry, not operated since December 1, 1903, lies between the 645 and the 735 foot levels, measures about 400 feet N. 75° W. by 250 feet across and from 35 to 90 feet in depth. The top of the working face is 30 feet below the top of the hill.

The sheets, from 3 to 30 feet thick, are horizontal or dip low north and also south. Joints A, striking N. 30° E. and dipping 60° N. and 90° , are spaced 20 to 70 feet. Joints B, striking N. 70° to 80° W. and vertical, are spaced 2 to 50 feet. A geode of pegmatite with smoky amethystine quartz crystals an inch long was noticed. Rusty stain is from 1 to 8 inches thick on the sheets and up to 2 feet along the joints.

The plant consists of 11 derricks, 4 Lidgerwood hoisting engines, 6 Lidgerwood "skeleton engines," 2 Lambert engines, 2 air compressors (Rand No. 10), 6 large drills, 16 air plug drills, a locomotive engine, and 4 steam pumps.

Transportation is by a private siding, $1\frac{1}{4}$ miles long, from the main line of the Boston and Maine Railroad. (See fig. 23.)

This quarry was opened by the contractors for the Boston dry dock at the Charlestown Navy-Yard, in which the stone was used. It but recently passed into the hands of its present owners.

The Fletcher & Lahey quarry is in the town of Madison, about $2\frac{1}{2}$ miles southwest of Conway Corners and a mile about west of the main line of the Boston and Maine Railroad. Operators, Fletcher & Lahey, West Chelmsford, Mass.

The granite (specimens D, XXVIII, 37, b, d)—the more pinkish variety—is a biotite granite of light pinkish gray color, mottled with dark purplish gray and with small black spots. Its texture is even grained, coarse, with feldspars up to 0.7 inch and mica to 0.2 inch. Its constituents, in descending order of abundance, are a light pinkish gray potash feldspar (orthoclase, mostly twinned), minutely intergrown with soda-lime feldspar (oligoclase-albite) and considerably kaolinized; dark amethystine-smoky quartz with cavities; translucent slightly greenish white striated soda-lime feldspar (oligoclase) partly micacized; and biotite (black mica), some of it chloritized. Accessory: Magnetite and allanite. Secondary: Kaolin, a white mica, and chlorite.

An estimate of the mineral percentages, by the Rosiwal method, yields the following results with mesh of one-half inch and total linear length of 20 inches:

Estimated mineral percentages in Madison, N. H., granite.

| | |
|---------------------|--------|
| Feldspars..... | 67.20 |
| Quartz..... | 28.60 |
| Mica (biotite)..... | 4.20 |
| | <hr/> |
| | 100.00 |

Mr. E. C. Sullivan, of the United States Geological Survey's chemical laboratory, finds that this granite contains 0.25 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates a content of 0.44 per cent of CaCO_3 (lime carbonate).

This is a coarse-textured constructional granite of warm tint, possessing marked contrasts of color, which come out strongly on the polished face (delicate pink, mottled with purplish smoke and dotted with black). The somewhat large mica scales are not favorable to the durability of the polish under long-continued outdoor exposure.

The less pinkish variety (specimen 37, a) is like the other except in that the orthoclase is more nearly cream colored. Apatite and zircon appear among its accessory minerals. Its contrasts are, if anything, a trifle more marked than those of the other.

The quarry, opened between 1888 and 1891, is at the east foot of a granite bluff 200 feet high, which also has a steep south side. It is about 500 feet square, with an extension on the bluff where there is a working face 100 feet high. Its depth is from 15 to 50 feet.

The sheets, from 2 to 20 feet thick, are horizontal but dip 10° E. on the east and on the bluff 10° E. to NE. There are two sets of joints: Set A, striking N. 80° W. and vertical, is spaced 5 to

100 feet and forms a 10-foot heading in the northern half of quarry and another at the north wall. Set B, striking N. 15° E. and vertical, is spaced 5 to 100 feet and forms a heading on the east side. The rift is reported as horizontal and the grain as vertical, with N. 80° W. course. The pinkish variety occurs on the south side and the lighter on the north. Rare granitic dikes, 1 to 6 inches wide, consist of a groundmass of medium-gray shade and fine to medium texture, spangled with biotite and with porphyritic pinkish feldspars up to 0.4 inch. The groundmass consists of orthoclase, microcline, oligoclase-albite, quartz, and biotite. Rusty stain is from 1 to 4 inches thick on upper sheets, decreasing below. Joint faces are coated with epidote.

The plant consists of 4 derricks, 4 hoisting engines, an air compressor (capacity, 250 cubic feet of air per minute), 3 large drills, 9 air plug drills, and 3 steam pumps. The firm has a cutting plant at West Chelmsford, Mass.

Transportation is by a siding 1 mile long to the main line of the Boston and Maine Railroad.

The product is used almost entirely for bridges and buildings. In 1906 the firm was filling contracts for certain piers on the Boston and Maine Prison Point Street Bridge, at East Cambridge, Mass. (see p. 164), and also for a bridge at South Acton, Mass. Specimen monument: Dudley Porter memorial fountain, at Haverhill, Mass.

AUBURN.

The granite described in this section is quarried at a point 7 miles east of Manchester, in the township of Auburn, Rockingham County. Hitchcock's geological map of New Hampshire (1877 and 1885) shows at about that point a belt of "Huronian" schist and conglomerate on the southeast in contact on the northwest with the belt of "Winnepesaukee" gneiss (referred to on p. 144) as including the Concord granites. Both belts have a northeasterly trend. The Auburn granite apparently belongs to the same general granite area as the Concord granite.

The granite (specimens, D, XXVIII, 46, a, b), "deep-pink Auburn," is a quartz monzonite of medium pink-buff color with very fine black dots. Its texture is fine, with feldspar and mica up to 0.1 inch. Its constituents, in descending order of abundance, are: Slightly pinkish potash feldspar (orthoclase and microcline); almost, if not quite as abundant, clear to milk-white soda-lime feldspar (oligoclase), some of it kaolinized and micacized; smoky quartz; and biotite (black mica), some of it chloritized and bleached. Accessory minerals are: Magnetite, apatite, and zircon. Secondard: Kaolin, a white mica, chlorite, and hematite stain.

The stone takes a fair polish, and the hammered face by its lightness offers not a little contrast to the rough and polished faces. It is used for monumental work.

The quarry is operated by W. H. Perry & Co., of Concord, N. H.

SUNAPEE.

The granite and diorite of the Sunapee quarry district are reported as occurring in vertical contact at a point about 2½ miles roughly east of Sunapee. Hitchcock's geological map of New Hampshire (1877 and 1885) shows very near this locality a contact between a belt of his "Atlantic system," which includes "Winnepesaukee" gneiss and the granite of Sunapee, Concord, and Milford, on the west, with a belt of his older "Laurentian" porphyritic gneiss on the east. The operator of the quarry states that the rift is horizontal in the granite but vertical in the adjacent diorite.

The granite (specimens, D, XXVIII, 47, a, b), "light Sunapee," is a biotite-muscovite granite of a light gray, slightly bluish color and very fine to fine texture, with feldspars up to 0.15 inch and mica to 0.1 inch. Its constituents, in descending order of abundance, are: Colorless, clear potash feldspar (microcline and orthoclase, the latter with hairlike crystals probably of rutile, both being intergrown with quartz circular in cross section); clear, colorless quartz, also with rutile needles; translucent to milk-white soda-lime feldspar (oligoclase-albite), somewhat kaolinized and intergrown with quartz; biotite (black mica), and muscovite (white mica). Accessory: Magnetite, garnet, zircon, and rutile. Secondary: Kaolin and carbonate.

This, as will be seen by comparing the descriptions, is finer grained than Concord granite. It lends itself well to fine carving. Its particles are too fine to afford contrasts. It takes a fair polish.

The "black granite" (specimen D, XXVIII, 48, a, b), "black pearl" or "dark Sunapee," is a quartz diorite of very dark bluish-gray color and fine, inclining to medium, texture, with feldspars up to 0.2 inch. Its constituents, in descending order of abundance, are: Clear, colorless to milk-white soda-lime feldspar (oligoclase-andesine to andesine), but little kaolinized, rarely intergrown with quartz; biotite (black mica); clear colorless quartz (possibly equal in amount to feldspar); and titanite. There is so much of this molasses-colored mineral present that it is easily seen with a loop. Accessory: Magnetite (ilmenite?), pyrite, allanite, and zircon. Secondary: Kaolin, epidote (about allanite), calcite, and hematite. It effervesces slightly with dilute muriatic acid.

When polished the rock appears black mottled with white. The polish is poor owing to the large size and abundance of mica. It

shows magnetite and a little pyrite. The hammered face is light gray and thus is in marked contrast to both rough and polished faces. The stone is used for monuments and is suitable for inscriptions.

The quarry is operated by W. H. Perry & Co., of Concord, N. H.

RHODE ISLAND.

GENERAL STATEMENT.

The granite industry of Rhode Island centers at Westerly. Some of the quarries are near Westerly, others near Niantic. Westerly is at the extreme western edge of the State, 5 miles north-northeast of Watch Hill on the Atlantic shore, and Niantic is $4\frac{1}{2}$ miles east-northeast of Westerly. (See map, Pl. I, and Stonington and Charlestown, R. I., topographic sheets of the United States Geological Survey.)

WESTERLY AND NIAN TIC.

Topography.—Some of the Westerly quarries are on an east-west ridge about a mile northeast of the city. This ridge attains an elevation of 200 feet above sea level and 160 feet above the city. Others are about a mile southeast of Westerly on the 130-foot level, and one lies a mile east of it on the 100-foot level. The Niantic quarries lie from a mile south-southeast to $1\frac{3}{4}$ miles southeast of the village of Niantic, some being in the town of Westerly, and one in the town of Charlestown. (See fig. 24.)

General geology.—The granites of Westerly and the closely related granites of Niantic have been briefly described by Merrill, by Kemp, and by Rice and Gregory;^a and in Gregory and Robinson's geologic map^b of Connecticut the granite gneiss area into which the Westerly granites were intruded in the adjacent parts of Connecticut is shown.

According to these geologists, the "white" and "blue" fine-grained Westerly granites were intruded as dikes in a molten state into certain older granite gneisses (Sterling granite gneiss), which formed extensive parts of the surface along the Atlantic shore. The medium-grained reddish granite of the Redstone quarry northeast of Westerly and the very coarse gneisses exposed at the other quarries all belong to this granite gneiss formation. These granite gneisses were originally granites which had likewise been intruded into an earlier overlying gneiss, a metamorphosed sedimentary rock ("Putnam gneiss," etc.) of which no remnants are reported as occurring at Westerly. Prior to the intrusion of the Westerly granite these older

^a Merrill, G. P., Report of building stones: Tenth Census, vol. 10, 1885, p. 20. Kemp, J. F., Granites of southern Rhode Island and Connecticut, with observations on Atlantic coast granites in general: Bull. Geol. Soc. America, vol. 10, 1899, pp. 361-382, especially pp. 365-370, 375, 376, and pl. 35. Rice, W. N., and Gregory, H. E., Manual of the geology of Connecticut: Connecticut State Geol. and Nat. Hist. Survey, Bull. 6, 1906, pp. 115, 136, 152, 154, 155.

