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THE GREEN SCHISTS AND ASSOCIATED GRANITES AND PORPHYRIES OF RHODE ISLAND

BY

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CONTENTS.

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ILLUSTRATIONS.

THE GREEN SCHISTS AND ASSOCIATED GRANITES AND PORPHYRIES OF RHODE ISLAND.

By B. K. Emerson and J. H. Perry.

INTRODUCTION.

SCOPE OF PAPER.

A great mass of coarse, porphyritic granitoid gneiss occupies the towns of Sutton, Northbridge, and Douglas, in Massachusetts, and extends southward across western Rhode Island to Kingston, on the Sound, just west of the territory to be described in this bulletin. A series of quartzites and hornblendic rocks wraps round the northern part of this mass, resting on it unconformably with a very sinuous boundary. These two groups of rocks—the first called the Northbridge gneiss, the second made up of the Grafton quartzite and the Marlboro formation—may be assigned with considerable probability to the pre-Cambrian and Cambrian, respectively.

The continuity of the Cambrian rocks is greatly interrupted in Massachusetts by broad areas of intruded granite, and farther south, in the region here studied, only broad, isolated patches of the sedimentary rocks appear, like ice floes on a pond, in a confluent expanse of various eruptives, which differ in age and in lithologic character. This paper is devoted principally to a discussion of such of these interesting Cambrian remnants as lie within the limits of the State of Rhode Island and to a description of the associated eruptives, especially the remarkable series of very fresh porphyritic rocks that extend westward from the town of East Greenwich. The field work occupied three summers and covered the crystalline area along the western border of the Carboniferous rocks in the Providence and Narragansett Bay quadrangles. The work was undertaken for the purpose of publication in folios of the Geologic Atlas of the United States, but as the publication of the folios has been deferred and as the results of the survey are needed in the explanation of the structure of the territory adjacent on the north, in which work is now in progress, they are here presented in the form of a bulletin.

PREVIOUS WORK IN THE REGION.

The rocks studied comprise the western border of the Carboniferous of the Narragansett basin in Rhode Island and the more highly metamorphosed varieties of the Carboniferous rocks that extend over the older rocks. The results presented therefore supplement those contained in the monograph on the geology of the Narragansett basin by Shaler, Woodworth, and Foerste,[a] in which these rocks were not discussed. The bibliography of the Cambrian and Carboniferous rocks of the basin given in that volume[b] includes nearly every publication that makes allusion to the region here described. The report on the geology of Rhode Island by Dr. C. T. Jackson[c] is the fullest account of this region that has been written. The area considered in this bulletin is represented in green and blue on Doctor Jackson's map, where it is labeled "hornblende rock and limestone" and referred to the Primary. Not the least interesting of the early writings on this region is the very clear description given by Prof. Ebenezer Emmons,[d] in which he assigns the green schists to the Taconic—that is, to the Cambrian (the age of the Stockbridge limestone)—and finds several members of the "Taconic system" represented here. He gives an accurate section across the area from southwest to northeast through the limestone quarry. Prof. W. O. Crosby, as the result of a brief visit to the region thirty-five years later, describes the rocks and assigns them doubtfully to the Huronian and Montalban.[e]

TABLE OF FORMATIONS.

The rocks in the area investigated are tabulated below, the table beginning with the oldest:

Formations in the Narragansett basin.

EARLIEST ROCKS:
- Pre-Cambrian.
  - Northbridge gneiss.

SEDIMENTARY ROCKS:
- Cambrian.
  - Grafton quartzite.
    - Albion schist member.
  - Marlboro formation, including green schists, amphibolite, mica schist, and, as a subordinate member, the Smithfield limestone, which changes into tremolite schist, steatite, and serpentine.

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[a] Mon. U. S. Geol. Survey, vol. 33, 1899.
[b] Idem, p. 212.
[c] Jackson, Charles T., Report on the Geological and Agricultural Survey of the State of Rhode Island, 1839. Published in 1840.
[d] Emmons, Ebenezer, Agriculture of New York, vol. 1, 1846, pp. 91–93.
[e] Crosby, W. O., Contributions to the Geology of Eastern Massachusetts, 1880, pp. 127–128.

SEDIMENTARY ROCKS—Continued.
- Carboniferous.
  - Unaltered rocks.
    - Shale.
    - Conglomerate.
  - Metamorphosed rocks.
    - Biotite-spangled phyllite.
    - Chloritoid-spangled phyllite.
    - Arenaceous chloritoid schist.
    - Magnetitic mica schist.
    - Conglomeratic mica schist.

IGNEOUS ROCKS:
- Cambrian.
  - Diorite.
- Post-Cambrian (pre-Carboniferous).
    - Milford blue-quartz granite.
    - Aplite.
    - Gabbro.
    - Odinite.
    - Cumberlandite.
- Early Carboniferous or late pre-Carboniferous.
  - Quincy group.
    - Porphyritic granite.
    - Granite porphyry.
    - Riebeckite porphyry.
    - Microgranite.
    - Hornblende granite.
  - East Greenwich group.
    - Granite.
    - Granite porphyry.
    - Blue-quartz porphyry.
    - Microgranite.
    - Graphic microgranite.
    - Graphic microgranite and granite-porphyry breccia.
- Post-Carboniferous.
  - Olivine-diabase porphyry.
  - Porphyritic diabase.

PRE-CAMBRIAN ROCKS.

NORTHBRIDGE GNEISS.

Northbridge gneiss is the name given elsewhere[a] to the great area of pre-Cambrian gneiss that extends southward from Southboro, Mass. A rock having all the characteristics of the Northbridge gneiss and forming its probable southward extension occupies the southwest corner of the area mapped in Pl. I. It is a medium- to coarse-grained granitoid gneiss, of light color, containing smoky quartz in long pencils. The feldspar, the most abundant constituent of the rock, presents a notable contrast with the quartz in being regularly and evenly granular. The grains are just visible to the eye. Bladed biotite, magnetite, and a little muscovite appear. The rock crumbles into a

[a] Emerson, B. K., Geology of old Hampshire County: Mon. U. S. Geol. Survey, vol. 29, 1898, p. 18.

mass of pencils, as does the gneiss in Northbridge, Mass. It grows coarser and porphyritic toward the west. The distinction here, as in Massachusetts, between a coarser, less crushed, and porphyritic facies and a finer, more schistose, and more completely mashed and stretched facies is noted on the map.

The connection of the rock of this area with the Northbridge porphyritic granite-gneiss has not been definitely traced in the field, but is very probable, since Jackson[a] described the rock as of wide extent across Kingston and represented it on his map at many points in West Greenwich, Coventry, and Foster, and we have traced it southward from Douglas, Mass., across Burrillville into Glocester, R. I., the town adjoining on the west the area here considered.

The porphyritic granite-gneiss that borders the Cambrian on the south and east of the Carboniferous rocks of the Narragansett basin, as, for example, around Conanicut, Newport, and Little Compton, would seem to be of the same age as the Northbridge gneiss if the contention of Dale is correct, that it is an older member underlying the Cambrian. Pirsson,[b] Crosby and Barton,[c] and Foerste[d] are, however, certain that this granite-gneiss cuts the Cambrian and is thus the newer rock, and in this case it is probably of the same age as the Milford granite.

The least stretched varieties of the Northbridge gneiss and the most crushed facies of the Milford granite are indistinguishable at some places in the field. The Northbridge gneiss is characterized by a coarse-meshed microcline, which is replaced in the Milford granite by a complex microperthite, the albitic constitutent of which is centrally dusted with epidote.

CAMBRIAN ROCKS.[e]

SUBDIVISIONS AND NOMENCLATURE.

The Cambrian rocks, as they appear along the Blackstone Valley between Woonsocket and Pawtucket, are described in this text and shown on the geologic map (Pl. I) under four subdivisions:

1. A central band of phyllite and fine-grained micaceous quartz schist—the Albion schist member.

2. Two flanking bands of a granular massive quartzite—the Grafton quartzite.

[a] Jackson, Charles T., Report on the Geological and Agricultural Survey of the State of Rhode Island, 1839. Published in 1840.

[b] Pirsson, L. V., On the geology and petrography of Conanicut Island, R. I.: Am. Jour. Sci., vol. 46, 1893, pp. 363-378.

[c] Crosby, W. O., and Barton, G. H., On the great dykes at Paradise, near Newport: Proc. Boston Soc. Nat. Hist. (1886), vol. 33, p. 325.

[d] Shaler, N. S., Woodworth, J. B., and Foerste, A. F., Geology of the Narragansett basin: Mon. U. S. Geol. Survey, 1899, vol. 33, p. 235.

[e] "Blackstone series" of Woodworth.

Henry Gannett, Chief Geographer
Marcus Baker, Geographer in charge
Triangulation by the U.S. Coast and Geodetic Survey and R.U. Goode
Topography by W^m Kramer, S.H. Bodfish, E.B. Clark, E.W.F. Natter, and J.H. Jennings
Surveyed in 1885, 1887, and 1888

Geology by B. K. Emerson

Scale
0 ½ 1 2 3 miles

Contour interval 20 feet
Datum is mean sea level

1906

MAP OF THE CRYSTALLINE ROCKS IN THE VICINITY OF PROVIDENCE AND NARRAGANSETT BAY RHODE ISLAND

A. HOEN & CO. BALTIMORE.

3. Two broad exterior bands of green schists and amphibolite—the Marlboro formation.

4. Thick beds of crystalline limestones with soapstone and serpentine in the sediments—the Smithfield limestone.

This series of rocks in Massachusetts was several years ago traced southward by the senior author of this paper[a] from Westboro (where the quartzite and amphibolite appear in typical development) with a good degree of continuity to the area here considered, and the names then proposed for them are here retained. Mr. Woodworth briefly touched upon the same rocks in connection with his description of the adjacent Carboniferous basin,[b] and proposed for them the name "Blackstone series." He gave the name "Cumberland quartzite" to the quartzose beds, and the name "Ashton schists" to the schistose beds. As we have found that the schistose beds are divisible, the name "Albion schist" is applied to the central quartz phyllite and mica schist upon which the village of Albion stands, and the larger group of green schists, amphibolites, soapstones, and limestones are called the Marlboro formation, from their equivalent farther north.

STRUCTURE.

The whole series occurs in several elongate patches which are inclosed in a great granite batholith on all sides up to the point where they are in contact with the Carboniferous. All its members have a uniform steep dip to the east. We can not tell whether the two broad bands of green schist that flank the central quartzite band are joined above the quartzite as a closed and overturned anticline, or beneath in synclinal arrangement. If our correlations are right, the green schists are probably the younger, as the hornblende schists of the Marlboro formation seem somewhat higher than the quartzites. At the south end of the isolated area of green schist north of Albion everything indicates that the green schist is the newer rock. The fact that the pebbles found in the green schists are of a quartzite like that of the central quartzite indicates that the green schists are the newer and that the structure is therefore anticlinal. The Providence area may be taken as a more irregular anticline of the quartzite flanked by the green schists, and, like the other, included in the Milford granite.

The dips and strikes given on the map (Pl. I) show the probable posture of the beds in the middle of the Cumberland area. The isolated central area of the green schist on the Albion schist makes it probable that it is a passage bed between the Grafton quartzite and the Marlboro formation.

[a] Mon. U. S. Geol. Survey, vol. 29, 1898, p. 18.
[b] Mon. U. S. Geol. Survey, vol. 33, 1899, p. 106.

GRAFTON QUARTZITE.[a]

GENERAL FEATURES.

The Grafton quartzite is generally a fine-grained, massive, saccharoidal quartzite of great purity, and resembles the Cheshire quartzite, of Cambrian age, in Berkshire County, Mass. It varies from white to pale flesh color, and some varieties have a greasy luster. It is entirely massive over large areas, as west of Manville, where it so exactly resembles the Cambrian quartzite of Berkshire that even the conchoidal fissures, which appear like gouge marks on the surface of the western rock, are here also present. At some places it shows thin lamination and cross bedding; at others it is greatly jointed or thin foliated by crushing or reduced to rude columnar masses by complex strains, as in the long cut east of Manville, where bands of massive quartzite containing grains of blue quartz alternate with thin fissile crushed micaceous beds. It is most crushed and altered on granite contacts.

It appears in force in the south and west of Natick, where it is slightly biotitic and carries beds of biotite schist 3 feet thick. Here it breaks into small angular blocks, all of whose faces are coated with a film of secondary muscovite. In some places it is distinctly a conglomerate.

The quartzite in places contains purple fluor derived from the granite. Small red garnets (110) of perfect form occur in the quartzite and conglomerate, and, at a point one-half mile southwest of Ashton it contains grains of blue quartz.

ALBION SCHIST MEMBER.

Down the center of the Grafton quartzite runs a band of rock which, although originally in large part a quartz sandstone and still prevailingly quartzitic, is so far muscovitic that it may be called a mica schist or muscovite schist. The light-gray color dependent upon the absence of the ferruginous minerals (biotite, hornblende, chlorite) separates it from the green schist. As the Grafton quartzite is at most places slightly muscovitic, the distinction between it and the Albion quartzose mica schist is of subordinate importance; but after the line of boundary had been traced in the field, it was thought better to preserve the subdivision and represent it on the map. The finer grain of this rock and the presence in it of considerable beds of phyllite distinguish it from the other. The road on the side of the hill east of Cumberland village is cut in a dark-gray to drab phyllite, so little metamorphosed that we felt justified in searching it carefully for fossils. The soft beds alternate with beds of quartzite, ranging in thickness from 4 to

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[a] "Cumberland quartzite" of Woodworth.

100 feet. The argillite shows in places the original bedding, which cuts the perfect slaty cleavage at a small angle. The rock resembles some phases of the Carboniferous slate of the Worcester basin, but is much more like the Cambrian slate of Weymouth.

MARLBORO FORMATION.

THE GREEN SCHISTS.

GENERAL CHARACTERS.

The Marlboro formation, as developed in the region stretching from Woonsocket to Pawtucket, includes a great variety of green schists, amphibolites, steatites, and limestones. In its least metamorphosed forms the green schist is a pale-green chlorite-sericite schist, soft and slaty; a green actinolite schist; a dark-gray, very fine-grained quartz-schist, or a slaty and penciled arenaceous limestone. These rocks west of Pawtucket are so little metamorphosed as to suggest their identity with the Carboniferous schists in the large quarry in Pawtucket. Farther northwest, nearer the granite, a dark-green, fissile, aphanitic, chloritic amphibolite, containing in places small altered pyrite cubes, abounds. There were originally several thin beds of limestone in the formation, and at least one of considerable thickness. These are in part or whole altered to beds of tremolite, tremolitic steatite, or impure serpentine, and are discussed separately on pages 26–28.

The green schists are nearly everywhere severely crushed, aphanitic, and slaty, and are in places gashed with open fissures, and ragged and cavernous exteriorly, because of the solution of calcite, and in the interior will nearly always effervesce with acid. Many specimens of the rocks are full of small magnetite octahedra.

In places, as, for instance, north of the Lime Rock quarry, beds of schist belonging to this formation contain traces of pebbles, some of them 1½ inches long. In rocks of this kind found north of Cumberland Hill the pebbles are much drawn out. These altered conglomerates extend from a point west of Sneech Pond 1 mile southward. Many of the pebbles are of epidotic quartzite.

Limestones and quartzites of undoubted sedimentary origin alternate with the green schists, amphibolites, and steatites at so many places and grade into them in so many ways that we have assigned to the whole series a sedimentary origin.

The large amount of iron present suggests the derivation of some part of the material from basic tuffs. We found but few beds in the green schist which, after study in the field or with the microscope, we were inclined to regard as directly derived from basic dikes or intruded sheets. The ferruginous sandstones and included tuffs and impure limestone beds of the Triassic could be changed into a similar series, and we have in a later section attempted to connect this formation with the similar ferruginous and calcareous Cambrian beds at North Attleboro. The more massive rocks, which most simulate eruptives, are the thick beds of tremolitic steatite and serpentine derived from limestone. A large slab of the conglomeratic green schist from a ledge on the top of the hill 100 rods north of the middle quarry at Lime Rock contains many well-rounded pebbles of a very fine-grained white-bleaching actinolitic quartzite like the finest beds of the Albion quartzitic schist; also many pebbles of coarser and finer varieties of a diorite which appears in a considerable mass in the same hill. This makes it certain that a part of the ferruginous material of the green schist is tuffaceous and related to these diorites. Before we made this discovery we had regarded the few occurrences of this diorite as eruptive. They occupy but a small area, and the hornblendic beds of the green schist proper are of a different and plainly metamorphic clastic type.

The aphanitic quartzite pebbles are unlike the coarse saccharoidal Grafton quartzite, but resemble the fine-grained calcareous quartzite of the green schist series itself, especially that form of it seen in inclosures in the porphyry in Cumberland; that is, the actinolite quartzite is such a rock as would be produced if the calcite of the latter rock had gone to the formation of abundant actinolite needles.

The interesting relations of this tuffaceous conglomerate and the adjacent diorite are discussed on page 44.

VARIETIES OF THE SCHIST.

Epidote-chlorite schist.—A typical green schist outcrops by the roadside a mile northwest of Lonsdale, near the granite. It is a fine-grained, irregularly fissile schist of gray-green color, with indistinct green veinlets of a shade suggesting pistachio green. There are minute perfect crystals of pyrite (100) (111), superficially changed to limonite. The sheen of a micaceous mineral can be seen. The veins alone give slight effervescence with cold acid. The slide (362) shows with the lens porphyritic rounded spots, around which the constituents have a somewhat concentric arrangement. The field shows a dense mat of elongate green (chlorite) and pale-green (actinolite) blades with a few small, angular, colorless grains of quartz, more or less strained, the whole being dusted with a shining, granular, almost colorless mineral (epidote). The chlorite is uniaxial and positive (pennine), with pleochroism ranging from yellow-green to emerald-green.

Some of the porphyritic spots are relics of plagioclase phenocrysts, now almost wholly changed to groups of small, stout epidotes and olive-green biotites. One of the plagioclase remnants gave extinction 13–13, with broad bands. These feldspars are rare and are irregularly distributed. They may have been derived from diorite grains in the tuff. The granular mineral shows red of the second order in a slide of normal thickness, and so is epidote rather than zoisite.

Another rock from the same locality is a similar green, mottled, very fine-grained schist or slate, with large chalcopyrite grains surrounded by a rim of just visible hornblende needles. The slide (370) is a mat of very fine-grained hornblende needles with blue absorption on *c* and chlorite scales in a clastic ground, with much epidote and many wisps of fasciculate tourmaline needles, with very strong absorption, salmon-colored parallel to *c*, blue-black parallel to *a*.

Actinolite quartzite.—A fine-grained massive rock, varying from white to dark gray, occurs as pebbles in the tuffaceous conglomerate and in independent beds. It is made up wholly of very fine grains of angular quartz and of needles of pale-green actinolite, the latter being in places abundant.

Chlorite-actinolite schist.—Another rock collected at a place one-third of a mile from the granite and one-half mile west of Woodville, in West Providence, was the common, greenish-black, fissile rock, showing with the lens stout, minute actinolite needles and chlorite scales. The slide (437) showed abundant broad blades of chlorite and actinolite with ragged ends, which form an open network in a ground made up of magnetite and epidote grains and minute actinolite needles.

Hornblende schist.—Hornblende schist is especially abundant in the green schist around the Lime Rock limestone and east of the river in the land west of Sneech Pond about Cumberland Hill, which is marked hornblende rock on Jackson's map. There is at Smithfield a beautiful satiny, thin-fissile amphibolite, made up of brilliant black needles pointing in a common direction.