^b Gregory, H. E., and Robinson, H. H., Preliminary geologic map of Connecticut, Sterling granite gneiss (24), also the accompanying Outline of the geology of the State: Conn. State Geol. and Nat. Hist. Survey, Bull. 7, 1907, p. 36.

granites had been subjected to an amount of lateral compression sufficient to crush, elongate, rearrange, and recrystallize their par-

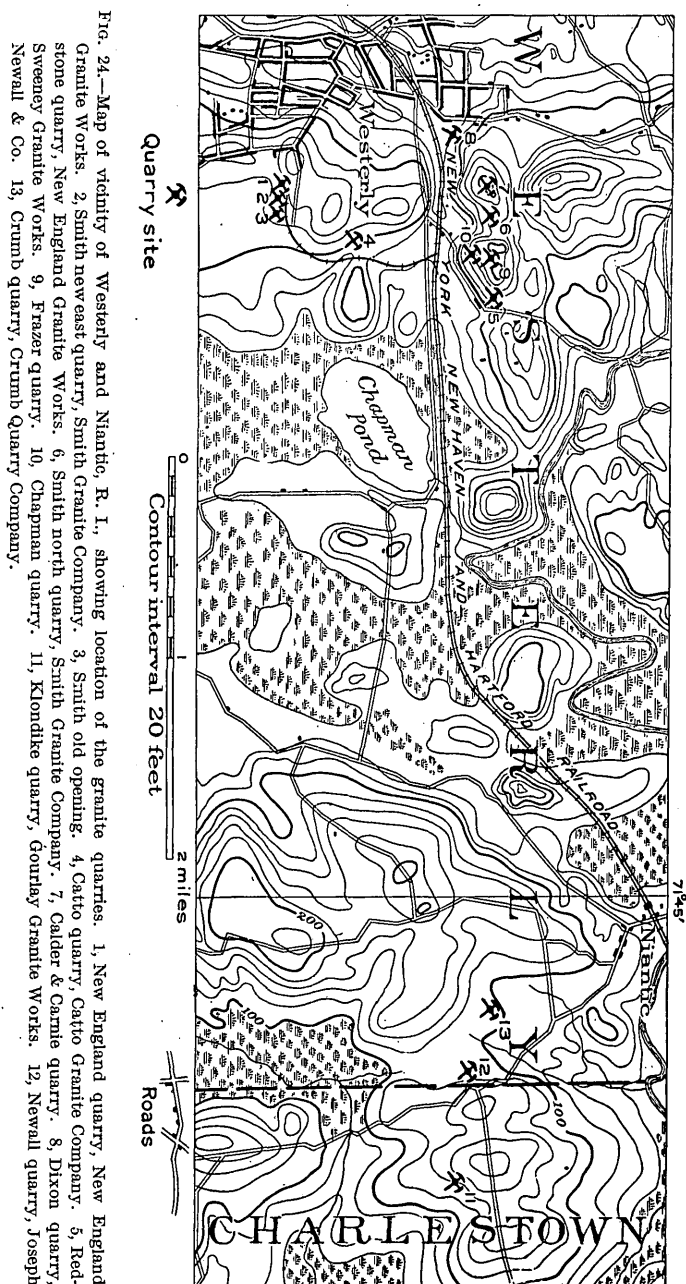


FIG. 24.—Map of vicinity of Westerly and Niantic, R. I., showing location of the granite quarries. 1, New England quarry, New England Granite Works. 2, Smith northeast quarry, Smith Granite Company. 3, Smith old opening, Smith Granite Company. 4, Catto quarry, Catto Granite Company. 5, Red-stone quarry, New England Granite Works. 6, Smith north quarry, Smith Granite Company. 7, Calder & Carnie quarry. 8, Dixon quarry, Sweezy Granite Works. 9, Frazer quarry. 10, Chapman quarry. 11, Klondike quarry, Goutley Granite Works. 12, Newall quarry, Joseph Newall & Co. 13, Crumb quarry, Crumb Quarry Company.

ticles and thus change them into a gneiss. The amount of this change is not always uniform. At some time prior to the intrusion

of the Westerly granite the granite gneiss was traversed by pegmatite dikes. The Westerly granites themselves were later also traversed by pegmatite dikes and at a still later time by basic dikes. These dikes are probably of Triassic age, as are the trap ridges of New Haven and the Connecticut Valley. Thus the Westerly region bears records of at least five periods of igneous activity.

Geology of Westerly and Niantic quarries.—That the fine statuary granite is of later date than the coarser red granite (Sterling granite gneiss) is clear from their relations at the Redstone, Smith north, and Calder & Carnie quarries. That the red granite itself is older than a banded biotite gneiss follows from its containing inclusions of it. Northeast of Westerly the fine statuary granite was intruded into the red granite, but at the Smith and Catto quarries (figs. 25, 26) it or its associated fine blue granite was intruded into a finely banded biotite gneiss not unlike that in the red granite, and at the Klondike, Newall, and Crumb quarries, near Niantic (Pl. IX, A, and fig. 27), it was intruded into a porphyritic biotite gneiss, which may be simply a more gneissic phase of a coarser Sterling granite gneiss than that exposed at the Redstone and Dixon quarries. But the finely banded gneiss of the other quarries and of the inclusions resembles the inclusions in the Redstone granite and differs from that granite itself both by the absence of microcline and by the predominance of oligoclase or of oligoclase-andesine to andesine so as to indicate that these finely banded gneisses belong to another formation, possibly to the Putnam gneiss of Connecticut geologists. The strike of the banded biotite gneiss is N. 35° W. at the Smith quarry.

The fine Westerly granites appear in dike-like masses from 50 to 150 feet thick, striking N. 75°–90° W., and dipping 30°–45° about south. At the Smith quarry they are underlain by a parallel mass of aplitic granite of similar character, carrying also inclusions of finely banded biotite gneiss. At the Klondike quarry the granite has a flow structure striking N. 10°–20° W., intersecting the course of the apparent dike. It is uncertain whether these are granite dikes or protuberances from a broad intrusive mass which have become exposed by the erosion of the thinner parts of the overlying gneiss.

The phenomena at the quarries indicate the following as the probable order of geological events about Westerly: (1) A finely banded biotite gneiss forms the surface; (2) intrusion by the red granite of the hill northeast of Westerly with a northeasterly flow structure, and also by the gray granite of Niantic; (3) metamorphism of the red and gray granite converting it about Niantic into a porphyritic gneiss (Sterling granite gneiss); (4) intrusion of the Westerly and Niantic fine granites, in some places into the earlier banded biotite gneiss, in others into the more or less altered Sterling granite gneiss; (5) peg-

matite and aplite dikes traverse both the Westerly granites and the Sterling granite gneiss, some in the latter, however, are connected with the intrusion of the finer granite; (6) a diabase dike traverses both the Westerly and the Sterling granite and the pegmatite dikes in the latter at the Redstone quarry. This occurred probably in Triassic time.

The chief joint course in the fine granites is N. 10° – 25° E. but the following also occur: N. 35° – 40° E., N. 50° – 60° E., N. 10° – 22° W., N. 45° – 55° W. In the older red granite the courses are N. 35° – 45° E. and N. 60° W. The rift is reported, in the fine granites, as either horizontal or inclined 10° north or south, and the grain as either vertical or 75° north, with an east-west or N. 65° W. or N. 70° E. course, in one instance with a dip of 45° S. 20° W., in another as scarcely perceptible. In the coarser granite the rift is reported as dipping 20° east or west. A compressive strain is reported as coming from the north and south, east and west, and northeast and southwest.

Description of Westerly granites.—The following summarizes the more detailed descriptions of specimens and thin sections, from both Westerly and Niantic quarries, given on pages 194–209.

“Westerly white statuary” granite is a quartz monzonite of more or less pinkish or buff medium-gray color, and of very fine even-grained texture, with slender feldspars not over 0.1 inch long and slender micas not over 0.15 inch long. Its constituents, in descending order of abundance, are: Pale smoky quartz; clear, colorless to milk-white soda-lime feldspar (oligoclase-albite to oligoclase); in nearly equal amount, slightly pinkish or cream-colored potash feldspar (microcline and orthoclase); and black mica. Magnetite and pyrite are among the accessory minerals, and calcite is among the secondary.

“Blue Westerly” granite is a quartz monzonite of more or less bluish medium-gray color, with fine black particles and of fine even-grained texture, with feldspars up to 0.1 or 0.2 inch and mica to 0.1 or 0.15 inch long. Its constituents, in descending order of abundance are: Clear to milk-white, pinkish or cream-colored soda-lime feldspar (oligoclase-albite to oligoclase); more or less transparent bluish or greenish potash feldspar (microcline and orthoclase); and black mica. Magnetite and pyrite are among the accessory minerals, and calcite is among the secondary.

“Red Westerly” granite is a biotite granite of reddish-gray color speckled with black and of even-grained medium, inclining to coarse, texture, with feldspars under 0.4 inch, exceptionally 0.5 inch, and mica up to 0.2 inch long. Its constituents, in descending order of abundance, are: Reddish potash feldspar (microcline and orthoclase-albite); and black mica. Both feldspars are in places stained

red from hematite, resulting from the oxidation of magnetite particles, which with pyrite is among its accessory minerals. Secondary calcite is present.

Estimates of the mineral percentages in the statuary granite, obtained by applying the Rosiwal method to camera lucida drawings of parts of two thin sections enlarged 40 diameters, yield the following results, with mesh of 1 and 1.4 inches and total linear lengths of 40 and 33.6 inches.

Estimated mineral percentages in Westerly-statuary granite.

| | |
|---|--------------|
| Quartz..... | 36.09 |
| Oligoclase-albite to oligoclase (soda-lime feldspar)..... | 30.63 |
| Microcline and orthoclase (potash feldspar)..... | 28.44 |
| Biotite (black mica)..... | 3.59 |
| White mica..... | .50 |
| Magnetite..... | .75 |
| | <hr/> 100.00 |

The average diameter of the particles, obtained by the same measurements, is 0.175 millimeter or 0.0069 inch. Measurements of the larger particles in four thin sections of this granite, made with the micrometer, give the following figures: Microcline and orthoclase 0.50 to 0.95 millimeter, oligoclase 0.56 to 1.122 millimeters, biotite 0.39 to 0.56 millimeter, white mica 0.168 to 0.392 millimeter, quartz 0.50 to 1.122 millimeters, magnetite 0.112 to 0.224 millimeter. The feldspars, quartz, and biotite in their coarser particles thus range from 0.39 to 1.122 millimeters, or 0.015 to 0.0439 inch.

Two estimates of the mineral percentages in "Westerly blue" granite (pp. 195, 208), made in the same way,^a average:

Estimated mineral percentages in Westerly blue granite.

| | |
|---|--------------|
| Soda-lime feldspar (oligoclase-albite to oligoclase)..... | 44.48 |
| Quartz..... | 25.28 |
| Potash feldspars (microcline 11.03, orthoclase 9.26)..... | 20.29 |
| Biotite (black mica)..... | 5.90 |
| White mica..... | 1.53 |
| Magnetite..... | 1.16 |
| Pyrite..... | .05 |
| Allanite and apatite..... | 1.31 |
| | <hr/> 100.00 |

The average diameter of the particles, obtained by the application of the same method to three Westerly blue granites, is 0.0099 inch, or about 50 per cent larger than that of the statuary.

An estimate of the mineral percentages in red Westerly granite will be found on page 200.

^a As bearing upon other methods of making such estimates of the mineral percentages in Westerly granites see Williams, I. A., The comparative accuracy of the methods for determining the percentages of the several components of an igneous rock: *Am. Geol.*, vol. 35, Jan., 1905, pp. 34-46.

Kemp^a gives two analyses of Westerly granite made by F. W. Love, then of Cornell University, which are repeated here for reference.

Analyses of Westerly granites by F. W. Love.

| | Gray granite. | Red granite. |
|---|------------------|------------------|
| | <i>Per cent.</i> | <i>Per cent.</i> |
| SiO ₂ (silica) | 71.64 | 73.05 |
| Al ₂ O ₃ (alumina) | 15.66 | 14.53 |
| Fe ₂ O ₃ (iron sesquioxide) | 2.34 | 2.96 |
| FeO (iron oxide) | | |
| MnO (manganese oxide) | Trace. | Trace. |
| CaO (lime) | 2.70 | 2.06 |
| Na ₂ O (soda) | 1.578 | 1.72 |
| K ₂ O (potash) | 5.60 | 5.39 |
| H ₂ O (water) | .482 | .29 |
| | 100.000 | 100.00 |

Kemp gives 2:654 as the specific gravity of the gray analyzed.

Messrs. Sullivan and Schaller, chemists, of the United States Geological Survey, find that 5 specimens of Westerly granites contain the following percentages of CaO (lime) soluble in hot dilute acetic acid, which indicate the presence of the percentages of CaCO₃ (lime carbonate) shown in the second column. All these granites effervesce slightly with cold dilute muriatic acid.