Doctor Jackson's remarks concerning the hornblende rock are extremely interesting and show that the doubts about its origin arose early (1839).

> The rock * * * presents some of the most perplexing geological enigmas that have fallen under my notice. It is generally regarded as an unstratified rock of igneous origin, but not unfrequently presents the appearance of regular stratification. * * * It passes frequently by imperceptible shades into chloritic and argillaceous slates, so that it is very difficult to define its exact limits. * * * I am of opinion that it is decidedly a rock of igneous origin; * * * that it derives its occasionally stratiform structure from an admixture of argillaceous slate rock through which it was elevated * * * and * * * that the serpentine frequently is a product of the interfusion of the hornblende rock and the soapstone. * * *. It is highly probable that * * * the hornblende rock has charged the Smithfield limestone near its junction with magnesia.[a]

It will be noted that we assign a part of Doctor Jackson's hornblende rock to an igneous origin and part to a sedimentary and metamorphic origin. His last three propositions we should hardly indorse, though we made no study of the dolomite in the Smithfield limestone.

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[a] Rept. Geol. and Agr. Survey of Rhode Island, 1840, pp. 30–31.

SMITHFIELD LIMESTONE MEMBER.

GENERAL FEATURES.

The great "Harris" and "Dexter" beds of limestone in Lincoln (formerly part of Smithfield, from which the name Smithfield limestone is derived) have long been known because of their economic importance and the interesting minerals found in them. They have given name to the village of Lime Rock and still sustain a considerable industry, although they are less important than they were before the advent of the railroad.

Formerly many other beds were worked that are now abandoned, for large beds of this rock occur in many parts of the Marlboro formation, and those now found are only a part of the limestone which was present in the original rock. Many beds of tremolite rock, soapstone, serpentine, amphibolite, and ores of iron and copper have replaced limestone. In color the rock is generally pure white, but is in some places banded in dark gray or tinged yellow with iron or pink with manganese, as if it contained rhodochrosite.

The Smithfield beds vary from massive saccharoidal marbles of fine to above medium grain to rocks laminated through shearing with the development of chlorite, asbestos, mountain leather, and talc upon the gliding planes. Professor Woodworth figures the echeloned fragments of a disjointed dike in the limestone in the southern bed in Lincoln, and calls attention to the fact that the limestone has under pressure flowed into all the interstices and now shows no trace of the separation.[a]

These beds are plainly the contemporaneous members of a sedimentary series intercalated originally with clayey, marly, and tuffaceous layers. They attain in places a thickness of 150 feet or more, and their present appearance in isolated, long, elliptical masses is due to faulting, solution, and the metamorphism of much of the original limestone into other rocks. They are in part dolomitic and in part pure limestones.

They have been in many places replaced by ores of iron and copper, especially at Copper Mine Hill, north of Sneech Pond, in Cumberland. Doctor Jackson says:[b]

> The magnesium limes of Rhode Island have always ranked high in the estimation of masons, and they are prized for the quickness of their setting when converted into mortar, as also for the beautiful whiteness of the lime. Hence the Smithfield "hard-jointer" rock, being a magnesium limestone, makes a variety of lime that commands a higher price in the market than any other. This kind of lime is, however, unfit for agriculture, and care should be taken to use only the soft rock for that purpose, since it is free from magnesia.

The dolomite of Rhode Island is that portion of the bed which lies in contact with or near the hornblende rock. In some places, however,

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[a] Mon. U. S. Geol. Survey, vol. 33, 1899, p. 108.

[b] Jackson, idem, p. 36.

the line of dolomitization appears to terminate abruptly at a distance of 6 or 10 feet from the hornblende rock.[a]

The figures given below show the annual value of the lime burned in Rhode Island, the industry being confined almost entirely to Providence County.[a]

Value of lime produced in Rhode Island, 1890–1905.

1890	$27,625	1898	$10,215
1891	25,000	1899	18,239
1892	30,000	1900	16,715
1893	24,800	1901	37,798
1894	20,433	1902	
1895		1903	34,432
1896	11,589	1904	31,871
1897	11,555	1905	42,743

The following table of analyses is taken from Doctor Jackson's report.[b]

Analyses of limestones from Rhode Island.

No.	Locality, owner, etc.	Variety.	Carbonate of lime.	Insoluble matter.	Oxide of iron.	Magnesia.	Lime.	Specific gravity.
1	Cumberland Hill, F. Brown.	White, greenish, granular.	52.2	6.0	......	40.6	29.4	2.728
2	Cumberland Hill.....	Greenstone (8.0 water)..	68.8	23.2	1.0	6.2	38.7	....
3	Johnston, Mr. Brown.	Stone, white with yellowish spots, crystalline.	55.2	46.6	......	4.2	31.1	....
4	Johnston, Mr. Jenkins.	Stone, white with yellowish and green spots, crystalline.	97.2	.8	......	.6	54.6	....
5	North Providence....	White, compact, subcrystalline.	56.1	11.4	......	32.5	31.6	....
6	Newport Harbor, Lime Islands.	Compact, blue and buff colored.	53.2	7.0	1.9	37.9	29.9	2.824
7	North Providence, lime quarry.	White and compact.....	68.6	8.6	......	21.0	38.6	....
8	Smithfield, Harris rock.	Rhomb spar............	92.8	....	3.8	3.4	52.2	....
9	Shore near Fort Adams.	Yellow, buff-colored, compact.	50.9	4.3	2.1	42.7	28.7	2.822
10	Smithfield, Harris quarries.	Soft rock..............	92.4	6.0	.4	1.2	52.0	....
11	Smithfield, Harris rock.	First quality hard rock.	60.4	1.0	2.6	36.0	34.0	....
12	Smithfield, Dexter quarry.	White, granular, and crumbly.	94.8	1.6	......	....	53.4	2.660
13	.....do..............	Compact, white, insoluble matter in acicular crystals.	64.6	2.0	Tr.	32.0	36.4	2.853
14	Smithfield, S. Arnold.	Stone, white, coated with talc and crystalline.	50.6	3.8	Tr.	44.4	28.5	....
15	Smithfield, Harris quarry.	First quality soft blue stone with blue and white stripes, crystalline.	92.2	1.0	......	6.8	51.9	....
16	Smithfield, Harris rock.	Crystalline and granular.	95.8	1.4	......	2.8	58.0	2.681
17	.....do..............	Very clear light blue stratified and crystalline.	87.0	12.4	......	....	49.0	2.715
18	Smithfield, E. Angell.	Stone white and crystalline.	97.6	1.0	......	....	54.9	....

[a] Twenty-first Ann. Rept. U. S. Geol. Survey, 1899, pt. 6 (continued), pp. 357-360; Mineral Resources U. S. for 1901, p. 667.

[b] Idem, p. 246.

The following analysis of the limestone quarried by Mr. Herbert Harris at his quarry at Lime Rock, Providence County, was made by Prof. J. H. Appleton, of Brown University.[a]

Analysis of limestone quarried at Lime Rock, R. I.

Moisture	0.040
Oxide of iron	.011
Alumina (Al_2O_3)	.309
Siliceous matter (insoluble)	2.748
Calcium carbonate ($CaCO_3$)	88.233
Magnesium carbonate ($MgCO_3$)	8.797
	100.138

DETAILED DESCRIPTIONS OF THE LIMESTONE BEDS.

ORES OF COPPER, MANGANESE, AND IRON.

On Doctor Jackson's map the symbol for copper is repeated several times in the area northwest of Sneech Pond. Reporting upon this area he says that[b] the limestone in the beds at Cumberland Hill, on the estate of Mr. F. Brown, runs N. 25° W., dips 35° E., and is 6 to 10 feet thick and dips beneath the granite. He states that it contains copper pyrites, tremolite, asbestos, and actinolite, and a number of curious minerals common to such limestones.

Continuing he writes:

Near Sneech Pond there is an ancient mine, sunk apparently for the purpose of extracting ores of copper, which are found there mixed with veins of granular magnetic iron ore. The shaft slopes to the northeast by east, following the dip of the vein, and is 20 to 30 feet wide, but it has for a long time been filled with water, so that its depth has not been ascertained.

Near the pond occurs a very thick bed of a remarkable ore of manganese, which is peculiar in its composition, but most nearly resembles the knebelite of Beudant. The bed is no less than 40 feet thick, and when any method of making use of the mineral is discovered it may prove an important locality. One hundred grains of this mineral were taken for analysis, and the following results were obtained:

Silicic acid	26.400
Protoxide iron	35.912
Protoxide manganese	32.488
Carbonic acid	5.200
	100.000

Another specimen yielded:

Silicic acid	29.400
Protoxide iron	37.707
Protoxide manganese	27.692
Carbonic acid	5.200
	99.999

Specific gravity mean of three specimens, 3.7881.

[a] Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6 (continued), p. 442. [b] Idem, pp. 54–56.

Associated with this mineral occur crystals of green quartz, or prase, and veins of quartz penetrated by delicate green crystals of actinolite, forming a kind of ornamental stone for which the name Thetis Hair stone has been proposed. Sulphuret of molybdena also occurs in the manganese ore, and the yenite formerly discovered near this place is said to have been formed in the accompanying quartz veins. Ligneous actinolite abounds in the veins with the quartz above mentioned.

Several excavations of considerable extent have been made in this vicinity, and were probably prompted by the discovery of masses of yellow copper pyrites, which was doubtless mistaken for gold, as it generally is by persons unacquainted with mineralogy. It is worth remarking that there are no less than 50 different ancient mine holes in this hill, and it is estimated that more than half a million dollars must have been spent in these fruitless researches for the precious metals. The iron ore appears to have been generally neglected, although when wood was abundant in this vicinity it might have been profitably wrought for iron.

At one of these ancient mines it was easy to discover what minerals were sought for, since one of the casks in which the ore had been packed for the purpose of sending it to England had been left, and from its broken and partly decomposed staves we picked up an abundance of the yellow copper pyrites which is found accompanying the granular magnetic iron ore. I took a fair specimen of this ore and subjected it to separation by the magnet, and then reduced the copper ore which was left. It contains, in 100 grains of the picked ore:

Copper	36.842
Iron	31.940
Sulphur	31.218
	100.000

Professor Woodworth reports that angular brecciated fragments of the limestone lie in the ore-bearing mass at this locality, and assumes that the ores of iron and copper have replaced the limestone, as is doubtless the case. He mentions that there are eruptive rocks near, but finds no means of determining whether the ore has been deposited through the action of heated waters connected with these eruptives or through the downward percolation of acidulated surface waters. Fluorspar in small quantity everywhere accompanies the eruptives, and we should expect to find it concentrated in considerable abundance in the ores if these were produced from solutions derived from the vicinity of these eruptives, and such we found to be the case.

Epidote occurs south of the road a mile east of Sneech Pond, in masses a foot thick, in the green schist doubtless derived from the alteration of small limestone beds.

NONOCCURRENCE OF ILVAITE IN RHODE ISLAND.

The citation of yenite, above, depends upon a determination in 1823 by Prof. C. U. Shepard[a] of a mineral having apparently all the properties of yenite. This mineral was found on Tower Hill, in Cumberland, in a matrix of quartz, epidote, and magnetite. Dr. Samuel Robinson cites the same mineral "1 mile east of Cumberland meeting-house, associated with calcareous spar, actinolite, quartz, and prase."[b]

[a] Am. Jour. Sci., vol. 7, 1824, p. 251.

[b] Am. Jour. Sci., vol. 8, 1824, p. 231.

Professor Shepard describes it in his Mineralogy[a] in 1832 and 1835 as traversing quartz in seams and as associated with magnetic iron and hornblende. In his third edition, in 1852, he omits the locality entirely, and in his collection there were no specimens from Rhode Island labeled yenite, but there were black crystals labeled knebelite. Neither is there a specimen labeled yenite in the second collection he formed, which came to Amherst College after his death. The citation has remained in Dana's Mineralogy from the beginning, but it should be canceled.

Professor Dana originally reported from Cumberland the minerals manganese, epidote, actinolite, garnet, titaniferous iron, magnetite, red hematite, chalcopyrite.[b] In the sixth edition E. S. Dana (1892) copied this list, with the additions of bornite, malachite, azurite, calcite, apatite, feldspar, zoisite, mica, quartz crystals, and ilvaite. At Beaconpole Hill he reports crocidolite; at Sneech Pond, chalcopyrite, ilvaite, wad, molybdenite, magnetite, epidote, and chlorite.

It is probable that the knebelite crystals from the manganese locality near Sneech Pond gave occasion for the incorrect citation given under ilvaite in each edition of Dana's Mineralogy, viz:

Reported as formerly found at Cumberland, R. I., in slender black or brownish black crystals traversing quartz along with magnetite and hornblende.

It is remarkable also that knebelite is not entered in these lists from the report of Doctor Jackson, particularly as his citation is sustained by the two analyses quoted above, which agree well with other analyses of this mineral.

Mr. George F. Kunz writes as follows concerning gem stones found at Cumberland, R. I.:[c]

The so-called Thetis hairstone described by Doctor Jackson, found at Cumberland, R. I., is really a quartz cat's-eye, and some very fair cat's-eyes have recently been cut from it by Mr. Edwin Passmore, one of them nearly two-thirds of an inch long, and quite equal to many from Hoff, Bavaria.

The beautiful specimens of limpid milky quartz, and also quartz crystals, the latter at times from three-fourths of an inch to 2 inches long, are found penetrated by crystals of black hornblende varying in size from acicular to those one-sixteenth inch in diameter and at times 6 inches long. They interlace and penetrate the quartz in every direction, making a very beautiful gem and ornamental stone. Fine pieces 6 inches square have been found. It occurs at the quarry at Calumet Hill, Cumberland, R. I., where the workmen, as a rule, knowing its value, secure the best specimens for disposal to the greatest advantage. Some hundreds of pounds of this material were sent abroad a few years ago to be cut up for jewelry at Idar and Oberstein. As, however, work has been suspended at the locality the mineral is likely to become somewhat uncommon. Cut specimens sell at from 50 cents to $5, and specimens polished on one side at from 25 cents to $5. This locality is one of the best known for this association.

[a] Treatise on Mineralogy, pt. 2, 1832, p. 288.

[b] System of Mineralogy, 1883, p. 770.

[c] Kunz, G. F., Precious stones: Mineral Resources U. S., 1883-4, pp. 755, 761.

It is interesting to go back to what may be called the mineralogical period of geological science in America, initiated by the early volumes of the American Journal of Science, and read the first citation of the molybdenite mentioned above (p. 20) as it appeared in that journal under the heading "Miscellaneous localities of minerals," [a] in an item by Dr. Samuel Robinson, of Providence, R. I., viz:

> *Sulphuret of Molybdena* with *magnetic oxide of Iron* and *magnetic pyritous Iron* ½ a mile N. N. E. from C. M. H. [Cumberland meeting house], at a place called the "Mine Hole," on the west side of a Hill which overlooks "Sneerch's Pond," where a shaft was sunk for Copper 70 feet deep, 40 to 45 years ago.

INCLUSION OF LIMESTONE IN GRANITE PORPHYRY.

A remarkably interesting inclusion from the north end of the Cumberland granite-porphyry dike (slide 369) seems at first sight to be a gray penciled slate or fine sandstone, but is a nearly pure, granular limestone with a few muscovite, biotite, quartz, and magnetite grains.

Many of the grains are idiomorphic, and are brought by pressure into a direction parallel to a single line, so as to give the pencil structure. The forces gave motion in only one direction, as in the "drawing" of a wire. There are parallel bands of coaly matter in rounded grains, but no magnetite.

A similar inclusion (slide 361) from the same place is a light-gray, fine-grained, coarse columnar or penciled micaceous limestone, very impure, but effervescing freely. It contains many grains of pyrite, and weathers rusty and cavernous, as is usual with a calcareous rock. It is full of dark grains, which may be partly anthracite, in foliation bands which are thickly crowded on the contact. Much magnetite is present. There are many trains of strained quartz grains. Some seem surrounded by secondary growth.

The small degree of metamorphism in the limestones found in the large Cumberland dike is noteworthy. It would seem that they were involved in the porphyry when but little metamorphosed and that the porphyry acted on them at so low a temperature, and perhaps with so small an amount of water that it did not produce the most striking effects, especially failing to utilize the lime and iron to make actinolite or garnet or the lime to make tremolite. It is, indeed, possible that its inclusion in the porphyry has protected it somewhat from the long-continued crushing and circulation of heated waters to which the rest of the schists were subjected, so that the inclusions represent a stage before the development of actinolite, tremolite, garnet, epidote, and serpentine. Other fragments of the same rock, without being more metamorphosed otherwise, were soaked so full of fluorite from the mineralizing of the porphyry that they have a rich purple color.

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[a] Am. Jour. Sci., 1st ser., vol. 8, 1824, p. 231.

HARRIS BED AT LIME ROCK.

The Harris bed is the largest bed of limestone and has been most extensively worked. It is at least 150 feet thick, and the present outcrops are the remnants of a more continuous band. It is largely a wholly massive, highly crystalline marble of rather fine grain and of snowy whiteness. It would be a very beautiful building stone, or would serve even as a statuary marble, if it were not so much fissured. Its fractured and broken structure has given it the name "jointer rock," by which it has long been known. Doctor Jackson says:[a]

It is included immediately in greenstone or hornblende rock of a dark brownish green color, compact in structure and exceedingly hard. * * * The Harris lime rock is largely wrought, it being considered the best quarry, and is usually known by the name of the jointer ledge, a name derived from the joints in the rocks. * * * That portion of the limestone which lies in contact with the hornblende rock is called the hard jointer, and is the variety of magnesian carbonate of lime called granular dolomite. About 10 feet from the hornblende rock the limestone graduates into pure granular carbonate of lime, occasionally colored with plumbaginous matter, oxides of manganese, and iron.

It is especially notable because of the dikes by which it is cut and the large number of interesting minerals which have been found in it.

Under the microscope the grains of calcite in some specimens are of coarse, even grain, and are rarely twinned. In other bands the calcite is crushed into a mass of elongate grains or finely powdered and many of the grains are twinned. The rock in some slides shows grains of colorless pyroxene and large plates of colorless hornblende broken up into separate fields by a growth of brightly polarizing talc, which itself merges into an aggregate of pale bluish plates of the colorless serpentine called bowenite. In other slides the rock contains much brown granular essonite. At its contact with the schist the limestone is tinted with malachite. Veins of a velvet-black, very greasy quartz run through the rock, and fine quartz crystals are found in the fissures.

The talc at the Harris quarry in Lime Rock is white, thin, and fissile, and some layers still effervesce with cold acid. It is derived from the tremolite, and inherits from it a matted fibrous structure. Tremolite, pure white asbestos, mountain leather, the pale-green serpentinous mineral "bowenite," and essonite are found at the eastern Lime Rock quarry. The last two are formed at the contact on the small dikes which cut the limestone.

Veins of compact epidote 3 inches thick occur in the white marble in Smithfield, and a similar rock made up of irregular alternating layers, about an inch thick, of dark-brown garnet and green epidote occur at Lime Rock. Similar epidote veins contain fragments of the black

[a] Idem, pp. 57, 58.

massive hornblende rock, which become so abundant in places as to form a breccia.

A pure white pyroxene occurs in the Lime Rock quarry, in coarse, radiate, columnar aggregates, the individuals of which are in some specimens developed in perfect crystals of the Nordmark type—100, 010, 001, 110, with parting parallel to 001. They are in prisms a half inch square, and resemble, even in the perfect basal parting, the canaanite from the Stockbridge marble.

The order of crystallization of the calcite in fissures in the limestone at Lime Rock is interesting. At first drusy surfaces of minute crystals having the form of the unit rhombohedron without modification were formed. These were calcite, as their effervescence with dilute acid shows. Upon this surface are perched simple forms—1/2 R and a very acuminate rhombohedron simulating a hexagonal prism. Upon this come scalenohedral forms of the greatest complexity. Some of these are flattened to resemble the half of one of the Egremont butterfly twins, or form square prisms with two opposite faces striated, and the two remaining faces polished. The corners of this apparently four-sided prism are replaced by the faces of an acute four-sided pyramid, producing an apparently quadratic form.

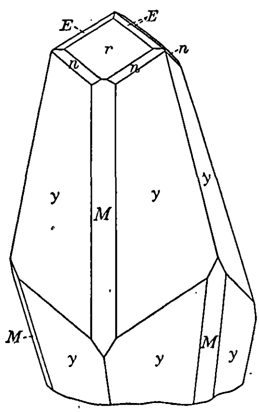


Fig. 1.—Calcite crystal from the Harris bed at Lime Rock.

Next an infiltration of limonite has covered the surface of the crystals with a tarnish of brilliant peacock colors. There has then followed a new growth of limpid calcite, which has placed upon the apex of the amber scalenohedra a capping having the form ∞P and −1. (See fig. 2.) Finally, rare needles of scolecite have grown in the drusy cavities. These are amber colored, transparent, and of the size of a fine hair, and have been bent in growing across the cavity. Only four of these delicate needles were found. One was found to be optically negative. Its greatest elasticity was parallel to its length, and a positive bisectrix emerges from the middle of one of its sides. It was decomposed by acid without effervescence. On revolution on the long axis the angle of extinction proved to be 7°.

Professor C. Palache has been so kind as to examine the calcite crystals and to send the following description and accompanying figures:

Fig. 1 shows the more important forms and the habit of most of the crystals. The dominant form is y, R 5, $3\ 2\ \bar{5}\ 1$, whose obtuse angles are truncated by the positive rhombohedron M, 4 R, $4\ \bar{4}\ 0\ 1$. The termination consists of r, R, $1\ 0\ \bar{1}\ 1$, with narrow planes of scalenohedrons of the principal zone, of which n, R 5/3, $4\ 1\ \bar{5}\ 3$, and E. 1/2R 5/3, $4\ 1\ \bar{5}\ 6$, are the commonest. e, −1/2R, $0\ 1\ \bar{1}\ 2$, is also sometimes present in the zone. M and r generally meet in a series of steplike oscillations not shown in the drawings.

Other steep scalenohedrons of the principal zone are also often present, sometimes in addition to y, sometimes taking its place. On one measured crystal the forms of this group found were as follows:

R 11/8, $19.3.\bar{22}.16$
n, R 5/3, $41\bar{5}3$
R 9/5, $72\bar{9}5$
R4, $53\bar{8}2$
R 16/3, $19.13.\bar{32}.6$
R6, $7.5.\bar{12}.2$
R 19/3, $11.8.\bar{19}.3$
R 20/3, $23.17.\bar{40}.6$

Fig. 2 shows an interesting parallel growth which was observed on one crystal. On a crystal of the ordinary habit is placed in parallel position a second consisting simply of the combination of prism of second order, a, ∞ P2, $11\bar{2}0$, and negative rhombohedron, e, —1/2R, $01\bar{1}2$.

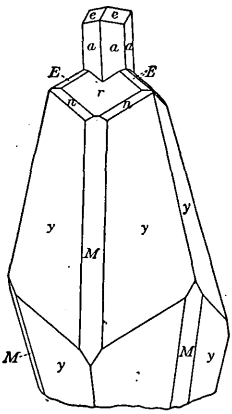


FIG. 2.—Calcite crystal from the Harris bed at Lime Rock. A later colorless addition is made to the golden yellow scalenohedron.

Another type of habit is illustrated in fig. 3. The forms are dominated by the same scalenohedron prominent in the other types, y, $32\bar{5}1$, + R5. No other scalenohedron is present but both first and second order prisms are found and a series of negative rhombohedrons; of these the only one accurately determined by measurement was e, $01\bar{1}2$, —1/2R. The others form a more or less rounded surface between *e* and the prism *m*, but the edges of the scalenohedron truncated by planes of a rhombohedron on several crystals, indicating the form X, 0772, —7/2R, shown in the drawing, and one measurement from a sharp face gave a value corresponding to L, $08\bar{8}7$, —8/7R which is also indicated in the figure.

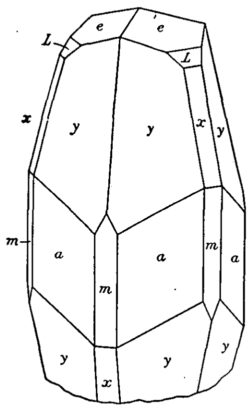


FIG. 3.—Calcite crystal of the square type from the Harris bed at Lime Rock.

m	$10\bar{1}0$	∞ P	
a	$11\bar{2}0$	∞ P2	
e	$01\bar{1}2$	—1/2R	
L	$08\bar{8}7$	—8/7R	
	$07\bar{7}2$	—7/2R	
y	$32\bar{5}1$	+R5	

DEXTER QUARRY.

The rock at the Dexter quarry, at Smithfield, is called locally the Dexter rock or the South rock. This outcrop is next in importance, economically, to the bed at Lime Rock, and is still worked in an extensive quarry for lime. It ranges in width from 12 to 15 rods and extends several times this distance on the strike. It is cut off abruptly on the south by the green schists but may extend far north in the depressed area beneath the till.

It is greatly jointed, pure white to gray banded, and carries fewer minerals than the former bed, quartz and calcite crystals and talc pseudomorph after tremolite being the only common ones found.

Octahedrite is reported as occurring in small crystals at "Dexter's lime rock at Smithfield, R. I."[a] I had not been able to verify this citation, nor to find any trace of the mineral at the locality, nor any specimen of the mineral from this place in any collection until recently Professor Palache wrote me that he had found in the Cambridge Museum a very pretty specimen, in a collection from the Dexter quarry made many years ago by Prof. M. E. Wadsworth.

BEDS WEST OF PROVIDENCE AND PAWTUCKET.

Doctor Jackson mentioned several small beds of limestone on the Aza Arnold farm.[b] This is the bed a mile west of Lonsdale, which is 20 to 30 feet wide and 300 feet long, and has now been about all quarried out. Unlike the other beds, this is isolated in the granite, but lies near the border of the green schist. It is bordered on the east side by a bed of tremolite rock several feet thick, and on the west by a similar thick bed of compact talc which is fibrous and pseudomorphic after tremolite. Both these beds have been derived from the limestone, and the transition can be plainly seen. The bed as a whole can be traced southeast with the strike for a mile to near Saylesville by a series of tremolitic serpentine outcrops.

Doctor Jackson mentions[c] also an extensive bed of limestone on the farm of Nathan Brown, 4 miles from Providence, which was worked for lime before the discovery of the Smithfield lime rocks. The bed is about 6 rods wide, and is included between hornblende schist and a compact altered graywacke that is nearly as crystalline as granite. Chlorite slate rocks in beds 10 feet thick lie southwest of the limestone, and include beds of talcose rock or soapstone. Green, acicular, and fasciculated actinolite and crystals of magnetic iron ore of an octahedral form are found here in chlorite and green talc. Granular and compact limestone also occurs on the Olney farm, in hornblende rock associated with beds of chlorite slate, soapstone, and serpentine. Coarsely granular layers of a bright-pink color occur west of the road on the west slope of Neutaconkanut Hill. They alternate with green chloritic limestone. The rock may contain some rhodochrosite. Associated with it are heavy beds made up of brown garnet and green epidote.

CRANSTON BED.

An ore bed is marked on Doctor Jackson's map at a place in Cranston, and this was the site of an iron mine. Professor Woodworth says of this bed: "The iron of the old mine in Cranston in the 'dug-

[a] Kunz, G. F., Mineral Resources U. S., 1883-84, p. 772. [b] Idem, p. 57. [c] Idem, pp. 80, 81.

way' is probably a ferruginous replacement of the limestone." In the bed of a small brook above this mine there is a vertical bed of limestone 10 feet thick.

ATTLEBORO BED.

In the Massachusetts State collection, under VII, Devonian or Old Red Sandstone rocks, there is a specimen marked "88 Petalite in limestone, Attleborough." This is a white chalcedony in a white crystallized limestone that effervesces with cold acid. This is wholly unlike the compact limestone interstratified with red shale from the ordinary Cambrian at Attleboro, and is exactly like the crystalline limestone of the green schist. It may be that it is a contact product of the intrusives of the region around Attleboro, which lies outside the area of our investigation. This may be taken to slightly increase the probability of the derivation of the green schists from strata similar to the Cambrian rocks at Attleboro, as maintained on page 33.

BEDS IN WOONSOCKET.

The green schist with limestone extends in scattered fragments out over the granite to the north and west. Thick beds of coarse pink marble occur in pyritous quartzose mica schist in Woonsocket.

A 3-inch layer of very coarse calcite (each grain 1½ inches square) occurs in a coarse biotite schist carrying coarse prisms of sillimanite in North Smithfield. These are just beyond the limits of the area mapped in Pl. I.

CONTACT ROCKS ON THE MILFORD GRANITE AND OTHER IGNEOUS ROCKS.

GENERAL FEATURES OF THE METAMORPHISM.

The normal members of the Cambrian formation are a fine-grained generally aphanitic chlorite slate, a fine-grained hornblende schist, a white crystalline limestone, and a slightly muscovitic saccharoidal quartzite. These represent the normal minimum of metamorphism which may be ascribed to the mashing to which the pre-Cambrian and Cambrian rocks were subjected, probably in Ordovician time and before the advent of the Milford granite.

In a broad band adjacent to the Milford granite these normal rocks are at some points greatly altered; the slates have become coarse chloritic or biotitic amphibolites, the limestones have changed to tremolite rock which may show transitions to steatite or impure steatite-serpentine masses, and the quartzites have become dark biotite schists. We have associated with these contact rocks some similar beds from the interior of the series for reasons given below.

The whole Cumberland region and the smaller area to the south are in effect large inclusions in the great batholith of Milford granite.

This is the justification of the term "batholithic structure" applied by Woodworth. The large Lonsdale limestone bed described above is inclosed wholly in this granite. The great beds of tremolite which have been formed from this limestone at the contact (since the limestone is wholly inclosed in the granite) can best be explained as formed by the union of silica derived from the granite with the bases of the limestone.

Southeastward for a mile along the strike, and at the same time along the border, there extends a thick bed of massive impure serpentine, or steatite-serpentine mixture, whose massiveness suggests an igneous origin, but whose fibrous texture indicates its derivation, through a tremolitic stage, from the limestone bed, as does its position in the strike of the limestone. The same kind of rock occurs at several other places on the border, as indicated on the map. These occurrences we ascribe to the contact influence of the Milford granite. Therefore, when we find the same impure serpentine and steatite rock associated at many places with the coarse garnet rock and forming a continuation of the great limestone beds in the midst of the green schists, we may fairly conclude that the granite beneath has produced the change, as at the border. Indeed, a small amount of granite appears at places where the serpentinous change is best developed, as at a point just north of the Lime Rock quarry. Where the tremolite border is lacking on the limestone beds, as it generally is in the interior of the limestone region, the granite was too distant to effect the change.

Again at some places the least altered beds of hornblende schist and chlorite schist contain pebbles and grade into quartzites and are interstratified with limestones; at other places the most highly crystalline beds, in which the coarse hornblende schists are porphyritic with large hornblende crystals and contain plagioclase, are also interstratified with limestone beds or their derivatives—tremolitic and garnet-epidote rocks and ore beds—and every gradation can be observed between the two kinds of rock. Thus some of the beds, such as the diorites described below among the igneous rocks, still show trace of igneous origin and are undoubtedly igneous, while other tremolitic and hornblendic beds are of different type and under the microscope and in the field give evidence of sedimentary origin. In this section we have considered only those contact effects which are exomorphic to the granite. A broad band of the latter is generally much darker than usual, a probable result of differentiation, though this is not so marked as in Massachusetts, where a broad hornblendic band is usually present.

CONTACT ROCKS DERIVED FROM THE LIMESTONE.

Tremolite rock and serpentine.—An interesting outcrop of a partly serpentinized tremolite rock occurs in Lime Rock, near the point where the road turns off to the quarry. It is a massive greenish-gray rock, having the appearance of serpentine, with abundant black porphyritic crystals that show the cleavage of hornblende.

The black-looking crystals are colorless hornblende, their black appearance being due to an abundance of magnetite arranged along the cleavage planes. The ground between these black crystals is made up of a matted network of tremolite needles. In this rock the grains of iron oxide are in some places so arranged that they mark out a former hornblende cleavage over large areas, showing that in these areas there were formerly large tremolite crystals that have by a kind of paramorphism been changed into the tremolite needles. Large patches are changed to a green serpentine. The great amount of the iron in the limestone has doubtless been brought in from the adjacent basic tuffs, and the ore beds mentioned above represent a more complete replacement of the limestone.

Several slides cut from the large dikelike mass 50 rods long by 20 rods wide on the top of the serpentine hill, just north of the Lime Rock quarry, are of the same type as the rock east of the Lime Rock road, and the two outcrops have been connected on the map. The rock is massive and of dark-gray color, the black hornblende crystals showing more or less distinctly. The serpentinous change in this rock is farther advanced than in the rock described above, and at many places only the dense masses of magnetite grains, with angular boundaries, indicate the former presence of the large crystals of hornblende, since this and the finer fibrous tremolite have changed to a mat of serpentine blades.

Tremolitic serpentine.—A rock from the granite contact, three-fourths of a mile southwest of the Lime Rock quarry, in Lincoln, is a dark-gray, harsh-feeling serpentine, full of large tremolite blades and rhombs of dolomite.

The slide (356) shows a black-dusted homogeneous serpentine made up of slightly polarizing flakes and showing traces of the rectangular cleavage of a former mineral, perhaps a pyroxene. Each of the untwinned rhombs of dolomite is surrounded by a band of dolomite differently orientated.

Steatite.—Just west of Manville, at the fork in the road, is a bed of a soft, dark-gray, coarse-grained steatite full of large rhombohedra of ankerite, many of them one-half inch in diameter, which range in color from wine-yellow to black. Another similar bed occurs a half mile west of Manton. These beds seem also to have been derived from a magnesian limestone, but have passed through an actinolitic stage.

Prof. C. W. Brown called our attention to the Indian "Ollah" quarry at Merino, where half-finished pots still remain attached to the ledge.

Garnet rock.—In the hill north of the Lime Rock limestone quarry, at the serpentine locality in the green schist, there is a thick short band 4 inches wide of brown-red garnet, and on each side of this there is a band 2 inches wide of a fine, granular, pistachio-green mass mixed with granular limestone. The rock contains much fine crystalline magnetite. The garnet is without strain or inclusions. The green mixture is fine, fibrous actinolite filled with fine granular epidote. Here and there are white, fine, granular veins of quartz. The rock passes into an epidote-garnet quartzite. A garnetiferous quartzite appears also as a border bed to the limestone at the Dexter quarry, and in considerable quantity in connection with several other limestone beds.

CONTACT ROCKS DERIVED FROM THE GREEN SCHISTS.

On Neutaconkanut Hill, west of Providence, and at points farther south, we were compelled to map separately a broad contact border because on the one side small offshoots of the granite intricately penetrate the schists and on the other the schists become coarsely crystalline. Generally the line of contact of the granite and the schists is remarkably straight, no lobes of the granite penetrating the schists. Here, however, the granite is intimately mixed with the schists in thin layers, which are at many places intruded between layers of the schist, and although the rocks here are all much more coarsely crystalline than usual the schist, limestone, and quartzite can still be distinguished from one another and from the granite.

Farther north, in Massachusetts, the Milford granite is at many places bordered by a black hornblende band, much injected by small granite veins, and part of this band may be of the same origin as that just described, but the calcareous and ferruginous green schists are so well fitted to change to similar hornblende schists that it is not easy to separate the two.

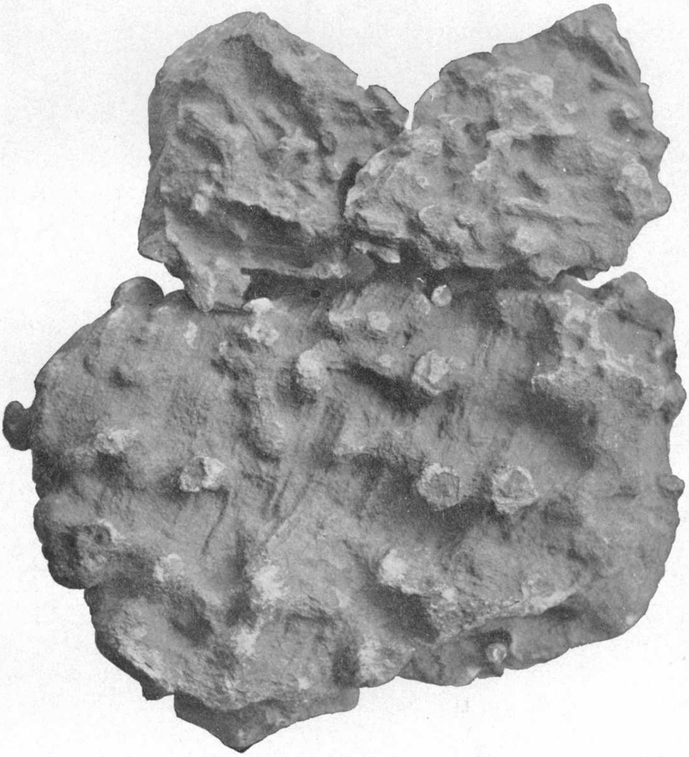
The common rock at the border on Neutaconkanut Hill is dark porphyritic, being closely dotted with perfect, stout, black hornblende crystals from one-eighth to one-fourth inch long, in a light groundmass made up of fine white grains of quartz and feldspar. The microscope shows it to be a biotite-actinolite-epidote schist. It is without calcite or magnetite, but is very cavernous at the surface, from the removal of some constituent. The large, perfectly bounded hornblende crystals are partly or wholly replaced by aggregates of biotite scales, which, where the replacement is partial, are in some cases grouped in the center of the crystal and in others are arranged in an annular band at or near its border.

The contact rocks are well shown along the road in North Providence, 2 miles south of Olney Pond. The noncalcareous chlorite-sericite schist can be traced into a greenish-gray massive rock containing a green mica in a fine-granular quartz-feldspar ground. The intervening calciferous green schist passes into coarse-grained dark green, pyroxenic amphibolite, or a light-colored gneissoid rock mottled by black, square, hornblende crystals or similar square biotite aggregates, as at Neutaconkanut Hill. We may assume that the first influence of the granite here was thermal, producing the coarser crystallization of the hornblende; the second chemical, consisting of a transfer of alkaline solutions from the granite to the schist, whereby the enlarged hornblendes have been in whole or part changed into groups of biotite scales.