Lime and lime carbonate in Westerly granite.

| Name of granite. | CaO. | CaCO ₃ . |
|----------------------|------|---------------------|
| White statuary | 0.34 | 0.6 |
| Blue, Westerly | .176 | .312 |
| Red Westerly | .25 | .446 |

The "white," really buff to slightly pinkish gray, and the "blue," really bluish gray, Westerly granites are strictly monumental granites, but the former may be called a statuary granite, as it lends itself to the most delicate carvings. The fineness of its texture becomes more apparent in comparing it with that of statuary marbles. Vogt classifies European marbles by texture in five groups:^b Extremely fine, in which the particles measure from 0.02 to 0.03 millimeter; very fine (Carrara ordinary), from 0.1 to 0.3 millimeter; moderately fine (Carrara statuary), from 0.25 to 0.75 millimeter; somewhat coarse, from 0.75 to 2 millimeters, and moderately coarse, from 1 to 3 millimeters. West Rutland, Vt., statuary marble measures from 0.07 to 0.3 millimeter, averaging 0.15 by micrometer.^c As the Westerly statuary granite averages by the Rosiwal method 0.175 millimeter, and its coarse particles by micrometer from 0.39 to 1.122

^a Kemp, J. F., *Granites of southern Rhode Island and Connecticut, with observations on Atlantic coast granites in general*: Bull. Geol. Soc. America, vol. 10, 1899, p. 375.

^b Vogt, J. H. L., *Der Marmor, seine Geologie, Struktur, und seine mechanische Eigenschaften*: Zeitsch. prakt. Geol., 1898, p. 12.

^c Bull. U. S. Geol. Survey No. 195, 1902, p. 14.

millimeters, its texture is but a trifle coarser than West Rutland statuary marble and between Carrara statuary and Vogt's "somewhat coarse" grade. It takes a high polish and its hammered surface is light, offering, as quartz monzonites generally do, a marked contrast of shade to the polished surface.

Although "blue Westerly" granite is 50 per cent coarser in texture than the "white Westerly statuary" it lends itself well to monumental and sculptural work, as is shown by Pl. IX, *B*. Its polish is not quite so high as that of the "white," owing to the larger size of its mica scales, but its contrast of shade is equally strong.

"Red Westerly" granite is used only for constructional purposes.

The Westerly quarries.—*The New England quarry* is nine-tenths of a mile southeast of the Westerly station and 100 feet above it. (See fig. 24.) Operator, The New England Granite Works, Westerly, R. I.

The granite is of two varieties: The first (specimens D, XXVIII, 1, f, i), "white Westerly statuary," is a quartz monzonite of very slightly pinkish medium-gray color, and of very fine even-grained texture, with very slender feldspars not over 0.1 inch long and slender mica scales rarely 0.1 or 0.15 inch long. The average diameter of all its particles, including the magnetite, as determined by the Rosiwal method, is 0.0069 inch or 0.175 millimeter, as given on page 192. Its constituents, in descending order of abundance are: Pale smoky quartz with hairlike crystals of rutile and a few cavities; clear colorless to milk-white soda-lime feldspar (oligoclase-albite to oligoclase), partly kaolinized and micacized; in almost equal amount, slightly pinkish or cream-colored potash feldspar (microcline and orthoclase), some of it intergrown with quartz circular in cross section; biotite (black mica), some of it chloritized and interleaved with white mica or else partially bleached; some separate muscovite may be present also. Accessory minerals are: Magnetite (ilmenite?), titanite, pyrite, allanite, apatite, zircon, and rutile. Secondary: Kaolin, one or two white micas, chlorite, and carbonate.

On the west side of a pegmatite dike referred to on page 196 this granite is decidedly pinkish, strictly a medium pinkish gray, owing, apparently, to hematitic stain in the kaolinized oligoclase. Some of the microcline is also kaolinized and micacized (specimen D, XXVIII, 1, e).

Estimates of mineral percentages in this stone have been given on page 192.

Mr. W. T. Schaller, chemist, of the United States Geological Survey, finds that it contains 0.34 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates a content of 0.6 per cent CaCO₃ (lime carbonate), the presence of which carbonate is shown by the microscope and by a slight effervescence with cold dilute muriatic acid.

A compression test made for the firm at the United States Arsenal at Watertown, Mass., in 1907, with a cube of about 2-inch face, gave this granite an ultimate compressive strength of 39,750 pounds per square inch. The direction of rift or grain with reference to pressure was not noted.

The sculptural qualities of this stone have already been dwelt upon. The great fineness of its particles contributes to its high polish. The polished face shows minute particles of magnetite and a few of pyrite. It hammers light gray and the contrast between this and the shade of the polished face is somewhat marked.

The second variety (specimens D, XXVIII, 1, c, cc), "old blue Westerly," is a quartz monzonite of very slightly bluish medium-gray color with fine black particles. Its texture is even grained fine, with feldspars up to 0.2 inch and mica to 0.15 inch. Its constituents, in descending order of abundance, are: Clear to milk-white or pinkish soda-lime feldspar (oligoclase-albite to oligoclase), much of it kaolinized and micacized; pale smoky quartz with a few needle-like crystals, probably of rutile, and with cavities in sheets; clear to blue-greenish and grayish potash feldspar (orthoclase and microcline), intergrown with quartz, circular in cross section, and slightly mica-cized; biotite (black mica), some of it chloritized, and with needle-like crystals of rutile (?); muscovite or bleached biotite. Accessory: Magnetite (ilmenite?), pyrite, apatite, allanite, zircon, and rutile. Secondary: Kaolin, two white micas, chlorite, carbonate, and rarely hematite and epidote.

An estimate of the mineral percentages, obtained by applying the Rosiwal method to a camera lucida drawing of part of a thin section enlarged 40 diameters, yields the following results with a mesh of 1.7 inches, and total linear length of 42 inches.

Estimated mineral percentages in "blue Westerly" granite from the quarry of the New England Granite Works.

| | |
|---|---------------|
| Quartz..... | 21. 15 |
| Soda-lime feldspar (oligoclase-albite to oligoclase)..... | 52. 64 |
| Potash feldspars (microcline 4.14, orthoclase 10.51)..... | 14. 65 |
| Biotite (black mica)..... | 5. 52 |
| White mica..... | 3. 05 |
| Magnetite..... | 1. 71 |
| Allanite..... | 1. 28 |
| | <hr/> 100. 00 |

No great value need to be attached to the figures for allanite, as a shifting of the mesh would have thrown it out altogether.

The average diameter of the particles obtained by the same method is 0.0112 inch.

Mr. E. C. Sullivan, chemist, of the United States Geological Survey, finds that this stone contains 0.20 per cent of CaO (lime) soluble in hot

dilute acetic acid which indicates a content of 0.35 per cent of CaCO_3 (lime carbonate), the presence of which carbonate is also shown by the microscope and by a very slight effervescence with cold dilute muriatic acid.

A compression test made for the firm at the United States Arsenal at Watertown, Mass., in 1907, with a cube of about 2-inch face, gave it an ultimate compressive strength of 31,970 pounds per square inch. The direction of rift or grain with reference to pressure was not noted.

This stone takes a high polish, but the mica scales, being a little larger than in the "white statuary," show more on the surface. The polished face shows not a little magnetite in fine particles, with rare grains of pyrite. The combination of a slightly bluish with a slightly pinkish feldspar, both in fine particles, results in a peculiar gray in the polished face. The hammered face is light gray and in contrast to the shade of the polished surface.

The quarry, opened about 1860, measures about 300 feet in a west-northwest direction by 200 feet north-northeast, and from 40 to 80 feet in depth. Within 20 feet west-northwest of it is another opening, not used in 1906, of about the same size, which it was proposed to unite with the main opening so as to obtain a working face 600 feet long.

The sheets, from 6 inches to 12 feet thick, are horizontal but somewhat irregular, owing to incomplete development, "growing on." There are two sets of joints: Set A, striking N. 15° – 25° E. and vertical, is spaced 8 inches to 30 feet, and forms a heading 15 to 20 feet wide on the west side, separating it from the older excavation, and another 5 to 10 feet wide on the east side, which divides this from the adjacent Smith quarry. Set B, striking N. 50° – 55° W. and vertical, is spaced 18 inches to 30 feet. The rift is reported as horizontal and the grain as vertical with N. 65° W. course. There is a 2-inch pegmatite dike striking N. 37° E. and dipping 75° E., consisting of pink potash feldspar, amethystine quartz and muscovite; the feldspar is partly altered to light-green epidote. Pegmatite dikes also traverse the heading on the west side. Rusty stain is from 1 to 7 inches thick on the sheet surfaces. There is much kaolinization of feldspar and limonite stain adjacent to the pegmatite dikes. On the south-southwest wall the granite is in contact with a southerly-inclined overhanging mass of dark biotite gneiss with a vertical foliation. This is also crossed by pegmatite dikes. The line of contact between granite and gneiss is jagged in places. The relations on the north wall are now largely concealed by dumps, but their character is well exposed in the adjoining Smith quarry and they are described on page 198. The structural relations of the pinkish-gray and bluish-gray granite to one another are not clear. At one point on the south-southwest wall the former seems to underlie the latter and

there seem to be also lateral changes in the color of both near the dike which are possibly caused by it. The width of the granite from north-northeast to south-southwest does not exceed 150 feet measured at right angles to dip.

The plant includes 6 derricks, 3 hoisting engines, 3 engines for hoisting and general work, a 10-ton locomotive crane, a small locomotive, 3 air compressors (capacity 540,250,125 cubic feet of air per minute), 3 large drills, 8 air-plug drills, 40 air-hand tools, 4 surfacers, 2 saws for stones 13 feet long, 4 lathes for stones 3 to 6 feet long, 7 polishers, a polisher for moldings, 2 polishing lathes for stones 4 feet long, 2 stone borers, and 3 steam pumps.

Transportation is by a siding from the New York, New Haven and Hartford Railroad. (See map, fig. 24.)

Ninety-eight per cent of the product is used in monumental work, the rest, "old blue," only in buildings, and the waste for paving; particularly, small blocks for electric roads. Specimen monuments: National monument, Gettysburg, Pa.; Antietam monument, Maryland. The Horne monument, with a 7 foot 6 inch figure of the statuary granite, Homewood Cemetery, Pittsburg, Pa. Pl. IX, *B*, shows lilies and passion flowers on the base of a recently finished cross of the "blue" stone. Specimen buildings of the "blue": Connecticut Mutual Insurance Building, Hartford; Mutual Life Insurance Building, Philadelphia.

The Smith quarry adjoins on the east the one just described, and is about nine-tenths of a mile southeast of Westerly station and 100 feet above it. (See fig. 24.) Operator, The Smith Granite Company, Westerly, R. I.

The granite consists of the identical two varieties, "Westerly white statuary" and "Westerly blue," already described from the New England quarry. Both are quartz monzonites; the first, a slightly pinkish medium gray of even-grained very fine texture; the second, a slightly bluish medium gray of even-grained fine texture. (For full descriptions see pp. 194, 195.)

The quarry, first opened in 1846, consists of two openings. The "New East quarry," separated from the New England quarry only by a heading, is 250 feet east-southeast by 200 feet across and 65 feet deep; the other, older one, contiguous to the last on the east, is about 400 feet east southeast by 125 feet across and 150 feet deep.

The sheets in the upper 25 feet are from 2 inches to 2 feet thick, and below that from 9 inches to 5 feet thick, and all horizontal. There is only one set of joints, which strikes N. 20°-22° E., is spaced 100 to 300 feet, and forms a 50-foot heading between the two openings, and a 5 to 10 foot one between the western opening and the New England quarry. The rift is reported as horizontal and the grain as vertical, with a N. 65° W. course. The apparent relations of the

granite are shown in fig. 25. On the south-southwest the granite is overlain by a mass of dark-gray banded biotite-hornblende gneiss of somewhat fine texture, "black horse," which strikes N. 30° W. and dips 45° SSW. The rock contains much soda-lime feldspar (oligoclase-andesine to andesine), but no microcline. On the north-northeast the granite is apparently underlain at 45° by a mass of granite (quartz monzonite) of more or less pinkish-gray color and of somewhat fine texture with a variable amount of black mica, so as in places to resemble an aplite. It is also marked in places by dark brownish stains, one-quarter inch in diameter and an inch or so apart, which are due to the alteration of allanite particles into hematite and limonite. This rock contains many angular inclusions, large and small, of a somewhat finely banded biotite gneiss which itself contains lenses and dikes of pegmatite parallel to its schistosity and evidently formed before the intrusion of the quartz monzonite. The northward extent of this mass has not yet been determined. The foreman states that the "blue granite" at the bottom of the larger opening contained an inclusion 10 feet in diameter like the inclusions of gneiss

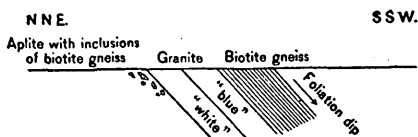


FIG. 25.—Structure at the Smith quarry, Westerly, R. I., looking east-southeast.

above described. In this opening about 40 feet of blue intervene between the overlying gneiss and the white statuary, as shown in fig. 25, but in the smaller opening these relations are reversed. The entire width of the mass of blue and white

granite appears to be between 80 and 100 feet, measured at right angles to its inclination. There can be no question as to the extension of these granites below, but whether they continue downward at the same angle or widen out horizontally under the gneiss mass on the south can only be determined by core-drilling. The heading which separates the two openings is much broken by subjoints parallel to it. For a thickness of 8 feet on the west it is altered to a dull greenish-reddish color. In thin section this shows the feldspars kaolinized, micacized, and chloritized, most of the biotite bleached, the magnetite passing into hematite and the pyrite into limonite. As its soda-lime feldspar is oligoclase-andesine, differing from that of the adjacent granite, this heading may be a transverse granite dike.

The plant comprises 8 derricks (one with a capacity of 50 tons), 8 hoisting engines, an engine for general work, 2 air compressors (capacity, 400 and 150 cubic feet of air per minute), 3 large air drills, 2 air plug drills, 27 air hand tools, 2 surfacers, a MacDonald surfacer, 2 stone lathes for stones 19 by 5 feet and 5 feet by 15 inches, a horizontal polisher, 5 vertical polishers, 2 polishing lathes, and 2 steam pumps.

Transportation is by a siding from the New York, New Haven and Hartford Railroad, but paving stones are carted one-third mile to wharf on Pawcatuck River.

The product is nearly all used for monuments; the waste goes into paving blocks of various sizes. Specimen monuments: Equestrian statue of Washington erected by the United Order of American Mechanics at Allegheny, Pa.; Roger Williams monument at Roger Williams Park, Providence, R. I.; First Massachusetts Volunteer Infantry monument, Gettysburg, Pa.; Ohio State monument, Vicksburg, Miss.; Jay Gould mausoleum, Woodlawn Cemetery, New York; J. G. Fair mausoleum, San Francisco.

The Catto quarry is about a mile east-southeast of Westerly station, 60 feet above it, and one-half mile northeast of the Smith and New England quarries. (See fig.

24.) Operator, Catto Granite Company, Westerly, R. I.

The granite (specimen D, XXVIII, 9, a), "blue Westerly," is a quartz monzonite of very slightly bluish medium-gray color with fine black particles. It is a trifle more bluish than that of the New England quarry. Its texture is fine with feldspar and mica up to 0.1 inch, the former exceptionally 0.16 inch. It is thus a trifle finer than specimens D, XXVIII, 1, c, cc (p. 195). As its constituents are identical with those of that granite, they are not repeated here.

The quarry, opened before 1886, is about 350 feet east-west by 200 feet across and from 75 to 100 feet in depth.

The sheets, from 6 inches to 10 feet thick, dip north at a low angle. But one set of joints occurs. This strikes N. 22° W., is vertical, spaced 3 to 50 feet, and is discontinuous below. The rift is reported as horizontal, and the grain as scarcely perceptible. Rusty stain measures up to an inch thick on sheet surfaces. The east face of quarry shows the relations of the granite to overlying banded gneiss. (See fig. 26.) This strip of gneiss extends the entire width of the quarry, with a foliation striking N. 65° W. and dipping 65° NNW. As the granite crops out in places above the gneiss this may be a very large inclusion, but probably from immediately under the original capping. The gneiss was so broken up here that hand specimens, half granite and half gneiss, with granite cutting the gneiss foliation can be readily obtained. The gneiss is rather fine grained and con-

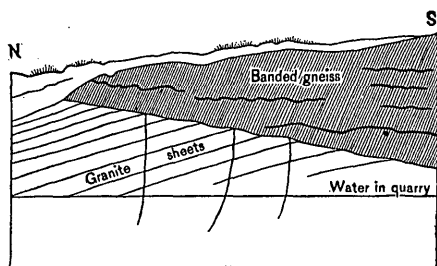


FIG. 26.—Diagram of east face of Catto quarry, Westerly, R. I., showing granite overlain by a mass of biotite gneiss, each with its own sheet structure. Length, 65 feet; height above quarry water, 50 feet.

sists of dark-gray very biotitic bands, 0.1 to 0.3 inch wide, alternating with light-gray bands with little biotite and with very light ones without any. The dominant feldspar is oligoclase. There is no microcline.

The plant consists of 3 derricks, 3 hoisting engines, 2 steam drills, and 3 steam pumps.

Transportation is by a siding from the quarry to the main siding of New York, New Haven and Hartford Railroad.

In 1906 the firm was filling a contract for 500,000 paying blocks for Jersey City.

The Redstone quarry is less than $1\frac{1}{2}$ miles east-northeast of Westerly station, at the east foot of an east-west ridge, one-fourth mile north of the New York, New Haven and Hartford Railroad. (See fig. 24.) Operator, the New England Granite Works, Westerly, R. I.

The chief granite of this quarry (specimens D, XXVIII, 2, b, h), "red Westerly," is a biotite granite of reddish-gray color speckled with black. Its texture is even grained, medium, inclining to coarse, with feldspars under 0.4 inch, exceptionally 0.5 inch, and mica to 0.2 inch. Its constituents, in descending order of abundance, are: Reddish potash feldspar (microcline and orthoclase), some of it slightly micacized, intergrown with quartz in vermicular structure, in places also with soda-lime feldspar; smoky quartz with hairlike crystals, probably of rutile, also with cavities in sheets with rift cracks parallel to them; cream-colored striated soda-lime feldspar (oligoclase-albite), kaolinized and micacized, and intergrown with quartz like the other; and biotite (black mica), some of it bleached. Accessory: Magnetite, pyrite, apatite, zircon, and rutile. Secondary: Kaolin, two white micas, hematite stain from magnetite particles, in places reddening both feldspars, and calcite.

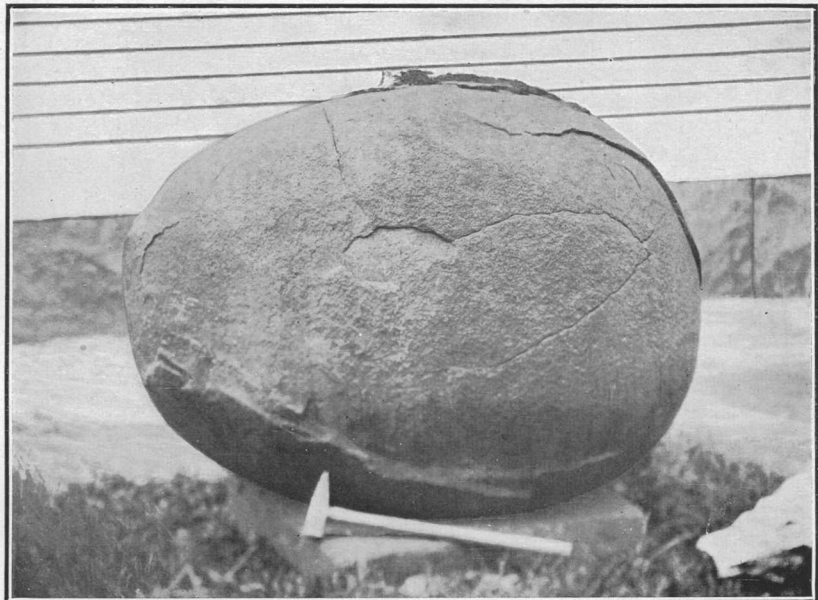
An estimate of the mineral percentages by the Rosiwal method yields the following results with a mesh of one-half inch and total linear length of $33\frac{1}{2}$ inches:

Estimated mineral percentages in "red Westerly" granite from the Redstone quarry.

| | |
|---|--------------|
| Potash feldspar (microcline and orthoclase) | 35.40 |
| Quartz..... | 29.87 |
| Soda-lime feldspar (oligoclase-albite) | 28.35 |
| Biotite (black mica)..... | 6.74 |
| (Both feldspars, 63.39.) | |
| | <hr/> 100.00 |

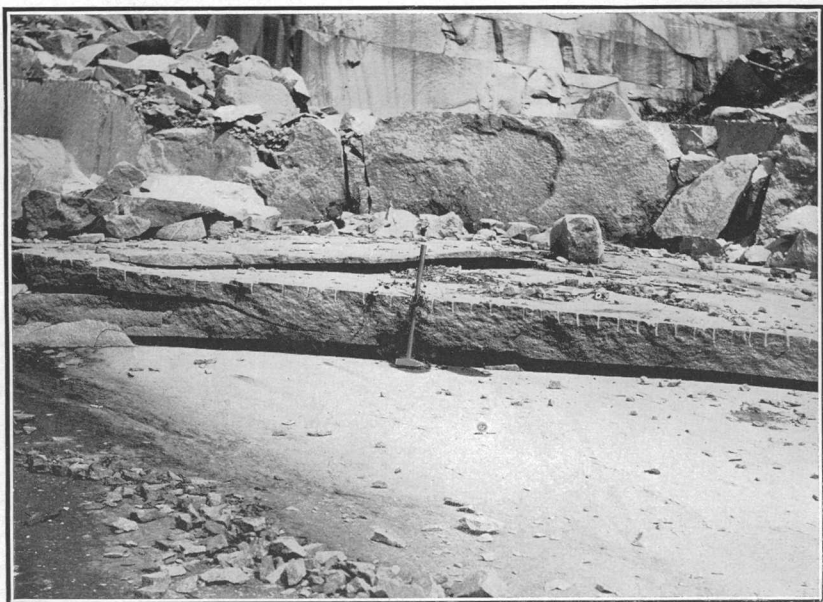
An analysis of this granite by Love has been given on page 193.

Mr. W. T. Schaller, chemist, of the United States Geological Survey, finds that it contains 0.25 per cent of CaO (lime) soluble in hot dilute acetic acid, which indicates a content of 0.446 per cent of CaCO_3 .



A. OVOIDAL BLOCK OF FINE STATUARY GRANITE (QUARTZ MONZONITE), PRODUCED BY WEATHERING WITHIN A HEADING AT REDSTONE QUARRY, WESTERLY, R. I.

Hammer $20\frac{1}{2}$ inches long.



B. GRANITE QUARRY AT WEST FOOT OF BLACK MOUNTAIN, WEST DUMMERSTON, VT.

Showing thin sheets formed after opening of quarry and parted by a compressive strain operating about north and south. Hammer about 30 inches long; head 6 inches long.

(lime carbonate), the presence of which carbonate is shown by the microscope and also by a slight effervescence with cold dilute muriatic acid.

A compression test made for the firm at the United States arsenal at Watertown, Mass., in 1907, with a cube of about 2-inch face, showed the first crack with 106,000 pounds and final fracture with 113,000 pounds, indicating an ultimate compressive strength of 28,540 pounds per square inch. The direction of rift or grain with reference to pressure was not noted.

The contrasts between the colors of the two feldspars come out strongly on the polished face which shows considerable magnetite and some pyrite. The size of the mica plate is not favorable to the durability of the polish in long-continued outdoor exposure. It is a constructional granite of warm tint.

The quarry, opened in 1880, measures about 850 feet, north-south by 250 feet east-west with a working face 100 feet high on west.