A very peculiar rock occurs by the north-south road at the northwest foot of Neutaconkanut Hill. (See Pl. II.) It is the common greenish-black contact form of the calcareous green schist, massive, aphanitic, and homogeneous in appearance when freshly broken, but developing on weathering the two structures shown in the figure—distant, straight, parallel ridges, which seem to represent a concealed foliation, and stout, prismatic projections, which generally comprise regular crystals that have more or less rounded edges and give in cross section the angles of hornblende. These crystals represent a mineral that has grown in the green schist during its first transformation, with only a partial expulsion of the original material of the soft schist—that is, they have grown in the schist somewhat as chiastolite grows in clay slates.

An examination of these crystals in thin section (466) bears out this conclusion. The crystal cross sections are markedly different from the surrounding ground, but their composition is so variable that they differ from one another as one kind of rock differs from another kind. The magnetite octahedra, single and grouped, are equally abundant in the crystal sections and in the ground outside, showing that the magnetite was crystalized before them both. The ground is a mica schist in which half the surface is of olive biotite scales in a colorless ground. The crystals are formed of a green substance, not resolvable by the lens, which is shot through by colorless rods in a sort of micrographic arrangement. There are also some biotite scales somewhat larger than in the ground. With the microscope the groundmass is seen to be made up of the small angular and rounded quartz grains of a very fine-grained sandstone (exactly like the calcareous sandstone described on p. 14) in which the biotite blades and magnetite are disseminated.

The large hornblende crystals preserve one original structure. This is a poikilitic intergrowth of plagioclase, still wholly fresh, which is regularly spread throughout the crystal nearly to its border, or appears in broad patches. It is in long notched rods and plates more or less



PORPHYRITIC GREEN SCHIST.

The ground is a dark mica schist. The distinctly crystalline projections are made up of matted actinolite, pseudomorphous after pyroxene or hornblende. (See page 32.)

rounded, with a parallel arrangement in places, as if controlled by the host. The plates are only rarely twinned and then extinguish at 23°.

The normal growth of the large hornblendes continued slightly after the intergrowth had ceased and then sometimes a few blades shot out from the ends of the large crystals, becoming themselves rather large, branching, and fasciculate, as in garben-schiefer. Groups of the same fasciculate actinolite occur independently. The whole of each large hornblende crystal was then changed into an exceedingly fine-grained felt of actinolite needles of several sizes, mostly so fine and overlapping that they present with low power an almost amorphous mass in which the larger blades shine out.

The rock was a very fine-grained calcareous and ferruginous sandstone, in which first a part of the iron crystallized in the black octahedra and a foliation was produced during the folding of the rock. Then followed the crystallization of the stout hornblende crystals with at first an intergrowth of a lime feldspar, producing a structure not uncommon in limestone contacts. We may infer that these crystals were not formed during the folding of the rock, since they cut across and disturb the remains of the foliation. As this required only the constituents of the original rock, we may assume that the heat of the adjacent granite produced the change. Then followed the development of the abundant biotite in the ground outside the crystals, and this also may be brought into connection with the intrusion of the great granite masses, which involved the sending out into the green schist of alkaline solutions that contributed the potash that joined with the magnesium and iron to make the abundant biotite of the ground. This regularly disseminated biotite is absent from the hornblende crystals, because they were formed at an earlier period. The heat of this intrusion may have caused the paramorphism of the bisilicate to a uralitic pseudomorph.

CONTACT EFFECT OF THE MILFORD GRANITE ON INCLOSED CAMBRIAN SCHISTS AT THE SAYLESVILLE GRANITE QUARRY.

The phenomena described below were at first believed to indicate the post-Carboniferous age of the Milford granite and to suggest that the sericite schists of the Carboniferous border may be due to contact metamorphism caused by that granite. A special study, therefore, was made of the Saylesville quarries northwest of Pawtucket, in Lincoln, because of the interesting inclusions of schist in the granite at that place.

The inclosing rock is a gray biotite granite, coarse, often subporphyritic, containing in some places blue quartz, and much jointed. At the time the quarry was visited, in 1900, large masses of pale greenish schist rose from the floor of the quarry with a width of 3 to

4 rods, a strike N. 35° W., and dip of 50° NE. Pieces taken from the centers of the masses are a soft, greasy sericite slate of leek-green color, closely like the original sericite schist of the Taunus. It is found that a portion of the Albion schist farther west is closely like the least altered portion of the included masses.

At the border the rock is granitoid and the quartz and feldspar of the granite are diffused through the dark material of the schist. For several feet beyond the border of the granite and schist the granite has lost its normal subporphyritic texture and seems to have been shattered by the influence of the moisture of the inclusion and recemented. Outside this belt on every side the granite shows its normal and original texture, with coarse fresh feldspar and distinct biotite films.

A slide (371) was cut from this granite at its contact with the large inclosure. The rock is thoroughly shattered, narrow granulated bands running through several grains and recementing them. The quartz is generally a mosaic, but at some places the rock contains blue quartz in perfect crystals, which are penetrated by lobes of the groundmass. It contains also squarish broken feldspars, some of which are orthoclase, judging from their refraction, but the commonest feldspar is albite. Pale red garnets surrounded by a kelyphitic rim of pale amber pyroxene appear, and also a colorless, limpid, isotropic mineral with purple border, doubtless fluorite. The slide shows also apatite and brilliant zircons.

Under the microscope the inclosed slate in its central portion is seen to be composed of matted parallel filaments of sericite with wavy boundaries dusted full of the coaly and clayey material of the unaltered slate and differing entirely from the nearest green schist, which is made up of sharply outlined crystals of actinolite, biotite, and epidote. The transition of this slate to microflaserig mica schist is clearly traceable. Near the center of the slate are a few lenticular groups of interlocked and greatly strained quartz grains, and these increase in number and size outward, away from the central portion, until a clear flaserig texture is produced and the micaceous films undulate between the augen of strained and interlocking quartz grains as if they had been spread apart by the growing quartz. These grains are often full of rutile needles, like true granite quartz. There is thus far no new mineral except the blue quartz added to the original schist, which consists of white and brown micas, chlorite, and a granular mineral which seems to be epidote; but in one section taken only a foot from the border feldspar, both orthoclase and plagioclase, is introduced in rather large crystals, forming a perfect paragneiss. In specimens taken just adjacent to the granite the grains of quartz and feldspar are larger, more abundant, and more irregular in size and shape, and are included in a small amount of the dark schistose material, which may explain the granite-quartz grains mentioned above.

The sharp border of the great blocks of schist against the granite and the uncrushed condition of the granite away from the border show that the two rocks have not been subjected to a common mashing since the granite cooled. The complete mashing of the schists elsewhere in the region has produced no blue quartz. The blue quartz is the characteristic of the inclosing granite. The granite has thus penetrated the schist for some distance; the blue quartz has been carried in solution still farther in, but is lacking in the central part. This occurrence is analogous to that of a granite stock which sends out into a country rock pegmatitic apophyses that grade outward into quartz veins.

CONTACT ROCK FROM THE GRAFTON QUARTZITE.

An interesting contact rock on the Milford granite occurs in the quartzite west of Manton. It is a black, very fine-grained mica schist that shows in the slide (437) colorless spots in a fine-grained biotite schist, thus having a porphyritic aspect. With polarized light these spots prove to be a colorless uniaxial mica, within which all the grains of the original sand still retain their places. Here also potash was introduced in large quantities, forming biotite.

AGE RELATIONS.

Professor Woodworth proposed the name "Blackstone series" for the complex of quartzites and green schists along the bed of Blackstone River.[a] The limestone and the hornblende rock of this series were assigned to the Primary by Dr. C. T. Jackson, in 1840, in his report upon the geology of Rhode Island. Prof. Ebenezer Emmons referred them, in 1846, to the Taconic[b]—that is to the age of the Stockbridge limestone in the Cambrian or at the base of the Silurian—an assignment which seems probable.

Professor Shaler, in his paper upon the Cambrian of Attleboro,[c] devotes three pages to a discussion of the character and age of the "Blackstone series." He regards it as of sedimentary origin, considers it pre-Cambrian, possibly Huronian, and estimates its probable thickness at more than 5,000 feet. He states that pebbles of the "Blackstone series" are found in the Cambrian, he having then assigned all the red beds in Attleboro to the Cambrian. Later, Foerste, Woodworth, and Shaler[d] give a much less area to the Cambrian, and do not cite pebbles of the "Blackstone" in the true Cambrian. The strike of the "Blackstone series" is northwest-southeast; that of the Cambrian at Attleboro northeast-southwest. Professor Woodworth

[a] Mon. U. S. Geol. Survey, vol. 33, 1899, p. 106.

[b] Agriculture of New York, vol. 1, 1846, pp. 90–93; also American Geology, vol. 1, 1855, p. 22.

[c] Shaler, N. S., On the geology of the Cambrian district of Bristol County, Mass.: Bull. Mus. Comp. Zool., vol. 16, No. 2, 1888, pp. 15–18.

[d] Mon. U. S. Geol. Survey, vol. 33, 1899.

bases the idea of a difference in age between this series and the Cambrian rocks on the fact that the Blackstone beds are greatly metamorphosed, the fossiliferous Cambrian very little, and refers the series to the Algonkian period. He says:[a]

The determination of the pre-Cambrian age of the group of limestones, schists, slates, and quartzites in the Blackstone River area rests upon the relation which it bears to the Lower Cambrian strata in North Attleboro. The Olenellus fauna occurs in little-altered, red, calcareous shales and slates at this latter place in close proximity to granite (hornblendic granitite). Four miles west of this inlier of the Carboniferous area occur the sediments involved in the complex already described. These strata are highly altered sediments, now hornblendic and chloritic schists, mainly of a green color, altered sandstone or quartzites, and crystalline limestones. The presumption that these rocks are pre-Cambrian rests, at present, therefore, on the difference in metamorphism between them and the Lower Cambrian rocks in the same field. The criterion appealed to in this case is embodied in the statement that where two sets of rock coexist in the same dynamic field, that group which has undergone one dynamic movement more than the other is the older. If this view is maintained, this series of rocks falls into the Algonkian. Evidence of unconformity with the Lower Cambrian is necessary to make this conclusion positive. The relation of the granitic intrusives to the pre-Cambrian on the one hand and to the Cambrian on the other is simply to show that the granitite is younger than the former, and that the sedimentary rocks are of different ages.

The reasons which have led us to believe that the "Blackstone series" is Cambrian and that it is the equivalent of the "Attleboro series" are as follows: The highly ferruginous and highly calcareous green schists must have been derived from rocks exactly like the red calcareous shales of the "Attleboro series" and the quartzites from rocks closely like the sandstones of the Braintree Cambrian. Evidence that there is a considerable bed of highly crystalline limestone in the Attleboro area is given above (p. 26).

When these rocks are traced farther northwest it is found that they wrap round a series of coarse, porphyritic, granitoid gneisses like the pre-Cambrian of the Berkshire Hills, and they are themselves indistinguishable from the Cambrian quartzites of Berkshire. Although the two are only 2 or 3 miles apart, the Attleboro rocks lie along a zone of least metamorphism, while the Blackstone rocks lie along a zone of maximum metamorphism. To make this point clear there is reproduced in fig. 4 a map drawn by Professor Woodworth, which shows a zone of maximum disturbance of the Carboniferous rocks extending along the west side of the basin and a zone of lesser change extending along to the east of the former. To Professor Woodworth's map have been added the areas of the "Blackstone series," marked *d*, which it will be seen lie in the continuation of this zone of maximum metamorphism, and the area of the Attleboro fossiliferous Cambrian, marked *e*, which lies in the zone of least change. The Carboniferous rocks in Attleboro contain annelid markings, impressions of

[a] Mon. U. S. Geol. Survey, vol. 33, 1899, p. 105.

raindrops, etc., and are as little altered as the Cambrian there, while farther west, adjacent to the "Blackstone series," Carboniferous conglomerates are metamorphosed into the semblance of granites and into coarse, crumpled mica schist, while the shales are changed into very coarse ottrelite garnet schists, fully as much metamorphosed as the green schists. Professor Woodworth emphasizes this contrast and the suddenness of the transition. He says:[a]

> The geologist who should pass from the nearly vertical metamorphic strata of the East Side in the city of Providence, R. I., to the slightly folded and unaltered shale beds of East Providence would, from a comparison of the rocks alone, be led to infer that there was in this field a set of very ancient tilted rocks flanked on the east by strata of much less antiquity. So short is the space between the two rock phases at this point, being the width of the Seekonk River only, that one is led to believe that an intermediate zone of considerable width has been concealed by a fault.

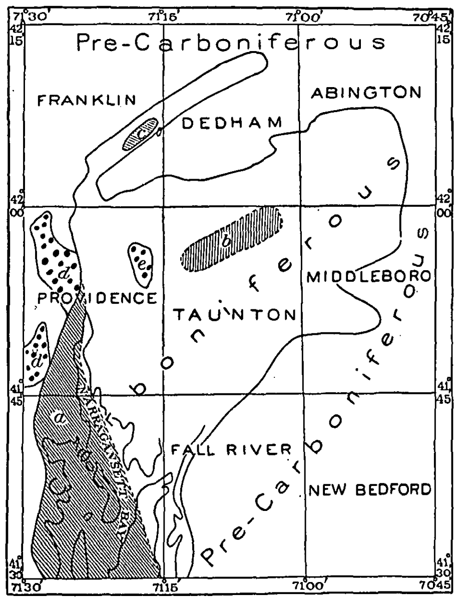


FIG. 4.—Map showing distribution of metamorphosed Carboniferous rocks. *a*, Narragansett Bay area of maximum metamorphism; *b*, Winneconnet area; *c*, Morrill's area, in Norfolk County basin; *d*, Cambrian; *e*, Attleboro fossiliferous Cambrian area.

We may be sure that the Cambrian of the Attleboro area extended some miles farther west of its present limits at the time of its deposition. Indeed, a small area of Cambrian rocks is shown by Professor Woodworth[b], with associated hornblende granite, only a mile from the green schist, on the north border of the Diamond Hill felsite. The geologic history of the region will present to our minds a much simpler picture if we assume that these rocks are represented in an altered state by the wholly similar "Blackstone series" and, farther west and northwest, by the Grafton quartzite and the Marlboro amphibolite, which wrap round the older Northbridge granitoid gneiss. The alternative hypothesis would involve an additional incursion of the sea into the region in pre-Cambrian time, to account for the deposition of the green-schist series. The same hornblendic granite appears in the Cambrian near the fossil beds and in the "Blackstone series" near Albion.

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[a] Mon. U. S. Geol. Survey, vol. 33, 1899, p. 119.

[b] Idem, Pl. XVII.

Green schist underlies Carboniferous rocks at the south end of Conanicut Island[a], and there is a large area in Little Compton, made up mostly of quartzite with some green schist, that is referred by Foerste to the Cambrian, with some reserve. Similar rocks occur about Newport Neck and Newport Harbor. To justify the probable correlation of these rocks at the mouth of Narragansett Bay with the Cambrian beds at North Attleboro, Mr. Foerste cites the very fact noted above, viz, the presence of layers of limestone in the Newport beds in considerable abundance, as in the Attleboro beds, and their absence from the Carboniferous.[b]

In relation to the quartzites and green schists of the "Blackstone series" from Natick to Manville, he says:[c]

> The question as to the geological position of these quartzites is very important, but is at present without a solution. On lithological grounds alone they might be considered of Cambrian age, but there is little real basis for such a determination. Perhaps the best reason so far known for considering these quartzites as of Cambrian age is the abundant occurrence of Cambrian quartzite pebbles in the Carboniferous conglomerates of the Narragansett basin.

But while the quartzite pebbles occur in all horizons in the Carboniferous those containing Cambrian fossils appear only in the upper beds, and these quartzites differ from any known outcrop of quartzite surrounding the basin. Moreover, while the fossiliferous quartzite pebbles are quite abundant in the Carboniferous, the quartzite beds around the basin are nonfossiliferous.

The "amphibolite aggregate" of Hitchcock (Mass. Col., VII, 102) from Middletown, near Newport, is made up of dark biotite changing to chlorite shot through with hornblende and very like the rock along the Blackstone, and the zoisite, which is cited as occurring with it (VII, 124), is in a sheet an inch thick, having a columnar structure. The rocks of Little Compton and Conanicut also bear close resemblance to those of the "Blackstone series."

The limestone of the Attleboro locality, of the Newport locality, and of the "Blackstone series" are alike in amount and distribution and in thickness of beds. A comparison of the analyses of the Newport and "Blackstone" limestones on page 17 will show that they are both prevailingly dolomitic.

In the harbor of Newport there are two islands of yellow, compact limestone, which are highly magnesian and manganesian.[d] The larger of these islands is 90 feet wide and 210 feet long; the smaller is half as large. At Fort Adams, in Newport Harbor, there are limestone beds 45 and 15 feet wide.[e] It is true that these limestones are less crystalline than those of the "Blackstone series," as the flinty slates associated with them around Newport are less metamorphosed than

[a] Foerste, A. F., Mon. U. S. Geol. Survey, vol. 33, 1899, p. 234.
[b] Foerste, A. F., idem, pp. 381-383.
[c] Idem, pp. 383-385.
[d] Jackson, idem, p. 34.
[e] Idem, pp. 91, 92.

the schists associated with the Blackstone rocks. In degree of change they are in fact intermediate between the two extremes, and they lie geographically along the band of transition between these two extremes. The crystalline limestone from Attleboro, cited on page 26, shows that the rock there may be in some places as crystalline as that from the Blackstone region.

A comparison of the altered limestones of the "Blackstone series" with the Cambro-Silurian limestone of the Housatonic Valley and the pre-Cambrian limestone of the Berkshire Hills is interesting in this connection.

The abundant tremolite, actinolite, canaanite, garnet, epidote, and iron ores of the "Blackstone" are closely like the derivative minerals of the western valley limestone (Cambrian), while most of the characteristic minerals of the older limestone are wanting, or rare, viz, phlogopite, chondrodite, scapolite, spinel, titanite, dark pyroxene, pyrrhotite.

CARBONIFEROUS ROCKS.

SCOPE OF THE DISCUSSION.

The pre-Carboniferous rocks in the Providence and Narragansett Bay quadrangles will be next considered, the discussion covering the ground not occupied by Messrs. Shaler, Woodworth, and Foerste in their monograph on the geology of the Narragansett basin.[a] It was not their purpose to report upon the isolated patches of Carboniferous conglomerate that rest upon the crystalline rocks in the area that lies west of the line which they had set as the western boundary of the basin, nor did they occupy themselves especially with some of the problems connected with the metamorphic changes of the Carboniferous rocks in immediate contact with the granite along the western border of the basin. Some of these problems are therefore here discussed, but no attempt is made to present a general description of the Carboniferous rocks.

CARBONIFEROUS BOUNDARY.

The high bluffs of crystalline rock extending northward from the southern edge of the area mapped are taken as the approximate boundary of the Carboniferous, although in the low ground at their base the conglomerates are not exposed for 6 miles to the east. From a point west of Wickford Junction, a half mile west of the edge of the Narragansett Bay quadrangle, the boundary of the conglomerate could be closely traced northward by bowlders. The character of the boundary along this line could not be determined.

The easternmost ledges in bluffs east of Davisville show traces of much-altered conglomerate. From this point to Natick the bluffs

[a] Mon. U. S. Geol. Survey, vol. 33, 1899.

everywhere show ledges of the older rocks, and the boundary of the Carboniferous is concealed beneath the Quaternary deposits.