The sheets, from 1 to 20 feet thick, are somewhat irregular. In the upper part most of them dip 10° about west-northwest, a few are horizontal, but lower down all are so. At the south end the sheets are intersected by sharply curved partings ("toe nails"). There are inclusions of finely banded biotite gneiss resembling the capping at the Smith and Catto quarries. The rift is reported as horizontal and the grain as fairly defined and vertical with a N. 20° E. course. There is but one set of joints, and that strikes N. 35° E., dips 70° S. 35° E. to 90° , is spaced 15 to 50 feet, and forms a heading in the center of the quarry and a heading at extreme north end which is 40 feet wide. A dike 5 to 10 feet thick runs the whole length of the quarry, with a dip of 10° S., consisting of alternating reddish aplite and coarse pegmatite (reddish feldspar, smoky quartz, and biotite), some of the surfaces of which are coated with iridescent drusy hematite. Beneath this almost horizontal dike is a mass of unknown extent of fine pinkish-gray statuary granite (quartz monzonite) like that at Smith and New England quarries described on page 194. This reaches the surface at the north end of quarry, but excavations at the south end will not expose it until 1908. The ovoidal mass, shown in Pl. VIII, A, and described on page 58, came from the 40-foot heading which crosses this quartz monzonite at the north end of quarry. Near the center is a meandering vertical dike, 6 inches thick, of porphyritic olivine diabase, striking N. 45° E., probably of Triassic age. The dike rock is almost black with decomposing greenish crystals up to one-half inch long and with less abundant minute black crystals. It is incrustated with fibrous calcite and generally is slightly calcareous. In thin section the groundmass is of minute soda-lime feldspar crystals altered to white

mica, a little black mica, and magnetite. The large greenish crystals are olivine altered to serpentine and epidote and veined with calcite. The black ones are augite. The rock has undergone alteration and weathering but not metamorphism. Ten feet west of this dike is a vertical meandering mass of coarse biotite schist about 6 inches thick, striking about northeast with foliation parallel to its course. In thin section this consists of biotite, muscovite, quartz, an opaque cream-colored mineral (probably kaolinized feldspar), calcite, and magnetite. This is probably a basic segregation or "knot" elongated in the direction of the flow. Rust stain on the sheet surfaces is up to 3, rarely 4, inches thick. A thin section of it shows both feldspars stained with limonite. It follows irregular cracks in the microcline and the quartz, as well as the boundaries between them. It proceeds in some cases clearly from the larger grains of magnetite and from biotite scales.

The plant consists of 4 derricks, 3 hoisting engines, 2 air compressors (capacity 750 and 500 cubic feet of air per minute), 2 large drills, 25 air plug drills, 2 surfacers, and 2 steam pumps.

Transportation is effected by a siding from the New York, New Haven, and Hartford Railroad not shown on fig. 24.

The product is used entirely for buildings. Specimens: Washington Life Insurance, American Exchange, American Tract Society, and Travelers Insurance Company buildings in New York.

The Smith North quarry is a mile N. 60° E. from the Westerly station, 120 feet above it, in a saddle on the east-west ridge north of the railroad. (See fig. 24.) Operator, The Smith Granite Company, Westerly, R. I.

The granite is of two sorts, "red Westerly," a medium-grained biotite granite of reddish-gray color identical with that of the Red-stone quarry (specimens D, XXVIII, 2, b, h), described on page 200, and "pink Westerly" (specimen D, XXVIII, 4, a), which is a quartz monzonite of medium buff-gray color and of very fine even-grained texture, with feldspars mostly up to 0.057 inch, exceptionally 0.1 inch; and mica to 0.028, exceptionally 0.15 inch. It is identical in composition with the "white Westerly statuary," described on page 194, but is of more pinkish tint. Its soda-lime feldspar is oligoclase.

The quarry, opened before 1892, is about 200 feet east-west by 150 feet across, with a working face 75 feet high on the west and 25 feet on the east.

The sheets, from 6 inches to 10 feet thick, are lenticular, but very irregular and without uniform dip. The only set of joints strikes N. 10° E., is vertical or nearly so, and is spaced 20 to 40 feet. The rift is reported as dipping 10° S. and the grain 75° N. Sixty feet of the fine granite overlie the "red," the plane of their contact dip-

ping 40° – 50° about south. At the top of the working face a pegmatite dike 10 feet thick dips 45° S. Rusty stain is only 2 inches thick on sheet faces.

The plant consists of 3 derricks, 3 hoisting engines, a steam drill, and 3 steam pumps.

Transportation is by cartage of one-fourth mile to New York, New Haven and Hartford Railroad. The cutting of the fine stone is done at the company's sheds at Westerly.

The product, thus far, has consisted mostly of the pink statuary, the underlying constructional granite not being yet much exposed.

The Calder & Carnie quarry is nine-tenths mile N. 50° E. from the Westerly station, and 160 feet above it, on the western hump of the ridge north of railroad. (See fig. 24.) Operator, Calder & Carnie Westerly Granite Company, Westerly, R. I.

The granite (specimen D, XXVIII, 8, a), "Westerly pink statuary," is a quartz monzonite of medium pinkish-buff gray color, more pinkish than any of the other fine Westerly granites excepting specimen I, e, from next to the pegmatite dike in the New England quarry. Its texture is even grained, very fine, with feldspars not over 0.1 inch and mica still less. Its constituents are the same as those of the fine stone from the Smith north quarry, but with a little more hematite stain. The thin section shows carbonate, and the stone effervesces slightly with dilute muriatic acid. The quarry also yields the "red" constructional granite described on page 200.

The quarry, first opened in 1882 and recently reopened, is about 400 by 250 feet and 90 feet deep.

The sheets, from 6 inches to 8 feet thick, are horizontal and irregular. There are two sets of joints: Set A, striking N. 20° W., dipping 45° S. 70° W., spaced 2 to 8 feet, and discontinuous, forms a heading 10 feet wide in the center. One of these joints has subjoints, striking N. 30° W., one-half to 1 inch apart. Set B, striking N. 35° – 40° E., dipping 80° N. 37° W. and 90° , is spaced 2 to 8 feet. The rift is reported as dipping north at a low angle and the grain as striking N. 70° E. and dipping 45° S. 20° W. The fine granite occurs here as a dike dipping 45° S. and 50 feet thick, with the medium grained "red" on both sides of it. It also contains pegmatite dikes parallel to its course. Light pinkish streaks (veinlets?) from 0.1 to 0.3 inch thick cross the quarry in the flow direction. In thin section these are found to consist of slightly altered granite. Both feldspars are much kaolinized, and the oligoclase is also much micacized; the biotite is chloritized and epidotized. The quartz particles are crowded with sheets of cavities (with liquid and vacuoles), and these are parallel to the sides of the veinlet as well as in line with streaks of kaolinization in its feldspars. Along joints A the granite is much reddened for 1 to 2 inches. In this reddish zone the feldspars are

much kaolinized and micacized, the biotite is chloritized, epidote occurs, and the magnetite is altered to hematite, which has reddened the feldspars. Rusty stain is up to $4\frac{1}{4}$ inches thick on sheet surfaces.

The plant consists of 2 derricks, a hoisting engine, a steam drill, and pump.

Transportation involves cartage of three-fourths mile to a siding of the New York, New Haven and Hartford Railroad.

The product is used for monuments and buildings. In 1906 the firm had contracts for monuments for Quincy, Mass.; Manchester, N. H., and Erie and York counties, Pa.

The Dixon quarry is about one-half mile northeast of Westerly station at the west foot of the east-west ridge north of the railroad. (See fig. 24.) Operator, Sweeney Granite Works, Westerly, R. I.

The granite (specimen D, XXVIII, 7, a) is a biotite granite of medium buff-gray color with fine black particles. Its texture is medium inclining to coarse with feldspars up to 0.4 inch, exceptionally 0.5 inch, and mica to 0.15 inch. Its constituents, in descending order of abundance, are: Pinkish-gray potash feldspar (microcline and orthoclase), slightly kaolinized and intergrown with quartz and soda-lime feldspar; smoky quartz with cavities; greenish-gray striated soda-lime feldspar (oligoclase-albite), some of it much micacized and kaolinized; and biotite (black mica), some of it chloritized. Accessory: Magnetite, pyrite, apatite, allanite, and zircon. Secondary: Kaolin, two white micas, chlorite, limonite, hematite, and carbonate.

This is a constructional granite which is closely related to the "red" of the Redstone quarry, but in which the potash feldspars are less reddish and the soda-lime feldspars are greenish instead of cream colored.

The quarry consists of 3 openings: One 150 by 100 feet and 20 to 40 feet deep, one 100 by 75 feet and 40 feet deep, and another 100 by 50 feet and 10 to 30 feet deep.

The sheets, from 6 inches to 6 feet thick, are generally horizontal. There are 2 sets of joints: Set A, striking N. 45° E. and vertical, is spaced 50 to 100 feet and forms several headings. Set B, striking N. 60° W. and vertical, is spaced 50 feet and over and is less frequent than set A.

The plant comprises several derricks, hoisting engines, and a stone crusher which turns out material of 3 sizes.

Although the stone is adapted for buildings, only crushed stone was being produced in August, 1906.

The Frazer quarry is less than one-fourth mile west of the Redstone quarry, on the east-west ridge north of railroad. (See fig. 24.) No longer operated; owner, W. L. Frazer, Westerly, R. I.

The granite (specimen D, XXVIII, 5, a), "Westerly statuary," is a quartz monzonite of medium buff-gray color with very fine black particles. Its texture is even grained, very fine, with feldspars and mica up to 0.1 inch. Its constituents are the same as those of the other fine-textured grayish-pinkish Westerly granites described on page 191.

The quarry is about 250 by 200 feet and over 50 feet deep.

The sheets, 6 inches to 5 feet thick, are horizontal. Joints, striking roughly about north and dipping 60° – 70° W. or 90° , are spaced up to 20 feet and form headings on the east and west. There are inclusions of biotite gneiss on the dumps, also pieces of pegmatite consisting of pinkish microcline intergrown with quartz and oligoclase; smoky quartz, cream-colored oligoclase, and biotite.

The Chapman quarry is about south of the Frazer quarry near the foot of the ridge. (See fig. 24.) It is abandoned, but is mentioned here only because of its geological features.

A joint face forming the west wall and working face strikes N. 10° W. It is intersected at intervals of 1 to 3 feet by vertical joints striking N. 50° E. At the top is an inclusion of biotite gneiss 10 feet in diameter. Dipping 10° south across this face is a pegmatite dike about a foot thick. Between 20 and 30 feet below it is an aplite dike a few inches thick with like dip. The sheets are only from 1 to 3 feet thick, and the joint intervals are too short to make quarrying profitable. The granite is the fine-textured statuary (pinkish-gray) quartz monzonite, already described.

The Niantic quarries.—*The Klondike quarry* is in Charlestown, $1\frac{3}{4}$ miles southwest of Niantic station and $5\frac{1}{4}$ miles about east of Westerly station. (See fig. 24.) Operator, Gourlay Granite Works, Westerly, R. I.

The granite (specimens D, XXVIII, 11, c, g), "blue-white Westerly," is a quartz monzonite of medium bluish-gray color with very fine black particles. Its texture is fine with feldspars up to 0.1, exceptionally 0.2 inch, and mica to 0.05, exceptionally 0.1 inch. Its constituents, in descending order of abundance, are: Clear to milk-white or cream-colored striated soda-lime feldspar (oligoclase), partly kaolinized and micacized. In some crystals the altered part is central; in others it forms a zone with unaltered feldspar within and without it; slightly smoky quartz with hairlike crystals, probably of rutile, and very few cavities; more or less transparent bluish potash feldspar (microcline and orthoclase, the first intergrown with quartz); and biotite (black mica), some of it chloritized. Accessory: Magnetite, titanite, pyrite rare, apatite, allanite, zircon, and rutile. Secondary: Kaolin, a white mica, and carbonate.

Mr. E. C. Sullivan, chemist, of the United States Geological Survey, finds that this granite contains 0.18 per cent of CaO (lime) soluble in

hot dilute acetic acid, which indicates a content of 0.32 per cent of CaCO_3 (lime carbonate), the presence of which carbonate is also shown by the microscope and by a slight effervescence in cold dilute muriatic acid.

A compression test made for the firm at the United States Arsenal at Watertown, Mass., in 1907, with a cube of about 2-inch face, showed the first crack with 107,000 pounds, and final fracture with 118,000 pounds, showing an ultimate compressive strength of 29,500 pounds per square inch. The direction of rift or grain with reference to pressure was not stated.

This is a monumental granite of fine texture and bluish tint. Its texture is a little finer than that of the "old blue" of the New England quarry, and about the same as that of the Newall quarry (p. 207). It is more bluish than the former, not containing any pinkish feldspar, and, its mica particles being finer, it takes a higher polish. The polished face shows magnetite in fine particles, but scarcely any

pyrite. There is quite a little contrast of shade between the hammered and polished faces.

The quarry, opened in 1897, is about 600 feet east-west by 100 feet across and from 75 to 100 feet deep. (See Pl. IX, A.)

On the south side the stripping of drift increases

from 5 feet in thickness at the west wall to 35 feet at the east wall, owing to the inclination of the rock surface.

The sheets, from 1 to 8 feet thick, dip generally 5° S. There is but one set of joints, which strikes N. 25° E., dips 70° W., and is spaced 5 to 50 feet. The rift is reported as horizontal, but feeble. A flow structure, indicated by streaks of black mica, strikes N. 10° – 20° W. and dips west. There is a dike of aplite striking N. 25° E., dipping 70° W. The structural relations are shown in fig. 27 and Pl. IX, A. The granite appears to have reached the present surface in a dikelike mass, the sides of which dipped about 30° S., and cut a mass of porphyritic biotite gneiss, to be described beyond. The granite mass is about 75 feet thick, measured at right angles to its inclination. The foliation of the gneiss is not far from horizontal. Within the gneiss are dikes of pegmatite and aplite, which appear to begin at the granite contact meander and taper out upward. On the south side the sheet structure extends into the gneiss, as shown in Pl. IX, A. Fifteen feet below the gneiss the granite contains one or more angular

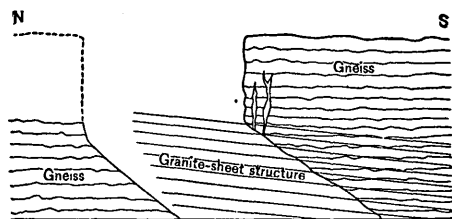
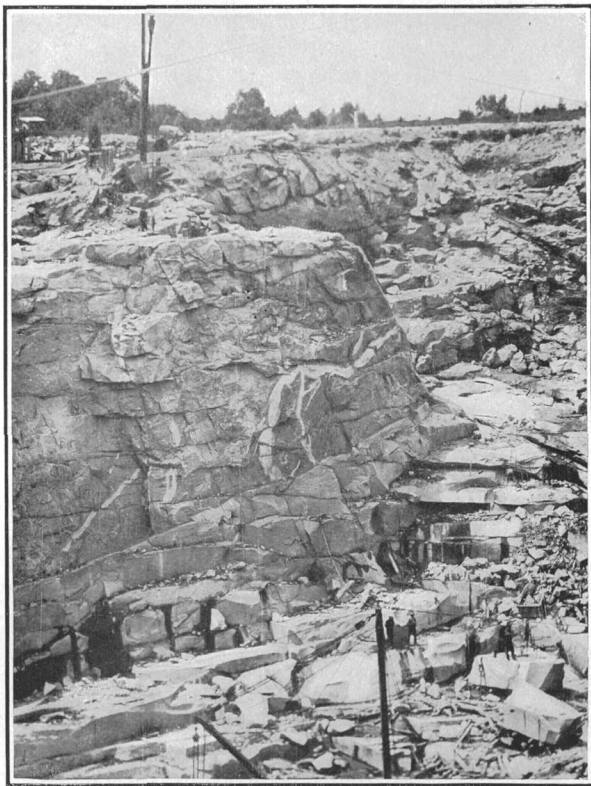
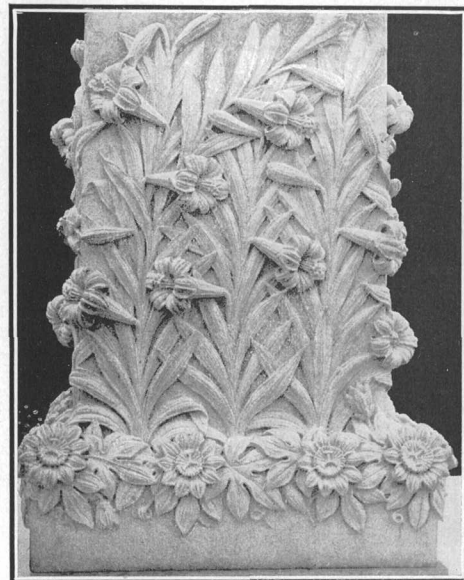


FIG. 27.—Approximate structure at the Klondike quarry, near Niantic, R. I.



A. CONTACT OF GRANITE WITH OVERLYING GNEISS ON WEST SIDE OF KLONDIKE QUARRY, NEAR NIANITIC, R. I.

Showing pegmatite dikes in the gneiss apparently starting from the granite surface; also sheet structure passing from granite into gneiss.



B. CARVING FROM WESTERLY BLUE GRANITE (QUARTZ MONZONITE), NEW ENGLAND GRANITE WORKS, WESTERLY, R. I.

inclusions of finely banded biotite gneiss. The problem presented by the structure here is whether this belt of granite 75 feet thick is simply a dike of indefinite depth or a minor protuberance in the undulating surface of a wide granitic intrusion which became exposed by the erosion of the overlying gneiss where it was thinnest. The gneiss (specimen D, XXVIII, 11, a) is of very dark gray shade and fine to medium texture, but with porphyritic feldspars from one-half to 1½ inches in diameter, consisting of a light pinkish-buff potash feldspar (microcline and orthoclase), rimmed with milk-white soda-lime feldspar (oligoclase-andesine). The groundmass consists of the same potash feldspar, smoky quartz, the same soda-lime feldspar, and biotite. The granite is crossed at irregular intervals by pinkish and pyritiferous "streaks," veinlets from 0.1 to 0.4 inches wide, with a central thread of epidote. Their course is parallel to the joints. In thin section the soda-lime feldspars of these veinlets are much kaolinized and micacized. Rusty stain along sheets is from 1 to 6 inches thick. Some joint faces are coated with a thin film of calcite; others with epidote from the alteration of feldspar.

The plant consists of 7 derricks driven by 4 hoisting engines, 2 air compressors (capacity 550 cubic feet of air per minute each), 5 large drills, 25 air-plug drills, and 2 steam pumps.

Transportation involves a cartage of 2½ miles to New York, New Haven and Hartford Railroad.

The product is used entirely for monuments.

The Newall quarry is in the town of Westerly just west of the Charlestown line, 5¼ miles about east of Westerly station, and 1¼ miles southeast of Niantic station. (See fig. 24.) Operator, Joseph Newall & Co., Westerly, R. I.

The granite (specimens D, XXVIII, 6, a, c), "blue Westerly," is a quartz monzonite of medium bluish-gray color, with very fine black particles. Its texture is even grained, fine, with feldspars and mica up to 0.1 inch. Its constituents, in descending order of abundance, are: Clear to milk-white striated soda-lime feldspar (oligoclase), somewhat kaolinized and micacized; pale, smoky quartz, with few hairlike crystals, probably of rutile, and cavities; clear bluish to translucent potash feldspar (orthoclase and microcline), intergrown with quartz and slightly kaolinized; and biotite (black mica), some of it chloritized. Accessory: Magnetite, pyrite, allanite, zircon, and rutile. Secondary: Kaolin, a white mica, and carbonate.

An estimate of the mineral percentages, obtained by applying the Rosiwal method to a camera lucida drawing of part of a thin section enlarged 40 diameters, yields the following results with a 2-inch mesh and a total linear length of 38 inches.

Estimated mineral percentages in "blue Westerly" granite from the Newall quarry near Niantic, R. I.

| | |
|---|--------|
| Soda-lime feldspar (oligoclase)..... | 36.32 |
| Quartz..... | 29.38 |
| Potash feldspars (microcline 17.91, orthoclase 8.00)..... | 25.91 |
| Biotite (black mica)..... | 6.27 |
| Magnetite..... | .60 |
| Pyrite..... | .10 |
| Apatite..... | .95 |
| Allanite..... | .47 |
| | <hr/> |
| | 100.00 |

Much weight should not be attached to the figures for apatite and allanite, for the mesh could have been shifted to avoid intersecting these particles, but their sum can be safely regarded as standing for the more abundant accessory minerals next to magnetite and pyrite.

The average diameter of all the particles obtained by the same measurements is 0.0087 inch.

Mr. W. T. Schaller, of the United States Geological Survey's chemical laboratory, finds that it contains 0.15 per cent of CaO (lime) soluble in dilute acetic acid, which indicates a content of 0.26 per cent of CaCO₃ (lime carbonate), the presence of which carbonate is also shown by the microscope and by a slight effervescence with cold dilute muriatic acid.

This is a fine-grained monumental granite susceptible of high polish and fine carving. It is of the same texture as the stone of the Klondike quarry, and a little finer than the blue of the New England and Smith quarries. Its shade is a trifle darker than that of the Klondike quarry. The polished face shows many minute particles of magnetite and a few of pyrite. There is marked contrast between the hammered and polished faces.

The quarry, opened in 1883, measures from 400 to 450 feet east-west by 250 feet across and from 50 to 100 feet in depth. In 1906 quarrying was confined to the deeper and wider part.

The sheets, from 1 to 9 feet thick, are horizontal at the east end, dip 10°-15° W. at the west end and 15° S. at the bottom. There are 2 sets of joints: Set A, striking N. 25° E., dipping 75° ESE., is spaced 5 to 200 feet. Set B, striking N. 45° W. and vertical, is exceptional. The rift is reported as dipping 20° about east, but in places west, and the grain as striking east-west and vertical. The granite occurs in a dikelike mass about 100 feet thick, dipping 45° S. and both underlain and overlain by "white horse," which here is a light pinkish-gray biotite gneiss consisting of light pinkish potash feldspar (microcline) in elongated crystals, smoky quartz, clear to milk-white oligoclase, and biotite. The foliation of this gneiss appears to strike about east-west and to dip with the surface 45° S. A pegmatite border separates granite from gneiss. Minute brownish veins

traverse the gneiss. Rusty stain is up to 14 inches thick on sheet surfaces, and ferruginous water exudes from between them halfway down the surface.

The plant, including that at the firm's cutting shed at Westerly, comprises 5 derricks, 5 hoisting engines, a 20-ton traveling crane, an engine for general work, 2 air compressors (capacity 350 and 135 cubic feet of air per minute), 6 steam drills, 2 air plug drills, 48 air hand tools, 3 surfacers, 3 polishers, and a steam pump.

Transportation is effected by cartage of $1\frac{1}{4}$ miles to the New York, New Haven and Hartford Railroad at Niantic, and thence $4\frac{1}{2}$ miles by rail to the cutting shed at Westerly.

The product is used exclusively for monuments. Specimens: Sarcophagus monument to Senator Sherman, Mansfield, Ohio; Obelisk to Gen. Lew Wallace, Crawfordsville, Ind.; W. L. Elkins and P. A. B. Widener mausoleums, Central Laurel Hill, Philadelphia; monument to J. D. Putnam erected by Fourteenth Wisconsin Regiment on the battlefield of Shiloh; reproduction of the elaborate Celtic cross of St. Martin in the island of Iona, erected by Mrs. McNeil in Rosedale Cemetery, Los Angeles, Cal.; also the T. M. Newall monument at Westerly, which has a delicate bas-relief of an entire poppy plant and a butterfly (design copyrighted).

The *Crumb quarry* is in Westerly, a mile S. 32° E. of Niantic station, and 5 miles about east of Westerly station. (See fig. 24.) Operator, The Crumb Quarry Company, Westerly, R. I.

The granite, "blue Westerly," is a quartz monzonite of medium bluish-gray color, with very fine black particles and even grained, fine texture, identical with that of the Newall quarry described on page 207.

The quarry, opened in 1857, is about 400 feet east-west by 125 feet across and 40 feet in depth.

The sheets, from 6 inches to 8 feet thick, are undulating horizontal. There are 2 sets of joints: Set A, striking N. 25° E., dipping 50° – 70° WSW., is spaced 10 to 150 feet and forms a heading across the center. Set B, striking N. 60° E. and vertical, is exceptional and discontinuous. The rift is reported as horizontal, but with a "run" dipping low east and the grain as vertical east-west. The granite occurs in a dikelike mass, apparently continuous with that of the Newall quarry, which is about 850 feet east-southeast of it. It is about 100 feet thick and is underlain on the north by a gneiss, "white horse," with a foliation and surface dipping 20° – 40° S. Owing to the quarry wall on the south being vertical, the dip of the foliation on that side could not be determined. This gneiss (specimen D, XXVIII, 12, b) is a light pinkish-gray biotite gneiss identical with that of the Newall quarry (p. 208). The light-pinkish feldspars (orthoclase and microcline) are in elongated lenses from 0.2 to 0.3 inch wide. The biotite

is fine and sparse. Although the schistosity of the stone may possibly be great enough to impair its strength, its contrasts of color are very attractive. The granite is crossed by a 1-inch pegmatite dike dipping 45° E. Rusty stain is 10 to 15 inches thick along sheet surfaces. The faces of joints A are in places bright reddish and thinly coated with radiating pearly crystals of a silicate, stilbite (?).