From Natick northward for 2½ miles into Cranston the boundary is well exposed in the bluffs. Beyond this point it is partially exposed on to Knightsville. It is a normal boundary on the different Cambrian formations and on the Milford granite. In the area just north of this the conglomerates are exposed at only a few places, and are not represented in that section on Professor Woodworth's map. We found traces of the basal beds as far north as Geneva, west of Providence. North of this point argillites adjoin the crystallines, except for a short distance southeast of Hunting Hill, and we have followed Professor Woodworth in assuming a fault along this portion of the boundary.

Just at the northwest corner of the area mapped begins another large area of the Carboniferous conglomerate in Woonsocket, the white quartzite pebbles in which are in some places mashed to rods and plates 12 to 14 inches long.

CARBONIFEROUS CONGLOMERATE.

CHARACTER AND DISTRIBUTION.

In the bare bluff above the church in the village of Natick the Carboniferous conglomerate rests in normal contact on massive jointed Cambrian quartzite. It is a very coarse conglomerate; one block is 3 feet in diameter, and many of the blocks are angular. A little farther north a fine greenish quartz groundmass envelops the large cobbles. This purely quartzose facies is confined to the basal portion of the conglomerate and to places where it is in immediate contact with the Cambrian quartzite.

Eastward across Natick, away from the contact, the pebbles become smaller. Many of them appear to be of a finer and whiter quartzite, but prove under the microscope to be a microgranite exactly like that which forms the border of the conglomerate for a long way south in East Greenwich. Pebbles of granite also occur, and these also, when studied in thin section, prove to be of the type of the East Greenwich granite found farther south, and quite unlike the Milford granite, found farther east and north.

A fine-grained interstitial material developed between the pebbles is metamorphosed into a shining white finely crumpled muscovite or sericite schist, in places full of small magnetite octahedra and spangled with biotite. Some specimens contain small garnets and chloritoid.

The friable microgranite pebbles crush easily, and, mingled probably with fine material of the same character, form this sericite schist. Many quartzite and granite pebbles remain intact and the microgranite pebbles wrap round them. Some of the pebbles are penetrated by large secondary magnetite octahedra for an inch in from the surface. These octahedra also fill the paste and were doubtless carried into the pebbles under heavy pressure by the same solutions that brought the biotite, and both seem to have come from the microgranite, the only magnetite-bearing rock that is common in the conglomerate.

Between the church and the schoolhouse in Natick there is a completely crushed zone of sericite schist. Farther on, through and east of the village, are abundant outcrops of the conglomerate with sericite-schist paste as described above. In Natick the transition from the basal, locally derived, quartz conglomerate to the microgranitic conglomerate derived from the East Greenwich rocks to the south is so sudden that we have suggested that the eruptive material was furnished by an explosive rupturing of the dome of the East Greenwich mass rather than by erosion. (See p. 69.)

The interesting relations of the conglomerate to the adjacent rocks in Natick and at a point a mile north of that place are beautifully shown in abundant outcrops.

One who follows the boundary three-fourths of a mile northward from Natick Church to the point where it crosses the east-west road will come to a point where the conglomerate rests on the Milford granite. This boundary can also be followed by abundant outcrops northeastward over a wooded hill to a place where it crosses the road and the Cranston line at the same time. The conglomerate contains abundant large cobbles, embedded in a paste of sericite schist. The majority of these are quartzite which has drifted northward from the Natick ledges. There are also many pebbles of microgranite and a few of granite, which might lead one to assume that they were derived from the adjacent Milford granite, and to infer the granite to be the older. But the quartzite pebbles are angular and larger, the microgranite and the granite pebbles are rounded and smaller, which would harmonize with the idea that they were far traveled and had been derived from the East Greenwich series which formed the shore to the southeast beyond the quartzite. The Milford granite is a coarse biotite gray-quartz microperthite rock. The granite in the pebbles is a blue-quartz plagioclase granite containing garnets and showing a marked micrographic structure, characters that are found in the East Greenwich pre-Carboniferous granite, but not in the Milford granite. The material is thus all far traveled.

Seven rods east of the bare rocky southern apex of the hill along which the boundary runs is a contact of the Milford granite and the conglomerate which might be interpreted as an intrusive contact, since it runs east-west (the prevailing direction of the boundary being north-south) and cuts across the laminæ of the sericite schist. The alteration of the rock here is probably due to crushing. The extreme metamorphism of the conglomerate, combined with the small amount of mashing and jointing, is very characteristic.

One-half mile east of Natick, near the base of the conglomerate, all the pebbles retain their shape and the paste is a coarse sericite schist full of biotite, garnet, and chloritoid.

On the Cranston line black amphibolite and green schist pebbles appear in the conglomerate. Here the adjacent rock is the green schist, but the far-transported material still predominates. If we follow the boundary 3 miles farther north, to the great hill a mile and a half southwest of Knightsville, we come on an area where the granite and the conglomerate are so mashed together that the whole east slope of the hill may be looked upon as the contact surface between the two. At the south end and just west of the road, in front of a new country house, the large ledge is on one side completely granitoid in aspect; on the other large rounded cobbles 6 to 8 inches long can be clearly distinguished.

In the northern part of this area, one-half mile west of Wayland station, the conglomerate becomes a shining muscovite schist with finely corrugated foliation surfaces, while the pebbles are in part present in broad, flat disks, and here and there a perfect cobble of granite 4 or 5 inches across remains quite intact.

The same blending continues farther westward between the Milford granite and the sericite schist, and distinct traces of pebbles rarely appear in the latter. A slide of the Milford granite from one side of a ledge near the summit showed uncrushed microcline with biotite in small distant bands. This granite appears in great force farther west. Another slide from a spot a few feet farther along the same ledge was a sericite schist with distant distinct biotites and garnets and strained blue quartz (all characteristics of the altered conglomerate and wanting in the adjacent granite), but with a single filament of microcline granite showing the intimacy of the blending.

OUTLIERS OF CARBONIFEROUS CONGLOMERATE ON THE BRECCIA OF THE EAST GREENWICH GROUP.[a]

One who follows the road along the south slope of Spencer Hill in Warwick westward will keep on the breccia for a considerable distance. Turning then northward along a road he will come, in about 40 rods, to a small schoolhouse. Just north of this school is a very interesting ledge that is broadly exposed on either side of the road. Areally it seems to be a part of the breccia, which is in place on every side, but it is plainly a thin film of the conglomerate, about 3 rods square, resting on the breccia, and as the abundant interstitial material is a fairly pure muscovite schist we are compelled by all our previous experience to assume that it is a Carboniferous conglomerate. It

[a] See p. 64 for description of the breccia.

contains red garnets, many of which are found in the altered paste of the Carboniferous conglomerate, and a few Cambrian quartzite pebbles (the larger angular and 2 inches across), as well as clastic grains of various feldspars; microcline orthoclase, oligoclase, and a few of blue quartz, of types exactly like those derived from the blue-quartz porphyry and the porphyritic microgranite. It contains also pebbles of the blue-quartz porphyry and of the granite, and one specimen exhibits a small block of the breccia with a half dozen fragments, each an inch long, of the graphic microgranite embedded in a paste of the normal blue-quartz porphyry. Adjacent to this block is a rounded pebble of the Cambrian quartzite, which seems at first sight to be also included in the porphyry, but proves, on careful study, to be adjacent to the latter and not included. Most of these grains and pebbles are almost wholly unchanged, although they have been subjected to influences which in places changed the paste into a clear, coarse mica schist. Here and there a feldspar grain is largely changed to coarse muscovite. The grains are also slightly fissured, and, as will be seen below, have probably been penetrated secondarily by magnetite. Rounded grains of quartzite exactly like those in the Cambrian quartzite are surrounded by attached magnetite grains. This magnetite is thus certainly secondary. Where it is spread regularly through the mica-schist paste it is also almost certainly secondary, and as it penetrates the feldspar grains in whole or in part very generally but not always, and as these feldspars are otherwise exactly like the porphyry feldspars which do not contain much magnetite, it is probably secondary here also.

This conglomerate contains also rather large pebbles of a peculiar rock which is so exceptional in character that it has been described elsewhere (p. 64) under the name microclinite as a distinct variety of the rocks of the East Greenwich group. Part of the microcline phenocrysts in this rock have been penetrated by the magnetite that is regularly distributed through it, and part of them have not. The secondary penetration of the magnetite into the Carboniferous conglomerate at the Cranston locality has already been described, and may be considered a second evidence of the Carboniferous age of the rock here discussed.

This film of arkose conglomerate, which contains all types of rocks of the eruptive series and a few quartzite pebbles, probably passed upward into a true Carboniferous quartz conglomerate. It rests on a brecciated fine-grained, graphic granite that is without porphyry cement. These associated rocks, as will be explained below (see p. 69), possibly had their origin in an explosive eruption of the mass of porphyry and graphic microgranite, which furnished the large amount of unaltered igneous material found here and at localities farther east, across Natick and Cranston.

This determination of the age of the East Greenwich group makes it agree in its time of eruption with the "Wamsutta series" and with the "Quincy series" as fixed by Woodworth. The alternative hypothesis, which is very plausible, would be that the breccia was a rather deep-seated formation—a reibungs breccia—that it was uncovered by erosion, and that the material which it has contributed to the Carboniferous conglomerate was transported a long time after. This would make the intrusion pre-Carboniferous. (See p. 67.)

A similar outcrop of the Carboniferous conglomerate rests on the breccia just west of the spring locality of the breccia.

CARBONIFEROUS SHALES AND SCHISTS.

The prevailing rock among the Carboniferous shales and schists is a dark roofing slate, which has reached but a low degree of metamorphism in the area extending from Providence northward, but in that extending from Providence southward consists of much more metamorphosed beds, mainly highly muscovitic schists, here and there spangled with biotite. The rock is at many places just such a spangled mica schist as occurs in the calciferous mica schist (Goshen schist) in the Devonian rocks of the Berkshire Hills and of Bernardston. It is the same light, shining, crumpled muscovite schist, with small black biotite crystals set at all angles to the bedding. There are many much-strained quartz grains, which seem to be derived from the granite and which contain sheets of fluid pores with moving bubbles and rutile needles. The biotite plates blend with the surrounding rock and are full of dark aureoles.

CHLORITOID (MASONITE) IN THE METAMORPHOSED CARBONIFEROUS CONGLOMERATE AND PHYLLITE.

Chloritoid is very abundant in bowlders, but we found it in place only in the brook cutting on the south line of East Greenwich, where it occurs in a shining mica schist, and at a point 40 rods east of the eastern railroad station in Natick, in a fine-grained Carboniferous conglomerate containing uncrushed pebbles in a paste of sericite schist with garnet and biotite. The plates of chloritoid are only one-eighth inch across.

A specimen of a dark-gray silvery schist from Cranston, very similar to the above, is also full of small, thin, black scales resembling biotite, but the rock is more mashed and the scales are of brittle chloritoid, so opaque that only with difficulty could light be seen through the thinnest plates.

A peculiar variety of this masonite occurs as a bowlder in Warwick, 1 mile south of Cowesett and 5 miles south of Natick. This is a coarse-grained massive rock, made up almost entirely of thick, squarish plates of masonite one-fourth inch across, set close together. It contains scattered red garnets of about the same size, and passes into a coarse garnet rock. Under the microscope c = yellowish, b = indigo blue, a = greenish yellow. This bowlder and the very similar ones found in Natick, which contain larger crystals of masonite, certainly come from the Carboniferous contact area north or northwest of Natick. Some of the great plates of masonite are 1 inch thick and 2 inches across.

The mother rock is the same finely corrugated silvery and finely arenaceous muscovite schist that forms the matrix of the Carboniferous conglomerate, and is doubtless of Carboniferous age. The typical masonite is associated with large garnets, and many of the small black plates that are scattered in the matrix are biotite like that of the spangled biotite phyllite described above.

Doctor Jackson makes the following report concerning the masonite at this locality:[a]

Nearly opposite the brick cotton factory in Natick, upon the roadside, there are three large blocks of a peculiar rock composed of a new mineral associated with mica and garnets. These blocks of stone are erratic and now rest on a totally different rock formation.

I have been informed by Professor Hitchcock that the same kind of rock is met in the town of Ward, in Worcester County, Mass. It is certain that no rock of the kind exists in place in Rhode Island, and it may appear surprising that these blocks should have been removed so far from their native locality. I measured one of them and found it to be 15 feet long, 10 feet wide, and 4 feet thick. * * *

My attention was first called to these rocks by Mr. Owen Mason, in Providence, and I examined them for the purpose of ascertaining the nature of a singular mineral of which they are chiefly composed. This mineral I have analyzed and find it to constitute an entirely new species, to which I propose giving the name masonite, in honor of one to whom the geology and mineralogy of the State is so much indebted. Masonite consists of the following ingredients:

			Ratio.	
Water	4.000	containing oxygen	3.555	
Silicic acid	33.200	containing oxygen	17.247	=3
Alumina	29.000	containing oxygen	13.543	=2
Magnesia	0.240	containing oxygen	0.092	
Protoxide of iron	25.934	containing oxygen	5.904	=1
Oxide of manganese	6.000	containing oxygen	1.814	
	98.374			

Its mineralogical formula is $\begin{matrix} Al_2 \\ Fe \\ Mn \end{matrix} : Si_3 + A_9.$

It is a silicate of alumina and protoxide of iron plus silicate of manganese, plus water. Its specific gravity is 3.450. It occurs in tabular crystals which cleave very easily with brilliant planes perpendicular to their axes and with great difficulty in other directions. Its primary appears to be a right rhombic prism. It scratches glass and yields to the knife with difficulty. It is with difficulty fusible to a dark-green enamel.

[a] Idem, p. 87.

This analysis was made at a time when "silicic acid" (that is, silica) was supposed to be a trioxid (SiO_3) instead of a dioxid (SiO_2). The mineralogic formula deduced from the analysis given above is therefore subject to correction.

IGNEOUS ROCKS.

IGNEOUS ROCKS OF CAMBRIAN AGE.

DIORITE.

The diorite of the pebbles in the conglomerate green schist on the hill a hundred rods north of the middle Lime Rock quarry varies in texture from medium to fine grain and shows in one type, on a continuous dull-white ground, black hornblende grains and lobate forms in somewhat regular arrangement. The hornblende increases in amount until the rôles of the two minerals are reversed and the white lobate forms stand out on a black ground. The pebbles vary greatly in coarseness. The adjacent diorite ledge, which borders the great dikelike bed of tremolitic serpentine, comprises all these types of diorite, and in addition other varieties. A diminution of the amount of feldspar produces a black, normal, fine-grained, wholly massive diorite, in which the lens still detects traces of the white constituent, and finally, where it is in contact with the serpentine, a very harsh-fracturing, black, almost aphanitic rock. In another portion of the mass is a coarse black hornblendite, massive and fresh-looking, with the stout phenocrysts often automorphic and a half inch long. Several slides (416, 417, 420, and 422) showed with a lens a gabbroid texture and little or no trace of crushing.

The microscope showed that a common feature of this rock was the abundant occurrence of grains of black ore surrounded by large borders of leucoxene, or even broad, cleaved crystals of titanite, exhibiting no trace of crushing. The white fields have the shape of stout feldspar blades and show in places traces of triclinic striation, but are thoroughly saussuritized and filled with actinolite needles. The dark fields are partly large squarish hornblendes, partly groups of smaller hornblendes. The hornblende shows moderate pleochroism in yellow, green, and bluish green, which may be secondary, but gives no trace of any earlier mineral. One doubtful remnant of pyroxene was noted.

Pebbles of the diorite show a texture that is very similar to that of fragments taken fresh from the ledge, so that the ledge has evidently suffered no considerable metamorphic change since the fragments were broken off in Cambrian time; in other words, it was then, as now, a hornblende-plagioclase rock—a diorite.

Another 20-foot dike which seems to be of the same type occurs in the quartzite one-fourth mile northwest of Albion, on the railroad.

Still farther south, one-half mile west of Woodville, by the roadside, is a similar fine-grained massive rock, in which the eye just detects abundant squarish hornblende grains and rare plagioclase prisms. In the slide the hornblende grains are like those in other slides of this diorite, but here and there distinct augite centers appear, and some of the saussuritized feldspars show distinct banding with extinctions of 13° to 16° on either side the twinning plane.

Another rock of the same type is found in what appears to be a dike at the northern foot of Copper Mine Hill, on the northern border of the green schist area at the contact of the schist and the granite. It is a fine-grained, traplike rock containing much magnetite in feathery crystal groups, but showing no trace of leucoxene. The large square anhedra of green hornblende show low pleochroism. The rock, as a whole, is distinctly gabbrolike in structure, and these hornblendes occupy about the position of the original bisilicate, while the intervening stout feldspar blades retain their boundaries intact, although internally they are largely saussuritized, but show rarely broad twinning bands which extinguish at 10° on either side.

IGNEOUS ROCKS OF POST-CAMBRIAN (PRE-CARBONIFEROUS) AGE.

MILFORD GRANITE.

General description.—A great granite area (batholith) 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." It differs from the Quincy granite, found farther east, in lacking hornblende and also in the fact that it is unaccompanied by the many varieties of rock that accompany that granite (porphyries, felsites, and breccias), and it differs from the rocks of many other groups that cross Massachusetts farther west by the lack of coarse porphyritic varieties.

Its two especially characteristic constituents constantly present are blue quartz and a microcline microperthite in which the 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 secondary 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 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. In granite from a point south of Woonsocket the central portions of the spots and bands of albite in the microcline are crowded with muscovite crystals more strikingly than in the rock at Fayville. The albite is in coarser bands in and around the microcline and is filled with much larger scales of muscovite.

The granite from the country north of Spencer Hill, in Warwick, is a rather coarse subporphyritic rock, without blue quartz. The large, perfect, microcline microperthite crystals are characteristic, and in one specimen of this rock a soda orthoclase was observed. It contains rarely garnet, and the distinct feldspars and large quartz grains give it a porphyritic aspect.

It will long be difficult to separate the pre-Cambrian porphyritic granite-gneiss (the Northbridge gneiss) from the post-Cambrian and pre-Carboniferous coarse porphyritic granites, like those on the south end of Conanicut, and the coarse, subporphyritic granite of the Milford type.

The dark contact granite.—In a zone that is at some places one-half mile wide, surrounding the green schists, the rock is generally present in contact facies of considerable variety. The first sign of approach to the green schist is in the increase of biotite, causing a darker color. Thus the rock becomes more or less foliated and jointed, and near the schist it is distinctly and at times decidedly hornblendic. In the hills west of Providence the included fragments of the schists become so abundant that they occupy more of the surface than the granite, and farther west is a band in which the green schist is cut in every direction by great numbers of small granite veins. For this reason a broad area between granite and green schist could be mapped only as a contact zone between the two.

The dark granite near the contact north of Woodville is full of beautiful titanite crystals 1 to 2 millimeters long, of the regular "envelope" shape, and of dark aureoles around zircon.

Where the Milford granite is in contact with limestone, as west of Lonsville, the dark border is wanting. Here, however, the rock is very fine grained near the limestone. From a point 1 mile west of Copper Mine Hill its contact with the riebeckite porphyry can be well observed for a long distance. Both rocks are normal up to the boundary and neither sends out branches into the other. This more basic granite is apparently in part due to an endomorphic contact change within the limits of the eruptive mass of the Milford granite. This change appears to have been an enrichment with iron which may be explained as in part a differentiation of the granitic magma and a transference of the iron to the border, and as in part an absorption of so much of the ferruginous green schist that the rock has become more basic and darker. This interpretation is supported by the fact that granite of this type is not found at the contact of the Milford rock with limestone, quartzite, and porphyry. Along the boundary line of the granite and schist many good-sized fragments of much-altered green schist are inclosed in the granite.

DIKE ROCKS.

Aplite.—A very interesting dike of aplite, only one-half inch across, cuts the 2½-foot odinite dike in the eastern Lime Rock quarry, west of Lime Rock, and is continued beyond through the limestone. It is a bluish-white, fine-grained rock, only slightly different from the marble in appearance, as it contains many calcite grains. It is made up wholly of rounded grains of feldspar, part of which is plagioclase, sometimes twinned in broad bands, and having low extinction angles. It contains much microcline, and perhaps orthoclase. Mica and ore are absent, and radiated wisps of tremolite needles are scattered through the rock. Quartz is present only in the abundant micrographic portion. Scattered through the rock, in irregular grains, many of them of large size, is a very large quantity of calcite which has been taken up from the limestone, dissolved and recrystallized in the magma, since it is intercrystallized with the plagioclase and included in it, and is of different size and shape from the grains of calcite of the marble.

At the border of the aplite and the amphibolite, wisps of hornblende of much larger size than that of the average of the amphibolite project into the aplite.

There is also a 4-inch aplite dike in the limestone at the eastern Lime Rock quarry, but under the microscope it shows a texture that is very different from that of the rock already described. The half-inch dike is a very fine and even-grained microgranite with many small grains of microcline, curiously abundant micrographic intergrowth, no mica and no alteration. The 4-inch dike is coarser grained, with micrographic texture, except for large grains of plagioclase (albite to oligoclase), with centers made opaque by the great mass of white mica scales developed in them, and a few large grains of microcline.

Pyritous aplite.—Another interesting dike of the same type as the last runs across the path that goes up from the south end of the same Lime Rock quarry. It is 8 inches wide, and is composed of a clear, rather dark-gray, aphanitic rock of harsh feel, broken up into half-inch plates crusted on all sides by cubes of pyrite, which also appears elsewhere in the rock, though in less quantity. It effervesces very actively with acid. When this rock is examined with a power of 85 the field is seen to be covered with many opaque white spots, which may be leucoxene or kaolin. With polarized light much of the surface is seen to be covered with irregular-lobed areas of calcite, which may have been derived from the limestone, but if so have crystallized in places in peculiar lobate shapes. Except for this calcite, the field is strewn about equally with minute low-polarizing plates, which seem to rest in an almost apolar ground, and which take up about half the surface. With a power of 230 the apolar places are seen to be occupied by overlapping plates of the same colorless low-polarizing material. This seems all to be a fine-grained mosaic of orthoclase, and in the larger plates are seen here and there more brightly polarizing plates of muscovite, and the opaque white areas which cluster round the larger orthoclase grains seem with the higher power to be distinctly kaolin derived from its decomposition. The rock is thus an aplite, and its bluish-gray color is caused by its very exceptional content of pyrite. All these small dikes are interesting as possible members of the distant East Greenwich group described below, and as similar micrographic and microgranitic types occur in the Quincy group they suggest a connection between the two. Its abundant content of coarse microcline, however, seems to ally this rock more closely with the Milford granite.

BASIC ERUPTIVES.

Gabbro.—A great range of gabbro and syenite hills and isolated bosses, which have not been described in detail, extends southwestward along the south side of the Norfolk County basin from Canton Junction[a] to Wrentham. The remarkable mass of cumberlandite in Cumberland Hill lies in the extension of this range. This hill stands just on the northern border of the area here mapped and probably enters it beneath the drift. It has been fully described by Woodworth.[b] It is largely coarse massive menaccanite with a few porphyritic plagioclase phenocrysts. Where bronzite and plagioclase appear abundantly in the menaccanite mass it becomes a gabbro.

[a] Woodworth, J. B., Geology of the Narragansett basin: Mon. U. S. Geol. Survey, vol. 33, 1899, p. 118.
[b] Bull. Mus. Comp. Zool., vol. 1, p. 183; Proc. Boston Soc. Nat. Hist., vol. 21, p. 195.

In the prolongation of the range to the southwest an ideal gabbro of the same type, of coarse grain and wholly massive, occurs in a large bowlder on the hill a half mile northeast of Albion. This was probably brought by the ice from some point 5° or 10° west of north but near at hand, since in the sheet farther south, which we have studied in detail, this type is not found. It is a dull, dark rock, with spots of a faint shade of brown or green, large squarish areas of a brownish pyroxenic mineral, and large, shining, striated plagioclase cleavages and grains of menaccanite.

The slide shows a ground of coarse-grained labradorite, with maximum extinction in the albite twinning of 23°, and with the twinning bands rigidly parallel. The second original mineral is bronzite, which is abundantly dusted with black grains. It was formerly present in large squarish fields, which are now wholly or mostly changed into a coarse radiate fibrous mass of a bluish-green hornblende, in which a=ochre yellow, b=pure green, c=deep blue; $c<b>a$. Outside this there is around many of the fields a rim of an oil-green, scarcely polarizing mineral full of black dust and calcite grains, which has the aspect of a serpentine. Outside this, against the plagioclase, is a second rim, perhaps a reaction rim, of white, brightly shining plates like muscovite or paragonite, which have eaten into the plagioclase. A few large garnet grains occur.

The large menaccanite plates are cracked and are surrounded by a rim of biotite in large plates full of rounded scales of menaccanite like those common in the bronzite. They are gathered centrally and arranged in curved, beaded bands. There is no leucoxene or rust; no strain or crushing of constituents, and thus no dynamic metamorphism. The change went on without motion of part on part, and without oxygen; but water, silica, and alkali were needed to change the labradorite into the shining white paragonite, the bronzite into the blue hornblende, and this into the chloritic or serpentinous mineral, and to develop biotite from the menaccanite.

Odinite.—It is noteworthy that beside the olivine-diabase dike described below from the Lime Rock marble quarry, which is remarkable for its freshness and for the sharp-cut completeness of all its crystals, there should run another dike, of about the same thickness (2½ feet) and with the same strike (N. 50° W.) and dip (60° NE.), of a dark, aphanitic trap which should prove under the microscope to be so unlike the other. It can be recognized in the quarry by the fact that it is cut by a half-inch aplite dike, and by its lighter gray color and more aphanitic and even texture, the minute porphyritic needles of plagioclase and glassy grains of olivine of the diabase being absent. Under the microscope it is found to be made up wholly, or almost wholly, of a confused network of hornblende needles, all very minute, so that it requires high power of the microscope to study it. The whole field has much more the aspect of a common, fine-grained hornblende schist of metamorphic origin than of an unchanged intrusive dike. The hornblende needles are ragged-edged and fibrous, so that a surface rarely shows a common polarizing color, and a basal section is made up of a bundle of diamond-shaped rods. This hornblende has very faint pleochroism; a=pale yellow, b=yellowish-green, c=pale bluish, b showing the strongest absorption.

This rock contains some large crystals of hornblende of the same type as the others. With the finer hornblende is intermixed over irregular and isolated patches a biotite that occurs here and there in parallel or radiate forms. This biotite is salmon-colored parallel to axis c, and nearly colorless in other directions. It is at some places changed into a pale-green chlorite. The rock contains a few menaccanite grains, most of which are surrounded by leucoxene, and many of the larger green hornblendes are centrally dusted with menaccanite grains and plates. Small areas of feldspar appear in the interstices between the hornblende needles. These are indeterminate because they are without cleavage or twinning, but have almost the same refractive index as the Canada balsam of the slide, or a little higher, and so are probably near oligoclase. This is probably the same dike that is described as amphibolite and figured from the southernmost limestone locality at Lincoln by Prof. J. B. Woodworth,[a] because its parts have been disconnected by faulting in the limestone, while all trace of these faults has disappeared from the adjacent limestone. He notes hornblende, chlorite, muscovite, titanite, magnetite, apatite, and quartz as constituents of this rock, and considers it, probably, an altered diabase. It bears considerable resemblance to the diorite in the serpentine hill directly north of the quarry, and may possibly be an apophysis of this rock. It is massive and unstrained, and has not suffered any dynamic change except the slight displacement which it and the limestone experienced together. Its walls against the limestone are intact. It does not effervesce with acid, and it seems to me possible that the only change since consolidation may be the chloritization of a part of the biotite and the growth of the leucoxene around the menaccanite. The central crowding of the hornblendes with black ore grains may be an original structure.

If the rock has suffered only the amount of change indicated above, it may be called an odinite and be associated with the gabbros of the region. It was intruded in the limestone after these had been metamorphosed, and is cut by the aplite which is here associated with the Milford granite.

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[a] Geology of the Narragansett basin: Mon. U. S. Geol. Survey, vol. 33, 1899, p. 108.

IGNEOUS ROCKS OF PRE-CARBONIFEROUS OR EARLY CARBONIFEROUS AGE.

SUBDIVISIONS.

The newer acid eruptive rocks, which occupy a large portion of the area mapped, may be conveniently divided into two large groups:

(1) The hornblende granites and granite porphyries in Cumberland on the northeast, which may be considered a southern prolongation of the granite and porphyry series that extends southward from Ipswich across the Boston basin and includes, in the middle of its extent, the large quarries at Quincy, from which these rocks may be called the Quincy group.

(2) The East Greenwich group of biotite-granite porphyries and graphic microgranites and the brecciated phases of the latter. It is a question whether this should be regarded as a southward prolongation of the Quincy or as an independent group. The rocks of the two groups show only partial resemblances.

QUINCY GRANITIC GROUP.

DISTRIBUTION AND GENERAL CHARACTER.

The rocks of the Quincy granitic group occupy the whole area between the green schist and the Carboniferous rocks along the northeastern border of the green schist from Diamond Hill southward to Berkeley, forming a southern lobe of the broad Quincy band in the Boston basin.

The commonest rock in the central parts, notably in all the large central lobes 2 miles south of Diamond Hill, is a coarse, light porphyritic granite with a few squarish feldspar phenocrysts two-thirds of an inch long—almost a granite porphyry, with here and there limpid quartz phenocrysts inclosing lobes of a microgranitic base.

A second type is a granite porphyry in which all the constituents are of dark-gray color, and the porphyritic character, although perfectly developed, comes out most distinctly only on weathered surfaces or under the microscope. At one extreme it is a rather fine-grained rock with abundant small square feldspars and dark-blue rounded but distinct primary quartz phenocrysts; at the other extreme it is a very peculiar rock, made up almost entirely of square feldspars (2 to 4 mm. across), the quartz appearing only in the microgranitic groundmass. An identical rock appears in the great Cumberland dike 1 mile west, and a similar dike occurs 1 mile west of Lonsdale, 2 miles south of the southernmost area of the granite porphyry, this occurrence serving to lessen the gap that separates this rock from those of the East Greenwich group.

A third and most interesting type is a riebeckite porphyry and granite in which the large rounded phenocrysts of quartz and smaller squares of feldspar are inclosed in a micrographic base that is at some places of a purplish tint, from the content of fluorspar grains and blue riebeckite needles. This forms a compact area along the north edge of the area mapped in Pl. I, and extends for an unknown distance northward.

A fourth type, forming the border rock near the green schist, is a bluish-white micrgranite. This appears only along the south side of the southern separate area between Hunting Hill and Berkeley. In the western portion of this southern area is a fifth type—a dark, hornblendic granite—and a dark chloritic facies of the same rock appears in a small patch at the border of the granite west of Diamond Hill.

The boundaries of the subdivisions as shown on the map (Pl. I) are only approximately exact, as these subdivisions were fixed after the field work was completed, partly by study of the material collected, and so no sharp, definitely marked boundary lines are drawn. Full notes and sufficient material were taken in the course of the field work, but much of the area is covered by till, and the determination of the nature of the underlying rock at some places is therefore difficult and doubtful.

PETROGRAPHIC DESCRIPTIONS.

Granite porphyry.—The granite porphyry occurring along the east branch of Sneech Brook in Cumberland (slide 359) and that of the Cumberland dike is a dull-black rock, with dark square feldspars and quartz crystals, generally smoky, but in a section (slide 371) from the north end of the dike the quartz was bipyramidal and of blue color. It was limpid, without microlitic inclusions, and with deep lobes of the light-gray micrgranitic ground. The feldspar was untwinned soda orthoclase, and showed extinction of 12° on M (010) and the vertical emergence of a positive bisectrix. Some of the feldspars inclose great numbers of large, stout, sharply rectangular rods of an acid plagioclase. These rods are singly twinned with small angle, have the suture parallel to the side of the square, and show a higher index of refraction and birefringence than their host. The feldspar also in places incloses many lobes of the groundmass. The micrgranitic ground contains quartz, feldspar, magnetite, biotite, muscovite, and calcite.

The rock shows distinctly a fluidal structure, and some specimens carry fluorite. It incloses fragments of a calcareous sandstone so full of fluorite as to impart to it a deep purple tinge. Where it lies in contact with the green schist this is only slightly indulated, but is soaked full of purple fluorite for one-half inch from the boundary. At the north end of the Cumberland dike the rock contains an inclusion of the coarse white granite of this series, which was also full of purple fluorite. A slide (384) cut from the rock adjacent to an inclusion of calcareous sandstone shows fluidal structure, adjacent phenocrysts being connected by bands of a much coarser groundmass, and so united into somewhat parallel trains. In this coarser groundmass many of the grains are fresh untwinned and unstained calcite that include and are included by the other constituents so that they appear to be an original constituent. Calcite is much rarer in the intervening fine-grained ground, but at some places trains of groups of calcite grains run through this also, each group being surrounded by a dense halo of black ore grains. These calcite grains are wholly unlike the calcite of the inclusions. In one slide an exceptionally large calcite grain is partly inclosed by a large phenocryst of soda orthoclase. The calcite must therefore have crystallized out early in the magma before the feldspar phenocrysts had been completely formed or the black ore had solidified. The latter is almost wanting in the phenocrysts, and was formed by a reaction of the carbonate and the iron-bearing solutions in the magma. Most of the grades that have the same shade as the large grains are also calcite.

There is another dike of the granite porphyry in the green schist by the schoolhouse 1½ miles west of Lonsdale, near the Moshassuck River, in Lincoln. It is 20 feet wide, with sharp boundaries. Under the microscope the rock (slide 402) shows the extreme of alteration without the slightest disturbance of its original structure. The feldspars are wholly idiomorphic and are set so closely together that there is but little interstitial material. These feldspars are in places changed to a congeries of epidote crystals without losing the original sharpness of boundary.

The groundmass shows micrographic structure where it borders the feldspars, from which the quartz rods radiate, and this structure passes into a microgranitic arrangement at the center of the interspaces. The abundant biotite is largely chloritized. This rock differs from that of the Cumberland dike in its greater quantity of feldspar and in the absence of large quartz phenocrysts of first consolidation.

Riebeckite porphyry.—The riebeckite porphyry is a fine-grained granite porphyry made up largely of small, square feldspars, larger rounded or bipyramidal quartz grains, and black amphibole (riebeckite) blades, these three constituents being embedded in a micrographic ground which looks like a fine, white quartzite.

The feldspars are Manebach twins of orthoclase microperthite, with broad anastomosing bands of albite in places in peglike arrangement; extinction, 16½° on (010). In places these bands coalesce at the surface to form broad continuous layers of albite. Some of them are dusted full of long needles of riebeckite. Others have the moiré surface and the optical character of soda orthoclase. The large quartz grains, some of which are bluish, are nearly all idiomorphic and have all the characteristics of porphyry quartz. They are limpid and show slight strain and sharp straight lines of cleavage and cavities with moving bubbles. They are penetrated by deep lobes of the fine, granular quartz-feldspar ground, which as a microgranitic groundmass also incloses the other constituents.

Riebeckite is present not only in the many microlites that penetrate the feldspar and are absent from the quartz, but in blades that inclose large angular grains of orthoclase. The mineral has the very strongest absorption: a = deep blue, b = dark greenish blue, c = yellow-brown; $a>b>c$. It has perfect prismatic and basal cleavage.

Purple fluorite is an interesting original constituent of the porphyry. It is found in rather large grains, especially in the vicinity of the riebeckite, and its presence may have determined the formation of the riebeckite rather than another form of hornblende or augite.[a] The best locality to study the rock is on the hill a mile southeast of Copper Mine Hill, in Cumberland.

Along its southern border, on the north slope of Copper Mine Hill, the rock retains its texture, except that all the iron has gone into magnetite. On page 66 is given an analysis of the riebeckite porphyry, and for comparison one of the riebeckite granite of the Hardwick quarry at Quincy, Mass.

White's description and figure of the rock of the Weymouth Fore River in the Quincy basin,[b] north of the area here studied, agree closely with that of the rock here discussed.

The "crocidolite" announced in 1879[c] and described in 1887[d] by A. H. Chester and F. I. Cairns from "Beacon Pole Hill,"[e] would seem to be the same mineral that we have here determined optically to be riebeckite. It occurs in seams in a granite ledge.

It is usually disseminated in fine particles through feldspar but often occurs in large masses up to the size of a butternut. Unbroken surfaces sometimes present a botryoidal appearance, and the nodules, when broken, show a radiated structure. * * * Its color is usually a dark bluish gray, the radiated nodules, however, being darker, almost an indigo blue. It is associated with dolomite, glassy quartz, and rarely with light purple fluorite.[f]

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[a] This suggestion has been independently developed as the result of an extended study of the riebeckite rocks by Mr. Murgucci in a paper read before the Geological Society in Philadelphia in December, 1904. (See Am. Jour. Sci., 4th ser., vol. 20, 1905, p. 133.)

[b] White, T. G., Contribution to petrography of the Boston basin: Proc. Boston Soc. Nat. Hist., vol. 28, 1899, p. 132, Pl. IV, fig. 12.

[c] Dana, Man. Min. and Lith., 3d ed., p. 252.

[d] Am. Jour. Sci., 3d ser., vol. 34, p. 108.

[e] This is the hill on the north edge of the area mapped northeast of Copper Mine Hill, which is apparently the Tower Hill of Shepard, cited above, and the Cumberland Hill of Chester and Cairns.

[f] Chester, A. H., and Cairns, F. I., Crocidolite from Cumberland, R. I.: Am. Jour. Sci., 3d ser., vol. 34, 1887, p. 108.

Analyses of "crocidolite."

	I.	II.		I.	II.
SiO_2	53.13	51.03	Na_2O	6.26	6.41
Fe_2O_3	15.93	17.88	H_2O	3.95	3.64
FeO	21.25	21.19			
MgO	0.22	0.09	Total	100.74	100.24

Hornblende granite.—A hornblende granite occurs abundantly in the southern area between Berkeley and Hunting Hill. It is dark, coarse, massive, and fresh looking, varying from a rock resembling a gabbro, in which the large feldspar and biotite phenocrysts and grains stand out on a greenish-black ground, to a more granitic facies, in which, on the dark mottled surface, the large black hornblende phenocrysts are relieved by a white border and many of them luster-mottled by large apatite crystals.

Slides of rock of both these types (366, 361) have under a lens an identical and very characteristic appearance. The magnetite, biotite, and hornblende, all of which occur in small amount, are massed in groups and more or less altered. The whole field seems to be made up of closely packed feldspar crystals of uniform size and shape, having perfect crystal faces except against the hornblende-biotite groups, and the small amount of limpid quartz is arranged in narrow areas between these crystals. They are uniformly Carlsbad twins of soda orthoclase, which, except around a narrow border band, are dusted full of perfect crystals and crystal groups of almost colorless hornblende, epidote, and garnets, the latter in model-like dodecahedra. The quartz is free from inclusions, granulation, or strain, and some crystals are of bipyramidal shape. The rock has thus the texture of a porphyry without a groundmass. The quartz in the center of the intersertal fields shows, where it adjoins the feldspar, a micrographic and microgranitic texture.