The plant comprises 5 derricks (1 with 50 tons capacity), 3 hoisting engines, 2 steam drills, a polisher and engine, and 3 steam pumps.

Transportation requires cartage of $1\frac{1}{4}$ miles to the railroad at Niantic.

The product is used for monuments, which are made mostly in Quincy, Mass. Specimens: Alexander Thompson and Oliver Hazard Cooper monuments, Swan Point Cemetery, Providence; Rhode Island monument, Andersonville, Ga.

CLASSIFICATION OF THE GRANITES.

The "granites" described in this report fall into the following ten petrographical groups: Biotite granite, biotite-muscovite granite, muscovite-biotite granite, quartz monzonite, hornblende granite, biotite-hornblende granite, riebeckite-ægirite granite, riebeckite-ægirite-biotite granite, quartz diorite, and diabase porphyry.

For economic purposes these granites fall naturally into the two classes of *constructional* and *monumental granites*. Some granites, however, are noted for their susceptibility of a high polish or possess colors which only become effective on a polished face. Such are, therefore, termed *polish granites*. To this class belong also several of the constructional and monumental granites. Still other granites, by virtue of the contrast between their hammered or cut and their polished surfaces, are peculiarly adapted to inscriptions and are therefore classed as *inscriptional granites*. Here belong the quartz monzonites and diorites because of their large content of soda-lime feldspar. One of the monumental and inscriptional granites, from its remarkable fineness of texture, lends itself to the very finest carving and is therefore also classed as *statuary granite*. In the following table all the granites treated in this bulletin are grouped in these five economic classes. The trade name, the scientific name, the real general color and shade, and the texture of each stone are added in separate columns, and page references to the detailed descriptions and quarries are also given. In defining their general color reference to the black spots or spangles produced by the black silicates has been omitted.

Economic classification of the chief commercial granites of Massachusetts, New Hampshire, and Rhode Island.

| Locality. | Trade name. | General color and shade. | Texture. | Scientific name. | Described on page — |
|---------------------|--------------------------------------|--|---|-------------------------------------|---------------------|
| Constitutional. | | | | | |
| Millford, Mass. | Millford pink. | Light to medium pinkish, or pinkish-greenish gray. | Medium to coarse, slightly gneissoid. | Biotite granite. | 75 |
| Quincy, Mass. | Extra light. | Light pea-greenish gray. | Medium to coarse. | Riebeckite-agirite granite. | 112 |
| Rockport, Mass. | Rockport gray, Bay View gray. | Medium gray. | Medium to coarse. | Hornblende granite. | 126, 128, 137 |
| Rockport, Mass. | Babson farm. | Somewhat dark greenish gray. | do. | do. | 132 |
| Concord, N. H. | Concord granite. | Medium bluish gray. | Fine to medium, somewhat porphyritic. | Muscovite-biotite granite. | 146 |
| Redstone, N. H. | Redstone red granite. | Light pink mottled with dark gray. | Coarse. | Biotite granite. | 179 |
| Madison, N. H. | Fletcher and Lahey. | Light pinkish gray mottled with dark purplish gray. | do. | do. | 185 |
| North Conway, N. H. | White Mountain quarry. | Medium pinkish-buff gray. | do. | do. | 184 |
| Millford, N. H. | Millford N. H. granite. | Medium bluish gray, light gray, light buff-gray. | Fine to medium. | Quartz monzonite. | 160, 161, 163 |
| Westerly, R. I. | Red Westerly. | Reddish gray. | Medium to coarse. | Biotite granite. | 191 |
| Monumental. | | | | | |
| Quincy, Mass. | Quincy dark and extra dark. | Dark gray (or bluish greenish, purplish) to very dark bluish or purplish gray. | Medium to coarse. | Riebeckite-agirite granite. | 91 |
| Becket, Mass. | Chester dark and light. | Medium bluish gray and medium-dark bluish gray. | Fine. | Muscovite-biotite granite. | 141 |
| Millford, N. H. | Millford, N. H. granite. | Light gray, light to medium buff, or bluish gray. | Fine (0.011 inch). | Quartz monzonite. | 164, 167, 168 |
| Millford, N. H. | Dark blue New Westerly and Soubegan. | Dark gray. | Fine (0.0084 inch). | do. | 171, 176 |
| Millford, N. H. | New Westerly blue. | Medium bluish gray. | Fine (0.009 inch). | do. | 173 |
| Sunapee, N. H. | Light Sunapee. | Light slightly bluish gray. | Very fine to fine. | Biotite-muscovite granite. | 187 |
| Suburn, N. H. | Deep pink Auburn. | Medium pink buff. | Fine. | Quartz monzonite. | 186 |
| Westerly, R. I. | Blue Westerly. | Bluish medium gray. | do. | do. | 191 |
| Westerly, R. I. | White and pink Westerly. | Pinkish or buff medium gray. | Extremely fine (0.0069 inch). | do. | 191, 194 |
| Polish granite. | | | | | |
| Quincy, Mass. | Quincy dark, extra dark. | Dark gray (or bluish greenish, purplish) to very dark bluish or purplish gray. | Medium to coarse. | Riebeckite-agirite granite. | 107, 109 |
| Quincy, Mass. | Quincy gold leaf. | Medium bluish gray with yellow brown spots. | do. | do. | 115 |
| Rockport, Mass. | Rockport and Bay View gray. | Medium gray. | do. | Hornblende granite. | 126, 128, 137 |
| Rockport, Mass. | Bay View green and Rockport green. | Olive gray. | do. | do. | 135 |
| Rockport, Mass. | Bay View dark (prospect). | Dark brownish gray. | do. | do. | 139 |
| Rockport, Mass. | Pigeon Cove porphyry. | Black ground with medium gray crystals. | Fine matrix and large porphyritic crystals. | Riebeckite-agirite-biotite granite. | 139 |
| Madison, N. H. | Fletcher and Lahey. | Light pinkish gray mottled with dark purplish gray. | Coarse. | Diabase porphyry. | 185 |
| Redstone, N. H. | Redstone red granite. | Light pink mottled with dark gray. | do. | Biotite granite. | 179 |
| Redstone, N. H. | Redstone green granite. | Dark yellow-greenish gray. | do. | do. | 182 |

Economic classification of the chief commercial granites of Massachusetts, New Hampshire, and Rhode Island—Continued.

| | Locality. | Trade name. | General color and shade. | Texture. | Scientific name. | Described on page— |
|--------------|----------------------|----------------------|-----------------------------------|-------------------------------|------------------------|--------------------|
| Insertional. | Millford, N. H. | Dark blue New West- | Dark gray | Fine (0.0084 inch) | Quartz monzonite | 168, 171 |
| | Sunapee, N. H. | Black pearl | Very dark bluish gray | Fine to medium | Quartz diorite | 187 |
| | Westerly, R. I. | Blue Westerly | Bluish medium gray | Fine (0.0099 inch) | Quartz monzonite | 191 |
| | Westerly, R. I. | White and pink West- | Pinkish or buff-medium gray | Extremely fine (0.0069 inch). | do. | 191, 194 |
| Stat- | Westerly, R. I. | Westerly white stat- | Buff medium gray | Extremely fine (0.0069 inch). | Quartz monzonite | 191, 194 |

COMMERCIAL VALUE OF THE GRANITES.

These granites represent quite a range in commercial value—from 25 cents to \$3.25 per cubic foot. The following prices were obtained from the larger concerns as current in 1906. All are f. o. b. and per cubic foot in the rough.

Constructional granites.—*Milford, Mass.*, pink, in blocks up to 10 tons, \$0.60 to \$0.70. Foundation and bridge rubble work, \$0.25. *Quincy*, light, for bases and hammered work, ordinary sizes, \$0.50 to \$0.85. Extra light, for bridge work, without reference to size, \$0.35. *Rockport*, gray, ordinary sizes (3 to 15 feet long, 1½ to 4 feet wide, and 1½ to 3 feet high), best quality, \$0.50. *Concord*, blocks under 9 feet square in base, \$0.60. *Redstone, N. H.*, red, ordinary sizes, \$0.40 to \$0.50. *Milford, N. H.*, dimension stone in blocks up to 100 cubic feet, \$0.40. *Westerly*, red, ordinary sizes, \$0.60.

Monumental granites.—*Quincy*, medium, in blocks up to 40 cubic feet, \$1 to \$1.10; 40 to 55 cubic feet, \$1.15. Dark, in blocks up to 40 cubic feet, \$1.30 to \$1.35; 40 to 55 cubic feet, \$1.40. Extra dark, in blocks up to 40 cubic feet, \$1.60. *Becket (Chester)*, in blocks up to 40 to 50 cubic feet, \$1.30 to \$1.40. *Redstone, N. H.*, green, ordinary sizes, \$0.65 to \$0.75. *Milford, N. H.*, in blocks up to 10 cubic feet, \$0.75 to \$1.25, averaging \$0.85. *Westerly*, blue, in blocks up to 10 cubic feet, \$1.10 to \$1.15. Up to 50 to 60 cubic feet, \$2.60 to \$2.75. White and pink statuary, in blocks up to 10 cubic feet, \$1.10 to \$1.25. Up to 50 to 60 cubic feet, \$2.70 to \$3.25. When the *Milford, Mass.*, pink is ordered finished for ornamental work the following prices prevail: Rock-faced ashlar building work, \$1.50. Cut building work, \$3.50. Polished building work, \$6. Cut monumental work, \$7. Polished monumental work, \$10.

STATISTICS OF GRANITE PRODUCTION.

By ALTHA T. COONS.

In this section is shown the value of the stone produced at Becket, Chester, Milford, Pigeon Cove, Rockport, Quincy, and West Quincy, Mass., at Concord, Milford, and Redstone, N. H., and at Niantic and Westerly, R. I., by uses, and the total value of the production of each State from 1902 to 1906.

The figures in the following tables represent the selling value of the stone to the quarrymen, exclusive of any freight charges. When the stone is cut or dressed by the quarrymen and sold in this manner the value of the dressed stone is given. This applies especially to the stone quarried and sold for use as building and monumental stone.

The principal uses of the stone as shown in the following tables are for building stone, rough and dressed, and monumental stone, rough

and dressed. Under stone sold for "other" purposes is included stone for curbstone, flagstone, some used for jetty purposes, stone posts, covers, a small quantity of crushed stone, and stone for various other rough work.

The total value for each State includes stone of all classes, rough and dressed building and monumental stone, flagstone, curbstone, riprap, rubble, crushed stone, and stone sold for various other purposes. A large quantity of trap rock quarried in Massachusetts and used chiefly for crushed stone is not included in the Massachusetts State total.

Production of granite by uses in the granite areas of Chester, Becket, Milford, Pigeon Cove, Rockport, Quincy, and West Quincy, Mass., and the value of the production of the entire State from 1902 to 1906.

| Uses. | 1902. | 1903. | 1904. | 1905. | 1906. |
|--------------------------------|-----------|-----------|-----------|-----------|-----------|
| Rough building..... | \$75,461 | \$88,900 | \$56,301 | \$85,796 | \$93,726 |
| Dressed building..... | 559,351 | 364,788 | 556,478 | 485,448 | 1,563,044 |
| Rough monumental..... | 468,016 | 357,449 | 319,448 | 396,187 | 346,311 |
| Dressed monumental..... | 290,678 | 231,375 | 201,877 | 187,361 | 239,310 |
| Paving blocks..... | 140,214 | 211,279 | 212,254 | 175,712 | 132,254 |
| Rubble and riprap..... | 73,011 | 91,951 | 67,962 | 35,085 | 24,476 |
| Other..... | 137,672 | 90,700 | 86,559 | 50,563 | 55,747 |
| Total..... | 1,744,403 | 1,436,442 | 1,500,879 | 1,416,152 | 2,454,868 |
| State total ^a | 3,080,857 | 2,351,027 | 2,554,748 | 2,251,319 | 3,327,416 |

^a This does not include trap rock, used for road metal, etc.