A similar rock on the west side of Diamond Hill has a more mashed and chloritized aspect and is probably adjacent to a fault. The slide (357) shows the feldspars to be a dense mass of overlapping blades of hornblende and epidote. The quartz is slightly strained and granulated and the biotite is chloritized. The rock contains the same abundance of large apatites and the same peculiar model-like garnets that were noted by Woodworth in the corresponding hornblende granite from the Cambrian area on Hoppin Hill, in Attleboro.

Microgranite.—The microgranite is a light pearl-gray rock of very fine grain, with a slight banding, due probably to flow structure. It is a mixture of granular quartz and microcline, which in some specimens of the rock interlock so completely as to produce almost a micrographic structure. The gray color is due to small grains of magnetite and biotite. (Slide 353.) It resembles very closely the microgranite of East Greenwich. (See p. 62.) It can be studied along the road southwest of Hunting Hill.

Vein quartz at Diamond Hill.—The enormous mass of vein quartz at Diamond Hill, only the southern half of which is shown on the map, lies on the border between the Carboniferous sediments and the granite porphyries. In the continuation of this mass to the north, beyond the limits of the area mapped in Pl. I, Professor Woodworth has mapped a large area of felsite, which he assigns to the same age as that of the felsites around Attleboro. According to his determination[a] the quartz was deposited by hot springs connected with the volcanic activity of which the felsites are the product, and its formation was therefore contemporaneous with that of the earlier Carboniferous beds in this area. This seems to be the only possible explanation of the great veinstone body. The mass is made up of many layers of quartz, much of which occurs in radiating crystals, suggesting diamond, and from these the hill gets its name. The mass comprises also much white compact and chalcedonic quartz.

Phosphate of lime and red hematite occur in beautiful botryoidal and stalactitic groups in the quartz on the southern slope of Diamond Hill.[b]

Mr. George F. Kunz writes as follows concerning the varieties of quartz found at this locality:

> The highly modified crystals from Diamond Hill and Cumberland Hill, Rhode Island, also the fine ones from White Plains and Stony Point, Alexander County, and from Catawba and Burke counties, N. C., are worthy of mention, and lately formed the subject of a crystallographic memoir by Prof. Gerhard vom Rath.[c]
>
> Jasper agate is found in considerable quantity at Diamond Hill, Cumberland, R. I., in all shades of white, yellow, red, and green; these colors are also all intermixed in one specimen, usually mottled, and at times beautifully banded in irregular seams of white, creamy brown, greenish, and brecciated. It is found in large quantities, and although fully 1,000 pounds is taken away every year by visitors and collectors not over $100 worth is sold or polished per annum.[d]

"WAMSUTTA GROUP" OF WOODWORTH.

The group of granite porphyries, felsites, and fine graphic granites described by Professor Woodworth,[e] the border of which makes a great curve in the "Wamsutta group" of Carboniferous beds from North Attleboro by Lanesville to Arnolds Mill is most interesting. The curve may perhaps be continued to include the larger granite-porphyry area at Diamond Hill. It conforms with the Carboniferous beds in their folding around the central Cambrian island. The rocks of this group are accompanied by a series of basic dikes. The larger felsitic mass has some of the characteristics of a tilted laccolith.

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[a] Mon. U. S. Geol. Survey, vol. 33, 1899, p. 155.
[b] Jackson, loc. cit., p. 52.
[c] Mineral Resources U. S. for 1883 and 1884, p. 749.
[d] Op. cit., p. 762.
[e] Mon. U. S. Geol. Survey, vol. 33, 1899, p. 153, and map (Pl. XVII).

There is frequent flow structure, with crumpled layers, and beneath the massive flow of felsite is a bed wherein the same felsite is the matrix of an agglomerate of rounded pebbles of felsite, granite porphyry, quartzite, and hornblende granite. Professor Woodworth states that "the peculiar features of the Wamsutta series * * * point to a volcano or volcanoes existing in this field in Carboniferous time," and compares the rocks with the flows and intrusives of the quartz-porphyry series in the Boston basin. He speaks of "Wamsutta volcanoes," and connects the intrusive granite porphyries described above with the effusive felsites and granite porphyries of the "Wamsutta series," and finds the same story repeated in the Blue Hills region on the north side of the Norfolk County basin, and still farther north in the larger felsite area about Boston.[a] He mentions and maps an area of granite porphyry, about 2 miles long, north of the quartz veinstone mass of Diamond Hill.[b] This is possibly the northern apex of the area shown on Pl. I. Another somewhat smaller area lies farther east, within the limits of the Carboniferous, one-half mile northwest of Arnolds Mill. The rock from this area contains rare microscopic garnet and fluid inclusions with moving bubbles. Professor Woodworth associates these two stocks of granite porphyry with the adjacent felsites, which are clearly interbedded with the Carboniferous, and therefore deduces the probable Carboniferous age of the whole series of the granite porphyries extending from this region to the vicinity of Boston, including the rocks in Cumberland. This is doubtless the most probable relation, but no certain evidence was found along the border between the granite porphyry and the Carboniferous to indicate that the granite porphyry was intruded into the Carboniferous, nor does Professor Woodworth adduce such evidence.

The felsite of Diamond Hill is unlike anything in the Quincy and East Greenwich groups. A sample taken from the northeast slope of the hill is a light pearl-gray rock, breaking in plates, and wholly aphanitic and hornstonelike. It fuses easily to a white enamel. The microscope shows a few small, angular kaolin spots, which are traces of former feldspar crystals, and minute quartz veins, in a uniform microfelsitic base of exceedingly minute plates and short needles, which polarize brightly and lie apparently in a colorless glass. There is no iron oxide. This rock is precisely like the felsite in slides taken from rock at Natick, Mass., in the middle of the Boston basin.

The granite mass in Cumberland forms the southern end of an extensive belt of igneous rocks, the main body of which lies north of the area mapped in Pl. I. The felsites (aporhyolites) of the Boston basin approach this area at the northeast base of Diamond Hill and swing round the Cambrian area in the "Wamsutta" region to the east.

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[a] Idem, pp. 155-156.

[b] Mon. U. S. Geol. Survey, vol. 33, 1899, pp. 117, 155.

Distinct surface flows are therefore not found in this southern extension of the Quincy rocks. The content of riebeckite and soda orthoclase connects the series with the Quincy granite. Eleolite found in the Essex basin is lacking here, but a nepheline tephrite occurs at a point not much farther west, at Fairmount Farms, in Woonsocket. (Slide 25920 of the Tenth Census rocks.)

Microgranite also is common in both groups. The hornblende granite described above, which might almost be called a granite porphyry, is much like the granite porphyry of the "Wamsutta" region. Both contain beautiful microscopic garnet. There is also a close resemblance between the porphyry and the microgranite of the Cumberland area and the corresponding rocks of the East Greenwich group described below, though hornblende is lacking in the latter and the limited dark border beds are biotitic.

EAST GREENWICH GROUP.

DISTRIBUTION AND GENERAL FEATURES.

The East Greenwich group of eruptives became interesting in the course of this survey because of the discovery that it carries the porphyries and fine graphic granites of the Boston basin much farther south than they have been known before.

A dozen broad bands of acid eruptive rocks cross the State of Massachusetts from north to south, either as continuous areas or in rows of great batholiths. Each band has many distinguishing characteristics. Porphyries and basic rocks are rare or for the most part wholly lacking in all of these bands that lie west of the broad easternmost band which extends southward from Ipswich across the Boston basin. In this belt porphyries and a great range of basic rocks accompany the granites. Professor Woodworth has connected the porphyries of the adjacent "Wamsutta group" with the porphyries and felsites of the Boston basin, and the porphyries of the two groups described in the present report show many points of resemblance to each other, to those of the "Wamsutta group," and to those of other members of the same band farther north, and, although isolated in surface occurrence from the rocks of the Boston basin, they seem to represent a southward prolongation of those rocks.

Much of the country occupied by the East Greenwich group, especially its central and most interesting portion, is covered by till, and the contact relations can be observed at only a few places. This group includes granite porphyry, some of it carrying rather small phenocrysts, microgranite, a massive and banded fine-grained micrographic rock, and a breccia formed of a great mass of angular fragments of all sizes of the latter rock, either alone or inclosed in the granite porphyry. A black biotite granite occurs in small amount on the border. A distinguishing common characteristic is the micro-granitic and micrographic groundmass. The former is even-granular, like a fine sandstone. Its grains become in places more and more lobate and interlocking until a continuous micrographic texture is produced. The microgranite appears in purity over large areas; the micrographic rock appears mostly as fragments in the breccia. Where quartz and microcline crystals appear in abundance in a much finer microgranitic groundmass porphyry is produced, and appears in continuous masses and as the paste of the graphic microgranite breccia. Thus where phenocrysts become predominant and the microgranitic groundmass is interstitial or absent we have granite porphyry and granite, an intermediate type occurring where the microcline wholly predominates. At the border these peculiarities are masked by the abundance of biotite in the black contact granite.

PETROGRAPHIC DESCRIPTIONS.

Granite and granite porphyry.—The granite of the East Greenwich series is always in aspect allied to granite porphyry. The feldspar and quartz are more or less idiomorphic and are inclosed in a small amount of granitic ground of rather fine grain. Where the small flesh-colored feldspars grow more distant and distinct and the rounded blue-quartz grains more individualized the rock becomes a granite porphyry, which is the prevailing form of rock in the areas mapped as granite and granite porphyry.

Another variety is found only in large bowlders at the quarry in the village of East Greenwich. Large flesh-colored feldspars an inch long and large blue-quartz grains appear in a rather coarse micro-granitic ground, and great oval and parallel blotches of biotite cover rude foliation faces.

At the extreme south end of the granite porphyry a specimen was obtained which showed its contact with the light-gray microgranite, and the contact was a rather sharp one, though more like a pronounced schlieren contact than an eruptive contact. This seems to indicate that the granite porphyry was consolidated a little later than the other because it is free from biotite and is distinctly coarser for a quarter of an inch from the contact.

Basic border of the granite porphyry.—Along the northern border of the granite porphyry of the East Greenwich group on Bald Hill in Warwick, separating it from the Cambrian quartzite, stretches a band, about 40 rods wide, of heavy black subporphyritic rock, which is in places spotted white with feldspar crystals and groups of crystals. It is of medium grain, and its dark color is due to its abundant content of biotite and magnetite. It is well exposed along the southern slope of Bald Hill and crosses the road just east of the hill, where it is slightly gneissoid. It grades at many points into the granite porphyry, the gradation showing that the two are parts of one mass. At some places the boundary of the two rocks is intrusive, the granite porphyry being the newer rock. At some localities the granite porphyry is unchanged up to the contact, though in other places it becomes finer grained in a belt several inches wide.

The black granite is cut by many small dikes of graphic micrograndite or of micrograndite containing small crystals of pyrite, and by one small dike of granite porphyry.

Rarely a fragment of the Cambrian quartzite is found inclosed in the granite. It is clear that this pure quartzite can not have supplied the iron to the border granite, which must be regarded as a basic border differentiate of the granite porphyry. The same brown garnets are found in both. As shown in several slides, the feldspars have the same idiomorphic character, and the graphic structure is abundantly developed in both.

A slide (652) shows a vein of graphic microgranite crossing at the top and a portion of the black granite below. A large idiomorphic feldspar in the center of the field extinguished as a single individual, but is dusted so full of minute crystals of an epidotic mineral and of micrographic quartz as to produce the effect of aggregate polarization. Dark spots are biotite aggregates. The slide shows with the lens so many well-defined feldspar crystals that it can be called a granite porphyry, though its porphyritic character is disguised by the abundant biotite. The vein of micrographic texture is very interesting. It is about 2 millimeters wide; has a central suture. It is white, and thus stands out clearly against the black granite. In thin section the micrographic structure of the black granite is seen to be continued into the white vein, in which it grows inward from both sides of the vein with a coarser texture than in the granite and meets along the central suture. This minute vein, which is free from the abundant epidote dust as well as the dark minerals that fill all the rest of the rock, is analogous to the limpid perthitic aftergrowth of many of the epidote-filled nuclei of the feldspars. The same slide contains a wider dike of microgranite.

The black granite is thus of the same type as the other members of the series, but is slightly older and is cut by veins or small dikes of them all.

Blue-quartz-microcline porphyry.—The porphyry from the important locality one-half mile southeast of the top of Spencer Hill is a fresh rock with a bluish to chocolate-colored base, just resolvable with the lens into a granular mass. It contains pale flesh-colored feldspars two or more millimeters long; large, clear, blue-quartz phenocrysts, and black biotite scales just visible with the lens. The feldspar groups show small miarolitic cavities. An analysis of this rock is given on page 66.

Under the microscope the quartz crystals are the most prominent and abundant (see fig. 5.) They have often perfect forms, with prism and double pyramid; they are free from inclosures but are penetrated by lobes of the groundmass. Here and there two or three of these crystals are grouped together. Many of them are often fissured with perfect cleavage and polarized with fine broad undulation, indicating incipient strain. The large-lobed blebs of quartz in the feldspars and the quartz grains of the ground are full of magnetite grains.

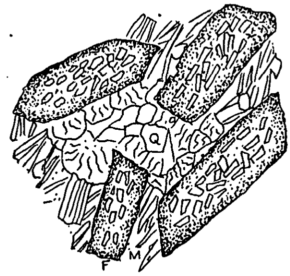

FIG. 5.—Crystals of feldspar embedded in quartz groundmass. F, Feldspar; M, magnetite; Q, quartz.

The feldspar is generally microcline. It showed with heavy solution the same specific gravity as the Ceylon moonstone. The microcline twinning is generally flamy and irregular, as shown in fig. 6. The composites are also twinned after the Carlsbad or Baveno law. Fig. 6 shows an upper crystal twinned to right and left with crystals on the Baveno law. There are also large included plates of bytownite in the large microcline, showing extinction −30 on M and emergence of an axis.

Biotite is regularly but distantly disseminated in the ground in long blades, many of them full of rounded quartz grains. Muscovite is

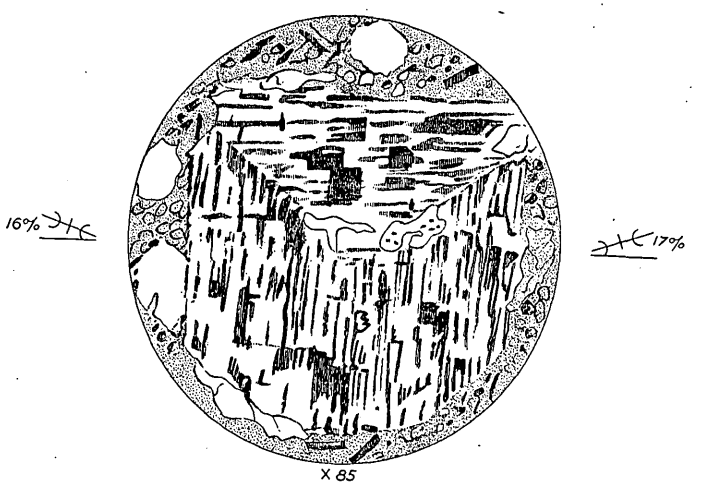

FIG. 6.—Microcline Baveno twin cut at right angles to *a*. Negative bisectrix nearly central. From quartz porphyry south of Spencer Hill.

abundant, in irregular plates surrounding the feldspar. Magnetite is more abundant, but occurs in smaller grains than the biotite. It is often in regular octahedra and arranged in long fluidal trains. The ground is microgranitic, and at some places shows fluidal structure. In this quartz-feldspar ground a few of the feldspars show micropegmatitic structure, vermiform quartz rods penetrate the feldspar and themselves contain blebs of feldspar orientated with the host. A fine dust of magnetite in octahedra or in vermiform shapes is scattered through the ground. Zircons cause dark borders in the biotite.

Outside the locality named above, southeast of Spencer Hill, the porphyry is generally of lighter color, and a slight fissility is in places produced by the aggregation of the biotite into flattened concretionary groups. That portion of the porphyry which forms the cement of the extrusive graphic granite-porphyry breccia is the latest member of the series. In a block from the southern border of the porphyry, at its contact with the microgranite, the microgranite penetrates the porphyry in delicate lobes, as seen in thin section, and has a distinct differentiation border, which is black from the concentration of magnetite grains. This is apparently a slightly later dike of the microgranite, resembling those penetrating the black border granite.

Microgranite.—The microgranite is best exposed in the quarry in the northwest corner of East Greenwich village. It is a fine-grained aplitic rock, often splitting in slaty slabs of a fresh bluish-white to dark-gray color, in which the biotite scales are just visible. Macroscopically it is like the graphic microgranite, but is generally darker; microscopically it has a very regular automorphic granular texture. An analysis is given on page 66.

In some parts of its mass small quartz and feldspar phenocrysts form in the microgranite; in others the quartz becomes more abundant, occurring in spherical grains nearly the size of a pea—the unit form with rounded faces. This forms a transition to the blue-quartz porphyry. These transitional forms show under the microscope a limpid wavy polarizing quartz, as in the porphyry. Seen with low powers the feldspar seems to be untwinned, but with high powers shows the finest laminæ. The feldspar is generally microcline. One section on M gave central positive bisectrix and extinction 11°, and is therefore soda orthoclase. It was full of long plates parallel to a steep positive orthodome of about 76°. Purple fluor occurs in the microgranite where it has been slightly sheared and has become banded with biotite.

The microgranite in the East Greenwich quarry has been partially crushed into flat fragments, which have been recemented by thin, black films of biotite, one of the many indications of the migration of the biotite. At some places the granite-porphyry cement of the breccia passes into this biotite facies by the disappearance of the quartz and feldspar phenocrysts, especially in thin layers, and the rock then generally becomes black near the contact from the great concentration of the magnetite in bands that may be an inch or more wide. The magnetite found in the conglomerate is probably derived from this rock, as the other constituents are mostly free from iron.

Microgranite or graphic microgranite.—The micrographic facies of the central granite mass is present in rather large amount, but mostly as a constituent of the breccia. It makes up some part of the rock mapped as microgranite, but can not well be separated without extensive microscopic work. Even at the East Greenwich quarry some slides are half micrographic in texture. It is a fine, even-grained rock, distinctly granular with the lens, bluish white, weathering pale fawn color. Under the microscope it is seen to be made up of rather large, rounded, or interlocking grains of orthoclase or microcline with exceedingly fine twinning structure, each grain filled with vermiform quartz rods in perfect micrographic structure, which are in places so abundant that they almost entirely mask the feldspar. Small, long plates of biotite are scattered evenly and distantly through the rock, which swarms with small octahedra of magnetite.

Many fragments of the graphic microgranite in the breccia, some over a foot across, show very distinct fluidal structure in the form of thin wavy bands of lighter and darker gray, and one of these fragments itself contains fragments, about an inch long, of micrographic texture, around which the fluidal bands bend. This banding is caused by the concentration of magnetite and biotite in zones and by the alternating narrow layers of micrographic and microgranitic rock.

An analysis of the graphic microgranite taken from a large fragment in the graphic microgranite breccia at a spring near Spencer Hill, at a locality described below, is given on page 66. It differs from the analysis of the microgranite mainly in showing the presence of the Fe_2O_3.

Dikes of microgranitic and micrographic texture.—Besides the large stocks of microgranite and graphic microgranite described in the preceding sections and designated on the map, there are many veins or small dikes of the same rock. A minute graphic microgranite dike in the dark granite seen in one slide is described on page 60. The same slide contains a vein or minute dike of microgranite. This constant association shows that the two types are closely allied. These dikes easily escape notice in the light-colored rocks, but are very abundant in the dark border granite and confirm the idea that it is the older rock. A dike of unusually coarse graphic microgranite, 2½ inches wide, was found on the border of this dark granite, where one wall was the normal granite porphyry and the other the dark fine-grained microgranite. One slide shows the microgranite in contact with the graphic microgranite which occupies the lower three-fourths of the slide. A large dark square at the bottom is a perfect crystal of soda orthoclase cut on M, and the nucleal crystal is full of microlites of a shining epidotic mineral, and is greatly enlarged outwardly by limpid and less twinned material in which the graphic structure first appears and is very marked.

A part of the same slide shows two dark adjoining miarolitic cavities, into which perfect crystal ends project, as well as forms with rounded crystal faces, to which the twin structure conforms, also projecting into the cavities. Both microcline and soda orthoclase appear.

Microclinite.—The Carboniferous conglomerate on the west slope of Spencer Hill contains grains of blue quartz and feldspar from the porphyry, grains of microgranite, and pebbles of Cambrian quartzite, as well as small pebbles of a very peculiar rock. This rock, here called microclinite, is made up wholly of large, squarish grains of microcline, all of about the same size and shape, which are filled full of magnetite in rounded grains and in beaded and branching growths that simulate very closely the micrographic texture of some of the granites. Muscovite in minute scales is present in the microcline in large amount, and assumes the same distribution as the black ore. Here and there is a bleb of quartz or a scale of biotite. There is no interstitial material between the interlocking grains of microcline, so the rock may be considered a form of microcline poryhyry, made up wholly of the feldspathic constituent, with secondary magnetite as the only important accessory.

The branching magnetite and muscovite growth penetrates the grain for a certain distance, and then halts abruptly in the middle of a row of microcline grains, as if the iron had been brought in from without, as in the Carboniferous conglomerate in Cranston. The magnetite grains are more abundant and larger in the mica-schist paste, but are at some places concentrated in a broad black band that passes through the microlinite.

Graphic microgranite breccia with granite-porphyry cement.—The microgranite is in places broken into thin, splintery fragments, which are cemented together by films of black biotite. This kind of fracturing occurs locally in the quarry in the northwest part of East Greenwich village, but only in a narrow layer, and the small fragments are only slightly moved upon one another.

The large area at Spencer Hill, in Warwick, which is represented on the map as about a mile square, is of much greater interest. The simplest form of this breccia occurs on the western slope of Spencer Hill, in the Kent quadrangle, just across the western boundary of the Narragansett Bay quadrangle, at a point south of a schoolhouse in latitude 41° 40′ 30″, longitude 71° 29′ 30″, and in the field to the east. It is a beautiful, fine-grained, mottled, pearl-gray rock, the angular fragments of graphic microgranite being cemented by thin films of magnetite and biotite. Here and there regular and partly rounded Cambrian quartzite fragments, 1 to 3 inches long, occur in the breccia, indicating that some part of the breccia must have formed near the surface, and that if the superincumbent beds had been preserved the rock would here show a transition upward into the Carboniferous conglomerate.

The most interesting form of the breccia occurs at a spring about 10 rods south of the road running south of Spencer Hill, in a depression just east of a house, latitude 41° 40′ 15″, longitude 71° 29′ 15″. In clearing the fields here large masses of the rock have been blasted to pieces, which afford samples of fresh rock for study. The breccia is made up of pearl-gray fragments of almost aphanitic graphic microgranite, ranging in size from fine dust to pieces a foot across. These fragments are mostly massive, but some large pieces show perfect fluidal structure and themselves inclose small fragments of massive graphic microgranite. These small fragments are cemented by a small quantity of a blue-quartz porphyry, which itself shows fluidal structure between the included pieces, marked by trains of magnetite grains that in some places pass through the large corroded biotite scales. This porphyry at some points at the border contains fluorite.

Small shining scales of biotite are abundant in the central portion of some of the micrographic fragments, but absent from the outer half inch. It may perhaps be assumed that the brecciation took place so soon after solidification that the porphyry filling the fissures reheated the graphic microgranite so that a resorption of the few scattered biotite grains took place. It may also be assumed that the cementing of the fragments with biotite or biotite and magnetite occurred at the same time in areas where the porphyry could not penetrate, but where, by pneumatolitic processes, superheated steam and other vapors carried the cementing minerals to their present position, and the same pneumatolitic process may have resorbed the biotite in the micrographic fragments.

The breccia also contains small pockets of granitic débris and large rounded cobbles of granite, from an inch to a foot in length. This granite is a medium-grained two-mica rock. The quartz and feldspar have a certain individuality; the feldspar is in small, perfect, opaque Carlsbad twins, and both quartz and feldspar are included in a small amount of fine ground, a characteristic that connects this rock with the granite porphyries described above.

CHEMICAL RELATIONS OF THE CARBONIFEROUS IGNEOUS ROCKS.

The analyses given below show the chemical composition of the igneous rocks of the two groups. Analyses of riebeckite-bearing granite from Quincy, Mass., and of the Milford granite are presented in columns V and VI for comparison.

Analyses of igneous rocks.

	I.	II.	III.	IV.	V.	VI.
SiO_2	76.81	74.52	77.35	73.01	73.93	77.08
Al_2O_3	10.57	10.07	10.89	11.23	12.29	12.54
Fe_2O_3	0.00	3.74	1.98	2.53	2.91	0.00
FeO	3.74	2.81	2.82	3.66	1.55	0.95
MnO	0.13	0.20	0.13	0.19	Trace.	....
MgO	0.05	0.01	0.09	0.02	0.04	0.01
CaO	0.32	0.86	0.70	0.75	0.31	0.75
Na_2O	3.42	3.88	4.24	5.56	4.66	3.64
K_2O	5.30	3.46	3.38	3.66	4.63	4.99
S	....	....	....	0.05	....	....
BaO	....	....	....	0.06	....	....
SrO	....	....	....	0.01	....	....
Li_2O	0.00	0.00	0.00	0.00	....	....
H_2O +	0.25	0.86	0.26	0.55	0.41	....
$H_2O - 110°$	0.00	0.07	0.05	0.00	0.18	....
	100.59	100.48	101.89	101.28	100.91	99.96

I. Microgranite. East Greenwich, R. I. From the quarry at the northwest corner of the village.
II. Graphic microgranite. East Greenwich, R. I. From the spring locality south of Spencer Hill, described on page 60.
III. Blue-quartz porphyry. East Greenwich, R. I. From a point a half mile southeast of the apex of Spencer Hill.
IV. Riebeckite porphyry. From top of hill 1 mile northeast of Sneech Pond, Cumberland River.
V. Riebeckite-bearing granite from Hardwick quarry, Quincy, Mass. Presented for comparison.
VI. Milford granite. (For comparison, see p. 45.)
Analysis I to IV, by J. H. Perry; analysis V, by Mr. H. S. Washington (Am. Jour. Sci., 4th ser., vol. 6, p. 181, 1898); analysis VI, by L. P. Kinnicutt.

In the quantitative classification the three types are related as follows:

Petrographic relations of igneous rocks analyzed.

Rock.	Class.	Order.	Rang.	Subrang.
Microgranite	I. Persalane	{3. Columbare 4. Britannare	1. Liparase	3. Liparose. (Sodipotassic.)
Graphic microgranite	I. Persalane	{3. Columbare 4. Britannare	2. Alsbachase.	4. Alsbachose. (Dosodic.)
Blue-quartz porphyry	I. Persalane	{3. Columbare 4. Britannare	1. Alaskase	4. (Dosodic.)
Riebeckite porphyry	II. Dosalane	4. Austrare	1. Pantellerase	4. Pantellerose.

It is probable that the analysis of the microgranite is slightly incorrect, as all the slides cut from this rock show a little magnetite. They come near the line between orders 3 and 4, but within order 3.

The slight increase in the calcium just throws the graphic microgranite into the second rang. The considerable increment of sodium the rock receives in passing from microgranite to porphyry is indicated by the subrangs. The above table shows the general order of the appearance of the rocks, the blue-quartz porphyry being the later. We may assume that the similar blue-quartz porphyry in the Cumberland area, which contains soda orthoclase and a little riebeckite, may carry even more sodium.

All these types come in the category of alkali granite, as does also the Milford granite. Of the four series present in the Essex County basin only the granito-dioritic and the related series of dike rocks occur in the region here considered. The foyaitic series and its dike rocks are absent, although the riebeckite porphyry has a foyaitic aspect.[a]

RÉSUMÉ SHOWING RELATION OF THE PORPHYRIES TO ONE ANOTHER AND TO THE CARBONIFEROUS SEDIMENTARY ROCKS.

We may imagine the complex of intrusive rocks here described to have intruded into the Cambrian schists, in an early stage of the Carboniferous period, as a laccolithic mass which, before solidifying, was slightly differentiated along its northern side into a more basic border, represented by the black gneiss of Bald Hill, which occurs along the only portion of the boundary that is exposed.

A broad, continuous band of the granite adjoins this narrow border on the south. The rock of this band seems to have solidified mainly a little later than that of the border, which it seems to underlie, and to have formed the nucleus of the stock. Still farther south is the extensive microgranite and graphic microgranite complex, which seems also to be a little older than the granite porphyry and to have mantled over it around the southern side, as the dark granite did around the northern. Indeed, a little of the microgranite is found on the north side where the dark gneiss joins the granite porphyry, and this occurrence increases the probability that the two former rocks are portions of a common mantle over the granite.

Only a part of the stock is exposed and of this the outcrops at critical points are so poor that no very clear evidence could be gathered concerning the exact relations of the three rock types, either as to time or superposition. They seem to blend by sharp transitions into one another and to be three very similar facies of a common stock, since they have a micrographitic groundmass and many other peculiarities in common and are closely allied chemically.

In the interesting central area the graphic microgranite is probably a variant of the granular microgranite formed somewhat below the present surface, and since the chemical constitution of the two is so nearly the same their difference of texture was caused by some small but unknown difference of physical conditions. This graphic microgranite has been brecciated and has been penetrated by a portion of the granite porphyry, and a certain stratiform structure has been given to the whole mass of the resulting breccia—a structure showing northerly dips, as represented upon the map.

The breccia contains more graphic microgranite in its southern por-

[a] Washington, H. S., The petrographical province of Essex County, Mass.: Jour. Geol., vol. 7, 1899, p. 469.

tion and more granite porphyry in its northern portion where it adjoins the granitoid rock. The breccia preserves the record of several stages: (1) The formation of a fine massive graphic micrograuite, (2) a partial breaking up of the rock, by which it was involved in a second microgranite or micrographic granite, which shows flow structure by distinct banding, and (3) the blending of great angular pieces of these two very fine-grained rocks and of granite with many small and very small fragments of the same rocks which seem (4) to have been carried along and to have been cemented by a small quantity of the granite porphyry. There is (5) indication of a blending of the breccia upward with the ordinary Carboniferous conglomerate. The fragments have been transported very slightly or not at all and still fit together and at places where the porphyry could not penetrate are cemented by films of biotite and magnetite brought in by heated solutions. This interstitial porphyry is much more irregular in grain than the normal porphyry outside, and is somewhat crushed and filled with trains of magnetite grains. There is no scoriaceous structure which would indicate a surface flow, and the rock was probably a somewhat deep-seated deposit of the intruding porphyry. The great quantity of angular and fresh fragments of the microgranite and granite porphyry that occur in the adjacent Carboniferous conglomerate suggest the idea that they are the result of an eruption of tuffaceous material rather than a result of slow erosion of the surface of the laccolith. The identity, under the microscope, of material taken from the fresh rock in the microgranite ledges and from small fragments in the Carboniferous conglomerate serves to confirm this suggestion, as does the fact that the later metamorphism of this conglomerate did not form aluminous silicates (chiastolite, fibrolite, andalusite), the common products of metamorphism of argillaceous Carboniferous rocks farther north, but formed sericite, biotite, and chloritoid; that is, if the igneous material of the breccia had been obtained by erosion it would have been largely altered and kaolinized and would have been largely metamorphosed into the aluminous silicates mentioned above, but as it consisted of fresh fragments of the microgranite it altered into the alkaline silicates named. The presence of chloritoid would be due to the abundant presence of iron, indicated by the abundance of secondary magnetite.

Under the postulates of piezocrystallization the presence of these minerals may be taken to indicate a somewhat deep-seated crystallization, though without invalidating the former conclusion. The microgranite mass and the dark border bed seem to have been first solidified against superincumbent rocks, which favored a slight basic differentiation on the north and the development of a fine-grained facies on the south. The granite solidified a little later, and lower. Later microgranite dikes penetrated the granite and the dark border granite.

An explosive eruption seems to have blown off the capping of micro-granite and graphic microgranite, furnishing the great mass of micro-granite and porphyritic granite fragments which find place in the adjacent Carboniferous conglomerate, and permitting the blending of the two seen at the schoolhouse west of Spencer Hill. That portion of the magma which ran in this conduit consolidated as a porphyry, because its quartz and feldspar phenocrysts had already solidified below, and on the sudden transference of the mass to a higher level the remainder solidified as an exceptionally fine-grained groundmass. The one part of this porphyry cemented shattered fragments of the graphic microgranite; the other filled the remainder of the chimney forming the central mass of porphyry.

The existence of the Wamsutta volcanoes of this age in the adjacent territory studied by Mr. Woodworth and the conclusion of Mr. Washington that the Essex County complex is laccolithic and not deep magmatic favor the conclusion that the consolidation of the mass may have been so superficial that a last explosion may have broken through the roof and supplied the fragmental material for the conglomerate.

The next step would be the further spreading of the Carboniferous conglomerates over the area, and the wide distribution of fragments of the granites and microgranites as bowlders in these conglomerates. Then came a metamorphism of the latter, changing their paste into a coarse mucovite schist, developing therein garnet, biotite, and chloritoid, and carrying iron in considerable quantity into the rock, where it is developed as magnetite in the paste and penetrated the pebbles of the microgranite and the feldspar of the microclinite, producing elaborate dendritic growths of the black oxide. In this connection we may recall the fact that scales of biotite are scattered through the inner portions of the fragments of graphic microgranite and are absent from their borders, where they come in contact with the quartz-porphyry, the condition indicating that they were resorbed by the caustic effect of the inclosing rock.

Continued study of the problem, however, has weakened each of the lines of evidence relied upon to prove the early Carboniferous age of the East Greenwich group:

(1) Professor Jaggar has collected much evidence to show that the Quincy hornblende granite differs in age from the biotite granite of the Boston basin, with which the East Greenwich group is more nearly allied.

(2) The recent discussions by Barrell,[a] Mansfield,[b] and others on the continental transport of unaltered feldspathic material in semiarid regions suggest another explanation of the fresh granite pebbles in the conglomerate.

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[a] Barrell, J., Studies for students: Jour. Geol., vol. 14, pp. 316–356, 430–457, 524–568, 1906.
[b] G. R. Mansfield, Roxbury conglomerate: Bull. Mus. Comp. Geol., vol. 49, 1906, p. 91.

(3) A further study of the schoolhouse locality mentioned above has shown that, while the transition from the breccia to the conglomerate seems complete, a break may be concealed by the considerable metamorphic change.

(4) The succession of events becomes simpler if we assume that the porphyries and microgranites of the series formed the surface of a rather thinly covered batholith, which was just exposed by erosion in early Carboniferous time.

Gould Island, east of Conanicut, would seem, from Mr. Foerste's description, to be made up of a graphic granite breccia like the one here described.[a]

IGNEOUS ROCKS OF POST-CARBONIFEROUS AGE.

Olivine-diabase porphyry.—In a quarry by the roadside, 1 mile southwest of Olney Pond, near the south line of Lincoln, is a dike 1½ to 2 feet wide, running N. 50° E. and dipping 60° NE. It indurates the granite, and is more compact at its border. It is a fine-grained, fresh, black trap, minutely porphyritic, with feldspar needles and olivine crystals, and contains quartz grains, probably derived from the granite. The large feldspars are labradorite, with extinction angles of 23½° on (010). The smaller feldspars are anorthite with maximum extinction 34° in the albite zone. The olivine phenocrysts are half serpentinized; otherwise the rock is very fresh. Granular pyroxene and feathery magnetite make the ground in the coarser center of the dike; an aphanitic ground of glass full of black oxide makes the ground on the border and incloses porphyritic labradorite and olivine exactly like those in the center of the dike, showing that these had floated there after first consolidation elsewhere.

In the deep limestone quarry north of the road and nearest Lime Rock are two dikes, 2 and 2½ feet thick, which run N. 50° W., and dip 60° NE. The trap dikes are echeloned by several slight displacements, while the limestone that incloses them, as noted by Woodworth, shows no different texture here to indicate the motion that has taken place. Many contact pieces obtained directly underneath the limekilns show no visible influence of the trap on the limestone, and in the slide the only endomorphic effect was a darkening of the ground of the trap for one-eighth inch. These dikes branch from a single one at the head of the quarry. The trap is the same jet-black rock as the trap at Lincoln described above, not quite so coarse at the center, but quite the same at the border. The large feldspars are labradorite, beautifully twinned on the albite and pericline laws. The olivine shows peculiar alteration. The olivine network does not appear. The few fissures and the surface are black with secondary magnetite. The whole mass is changed into a fibrous

[a] Geology of the Narragansett basin: Mon. U. S. Geol. Survey, vol. 33, 1899, p. 272.

mass of talc needles radiating from many centers. At some places a later agent has changed the central portion of the olivines into an oil-green serpentine. At others the large feldspars, though generally quite fresh, are changed within sharply defined fields, or within segments of a single crystal, into a fibrous mass of a white micaceous mineral.

A similar dike, or vein, 1½ inches wide, has just been exposed beneath the buildings at the quarry. It is fused with the limestone, and portions taken from its black pitchstonelike mass, at places where it is penetrated by the pure white limestone, form beautiful cabinet specimens. This dike has produced no metamorphic effect on the limestone.

Doctor Jackson[a] maps another dike east of the river opposite the Dexter quarry.

Porphyritic diabase.—One mile southeast of Spencer Hill, in Warwick, a rather coarse and exceptionally fresh diabase was found, which is of exactly the same type as the Holyoke trap. It has a porphyritic aspect, due to the presence of small groups of stout plagioclase plates of first consolidation, which are near bytownite in composition. The augite is amethystine, often twinned and mostly xenomorphic. The rock contains rather large blebs of brightly polarizing devitrified glass, wherein an original perlitic structure is now marked by lines of black ore grains.

Basic eruptive rocks are rare in the region, especially in the Carboniferous area. Professor Woodworth maps a series of altered diabase dikes that extend from North Attleboro by Lanesville to Arnolds Mill, in the "Wamsutta group" of the Carboniferous.[b]

Mr. Foerste mentions two minette dikes that cut the Carboniferous shales in the southern half of Conanicut Island.[c] The authors found dikes of coarse gabbroid diabase in Woonsocket.

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[a] Report on the Geological and Agricultural Survey of the State of Rhode Island, 1840.

[b] Mon. U. S. Geol. Survey, vol. 33, 1899, p. 152.

[c] Idem, p. 232.

INDEX.