Production of granite by uses in the granite areas of Concord, Milford, and Redstone, N. H., and the value of the production of the entire State from 1902 to 1906.

| Uses. | 1902. | 1903. | 1904. | 1905. | 1906. |
|-------------------------|-----------|----------|----------|----------|----------|
| Rough building..... | \$67,704 | \$33,154 | \$32,733 | \$15,752 | \$29,022 |
| Dressed building..... | 272,385 | 239,201 | 367,610 | 178,757 | 198,931 |
| Rough monumental..... | 32,727 | 47,774 | 63,962 | 88,414 | 49,825 |
| Dressed monumental..... | 233,647 | 204,937 | 199,538 | 171,099 | 102,296 |
| Paving blocks..... | 28,001 | 34,907 | 40,045 | 48,484 | 76,229 |
| Rubble and riprap..... | 5,169 | 7,283 | 1,685 | 1,759 | 5,886 |
| Other..... | 25,996 | 38,707 | 23,378 | 35,866 | 58,689 |
| Total..... | 665,629 | 605,963 | 728,951 | 540,131 | 521,478 |
| State total..... | 1,147,097 | 854,513 | 927,487 | 838,371 | 818,131 |

Production of granite by uses in the granite areas of Niantic and Westerly, R. I., and the value of the production of the entire State from 1902 to 1906.

| Uses. | 1902. | 1903. | 1904. | 1905. | 1906. |
|-------------------------|---------|---------|---------|---------|---------|
| Rough building..... | \$4,478 | \$4,275 | \$6,225 | \$250 | \$160 |
| Dressed building..... | 80,967 | 101,914 | 203,649 | 62,688 | 184,614 |
| Rough monumental..... | 111,502 | 111,308 | 118,236 | 134,063 | 159,525 |
| Dressed monumental..... | 438,472 | 359,618 | 153,930 | 203,267 | 171,700 |
| Paving blocks..... | 13,884 | 36,634 | 41,791 | 79,641 | 25,332 |
| Other..... | 3,364 | 2,298 | 3,123 | 5,538 | 5,988 |
| Total..... | 652,667 | 616,047 | 526,954 | 485,447 | 550,319 |
| State total..... | 734,623 | 710,291 | 684,952 | 556,364 | 622,812 |

CONCLUSIONS.

In reviewing the very numerous details brought together in the preceding pages several general ideas will impress themselves upon the reader: First, the long and complex geological history of the rock masses which are being quarried. Next, the very intricate microscopic character of the various granites described, both in their mineral composition and texture and in the changes which have taken place in them. Then, also, the great ingenuity shown in the various mechanical devices for quarrying the stone, and especially in the modern pneumatic machinery for working and finishing it; and, finally, the architectural and sculptural skill displayed in the structures and monuments made of it. Among the more notable of those made or being made of these granites are: The Pennsylvania Railroad terminal at New York, the Congressional Library, the Cambridge and Boston bridge, the Bunker Hill Monument, and the National Monument at Gettysburg.

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Mitteilungen der Anstalt zur Prüfung von Baumaterialien am Polytechnikum in Zürich.

Mitteilungen aus dem mechanisch-technischen Laboratorium der Königlichen technischen Hochschule in München.

The substance of the paper by Merrill in vol. 10 of the United States Tenth Census, 1888, and by Merrill in the Proceedings of the U. S. National Museum, vol. 6, 1883, has reappeared in more modern form in his other works.

GLOSSARY OF SCIENTIFIC AND QUARRY TERMS.

ACCESSORY MINERALS in granite are original constituents of the rock, found only in small, often only in microscopic quantity.

ACIDIC. A term applied to rocks in which silicic acid (silica) or quartz predominates.

ALLANITE. An opaque black mineral (silicate), brown in thin section, one of the primary less common accessory constituents of granite, which contains from 12 to 17 elements, including 6 of the rarer ones. For analyses see Dana, E. S., System of Mineralogy, 6th ed. 1892. pp. 522-526.

ANTICLINE. A term applied to granite sheets or sedimentary beds that form an arch.

APLITE. Fine-grained granite, usually occurring in dikes and containing little mica and a high percentage of silica.

BASIC. A term applied to rocks in which the iron-magnesia minerals and feldspars with lime and soda predominate, such as diabase or basalts.

BLACK HORSE. Term used by quarrymen in Rhode Island to denote a dark biotite gneiss in contact with the granite.

BLIND SEAMS. Quarrymen's term for incipient joints.

BOWLDER QUARRY. One in which the joints are either so close or so irregular that no very large blocks of stone can be quarried.

CHANNEL. A narrow artificial incision across a mass of rock, which, in the case of a granite sheet, is made either by a series of contiguous drill holes or by blasting a series of holes arranged in zigzag order.

CLEAVAGE, when applied to a mineral, designates a structure consequent upon the geometrical arrangement of its molecules at the time of its crystallization.

CLOSE JOINTED. A term applied to joints that are very near together.

CROCUS. A term used in the Milford, N. H., quarries to denote gneiss or any other rock in contact with granite.

CRUSH-BORDER. A microscopic granular structure sometimes characterizing adjacent feldspar particles in granite in consequence of their having been crushed together during or subsequent to their crystallization.

CUT-OFF. Quarrymen's term for the direction along which the granite must be channeled, because it will not split. Same as "hardway."

DENDRITES. Plantlike crystallization of iron or manganese oxides on the surfaces of fissures in any rock or mineral. Frost crystals on window panes are of like character.

DIKE. A mass of granite, diabase, basalt, or other rock which has been erupted through a narrow fissure.

DIMENSION STONE. A term applied to stones that are quarried of required dimensions.

DIP. The inclination from the horizon, given in terms of degrees, of a sheet, joint, heading, dike, or other structural plane in a rock.

DRIFT. Sand and boulders deposited by the continental glacier.

DRUMLIN. Oval hillock of clay and boulders formed beneath the ice sheet of the glacial epoch.

EROSION. The wearing away of portions of a rock by such natural agencies as stream or ice action.

EXFOLIATION. The peeling of a rock surface in sheets owing to changes of temperature or other causes.

FAULTING. The slippage of a rock mass or masses along a natural fracture.

FLOW-STRUCTURE. The parallel arrangement of the minerals in granite or other igneous rock in the direction of its flowage during its intrusion.

GEODE. A rock cavity lined with crystals. Geodes in granite are attributed to steam or gas bubbles.

GRAIN in granite is practically the direction in which the stone splits "next easiest," the "rift" being that in which it splits most readily.

GROUT. A term applied to the waste material of all sizes obtained in quarrying stone.

GROW-ON. Quarrymen's term to designate the place where the sheet structure dies out, or the place where two sheets appear to grow onto one another.

HARD-WAY. The direction at right angles to both rift and grain in which granite does not split readily. (See Cut-off.)

HEADING. A collection of close joints.

HEADING-SEAM. See Joint.

HEMATITE. An oxide of iron (Fe_2O_3) which when scratched or powdered gives a cherry-red color.

IGNEOUS. A term applied to rocks that have originated in a molten condition.

JOINTS. More or less steeply inclined fractures which cross the granite sheets and which are attributed to various stresses.

KAOLIN. A hydrous silicate of alumina derived from the alteration of feldspar.

KAOLINIZATION. The process by which a feldspar passes into kaolin.

KNOTS. A term applied by quarrymen to dark gray or black objects, more or less oval or circular in cross-section, which are segregations of black mica or hornblende formed in the granite while in a molten state. English quarrymen call them "heathen."

KNOX HOLE. A circular drill hole with two opposite vertical grooves which direct the explosive power of the blast.

LEWIS HOLE. An opening made by drilling two or three holes near together and chiseling out the intervening rock.

LIMONITE. A hydrous oxide of iron ($2\text{Fe}_2\text{O}_3, 3\text{H}_2\text{O}$); a hydrated hematite, which, when scratched or powdered, gives a brownish rust color.

MATRIX. The general mass of a rock which has isolated crystals; sometimes called groundmass.

- MILLIMETER.** French decimal lineal measure, the thousandth part of a meter or the tenth part of a centimeter. It is equivalent to nearly 0.04 inches, the meter being $39\frac{1}{4}$ inches.
- MONOLITH.** A column or monument of one stone.
- MOTION.** A term used in granite regions to designate small paving-block quarries.
- OPHITIC.** A term applied to microscopic rock texture to designate a mass of longish interlacing crystals, the spaces between which have been filled with minerals of later crystallization.
- OREÏ.** A term applied in the Quincy quarries to Quincy granite which has been rendered valueless by the alteration of its agirite particles.
- PEGMATITE.** A very coarse granite occurring in irregular dikes or lenses in granites and some other rocks.
- PLAGIOCLASE.** A term applied to all those feldspars that are not potash feldspars.
- POLARIZED LIGHT.** Light whose vibrations, unlike those of ordinary light, which are in all directions, are in only one plane. Polarized light is used in the microscopic study of rocks.
- PORPHYRITIC.** A term applied to rock texture to designate the presence of isolated crystals in a general mass (matrix or groundmass) of finer material.
- PSEUDOMORPH.** Signifies false form, and designates a crystal in which, owing to various chemical changes, the original mineral has been more or less replaced by others. The form of the crystal no longer corresponds to the mineral.
- QUARTZ MONZONITE.** Technical designation for a granite in which the percentages of soda-lime and of potash feldspar are nearly the same or in which the former exceeds the latter. In ordinary granites the amount of soda-lime feldspar is relatively small.
- RANDOM STONE.** A term applied by quarrymen to quarried blocks of any dimensions. (See definition of dimension stone.)
- RIFT.** A quarrymen's term to designate an obscure microscopic cleavage in granite which greatly facilitates quarrying.
- RUN.** A term used by quarrymen in connection with "rift," apparently to denote the course of the deflection of the rift due to gravity, strain, or other not yet understood cause.
- SALT-HORSE.** Quarrymen's term for aplite.
- SAND SEAMS.** Quarry term for more or less minute veins or dikes of muscovite (white mica) with some quartz, in cases also with feldspar. (See p. 51.)
- SAND STREAKS.** Same as sand seams.
- SAP.** Quarrymen's term for ferruginous discoloration along sheet or joint surfaces.
- SCHIST.** A rock made up of flattish particles arranged in rough parallelism, some or all of which have crystallized under pressure.
- SCHISTOSITY.** The quality of being like a schist.
- SEAM.** Quarrymen's term for joint.
- SECONDARY MINERALS.** Minerals whose presence is due to the alteration of the original minerals.
- SEDIMENTARY.** A term designating those rocks that consist of particles deposited under water.
- SEGREGATION.** The scientific term for "knot;" a collection of material separated from other material. A **VEIN OF SEGREGATION** is one formed by the filling of a fissure with mineral matter originating in the surrounding rock.
- SERICITE.** A more or less fibrous form of muscovite (potash mica), often resulting from the alteration of feldspar.

SHAKES. Quarrymen's term to designate a somewhat minute close-joint structure, which forms along the sheet surface as a result of weathering.

SHEET QUARRY. A quarry in which the granite lies in sheets, crossed by wide-spaced steep joints.

SLICKENSIDES. The polished and grooved faces of a joint or bed caused by motion and friction.

SPECIFIC GRAVITY. The weight of a rock or mineral compared to that of a body of distilled water of the same bulk.

STRAIN-SHEET. Quarrymen's term for granite sheets produced by present compressive strain.

STRATIFIED. A term applied to rock consisting of originally horizontal beds or strata.

STRIKE. The direction at right angles to the inclination of a plane of bedding, a sheet, or joint, etc.

STRIPPING. The material (sand, clay, soil, etc.) overlying a rock of economic value, which must be removed before quarrying.

SUBJOINT. Minor joints diverging from or parallel to the regular joints.

SYNCLINE. A geological term for the trough part of a wave-like sheet or bed of rock.

TILL. A mixture of clay and boulders deposited by glaciers.

TOEING-IN. Quarrymen's term for the wedging in of the end of a granite sheet under an overhanging joint, probably in consequence of the faulting of the sheets along the joint. It is also applied to the overlapping of lenticular sheets.

"TOE NAILS." Curved joints intersecting the sheet structure, in most cases striking with the sheets, in some differing from them in strike 45° or more.

TWIN CRYSTALS. Two adjacent crystals which have formed with the poles of their main axes in opposite or different directions.

WEATHERING. The decomposition of a rock owing to the action of the weather.

WHITE HORSE. Term used by quarrymen to denote a light-colored gneiss, aplite, or pegmatite.

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