Bedrock Geology of Rhode Island

GEOLOGICAL SURVEY BULLETIN 1295

Prepared in cooperation with the State of Rhode Island Development Council

Quinn—BEDROCK GEOLOGY OF RHODE ISLAND—Geological Survey Bulletin 1295

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By ALONZO W. QUINN

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Lithology, structure, and metamorphism of Narragansett basin sedimentary rocks of Pennsylvanian age, younger Westerly Granite, and underlying igneous and metamorphic rocks of early Paleozoic or Precambrian age

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BEDROCK GEOLOGY OF RHODE ISLAND

By Alonzo W. Quinn

ABSTRACT

Probably the oldest rocks in Rhode Island are the Blackstone Series of Precambrian (?) age. These and several other groups of metamorphic rocks in the State include quartzite, quartz-mica schist, greenstone, amphibolite, marble, and several types of gneiss. All were folded and metamorphosed one or more times before the Pennsylvanian Period. Intrusive into these older metamorphic rocks are varied plutonic rocks that range from metadiorite through quartz diorite and granodiorite to granite, and from strongly gneissic syntectonic granitic rocks to almost massive granites. These plutonic rocks probably are of Paleozoic age, and they may belong to one series or to more than one. After solidifying at depth, they were exposed at the surface by erosion before the formation of the volcanic, hypabyssal, and plutonic rocks of the East Greenwich Group. This group and the Quincy Granite of northern Rhode Island were exposed by erosion before Pennsylvanian time when the Narragansett basin rocks were deposited.

The Narragansett basin contains several thousand feet of coarse clastic nonmarine rocks, which contain plant fossils and some meta-anthracite. These rocks were folded, faulted, and progressively metamorphosed in Pennsylvanian or post-Pennsylvanian time. They were also intruded by the Narragansett Pier Granite, which in turn was intruded by the Westerly Granite. Two masses of vein quartz and several mafic dikes have also been mapped. The Raritan Formation (?) of Late Cretaceous age is exposed on Block Island.

INTRODUCTION

Various aspects of the geology of Rhode Island have been treated in many reports published over a long period of time. Since 1944, almost all the bedrock of the State has been mapped in a series of quadrangle maps on scales of 1:31,680 and 1:24,000. These were done under a cooperative project between the U.S. Geological Survey and the Rhode Island Development Council and predecessor State agencies. Rhode Island probably is the first State to be geologically mapped on a scale of 1:31,680 (2 inches to 1 mile) or larger. On the basis of these maps, a geologic map of the whole State has been compiled on a scale of 1:125,000 (pl. 1).

The present report, which is the descriptive text to accompany this map, is based mainly on the quadrangle reports; unpublished maps have also been made available by H. R. Dixon, U.S. Geological Survey, and G. E. Moore, Jr., Ohio State University and U.S. Geological Survey. Most of the information on Block Island has been provided by C. A. Kaye, U.S. Geological Survey. This help is gratefully acknowledged. I mapped several other areas, chiefly in quadrangles that are mostly in Massachusetts or Connecticut. Officers in the cooperating State agencies who worked most in this program were Mr. Clifton N. Lovenberg, Mr. Everett S. Woodmancy, and Mr. Lachlan F. Blair.

In the text, references are made to the names of specific quadrangles. These quadrangles are shown on the index map (fig. 1); those for which there are published reports or unpublished maps are listed below in alphabetical order. The publications dealing with these quadrangles are fully cited in the list of references at the end of this report.

Figure 2 is a generalized geology map of Rhode Island.

Quadrangle	*Reference*
Ashaway	Feininger, 1965a.
Blackstone	Quinn and Allen, 1950.
Bristol	Quinn and Springer, 1954.
Carolina	Moore, 1959.
Chepachet	Quinn, 1967.
Clayville	G. E. Moore, Jr., unpub. data.
Coventry Center	Moore, 1963.
Crompton	Quinn, 1963.
East Greenwich	Quinn, 1952.
East Killingly	G. E. Moore, Jr., unpub. data.
East Providence	A. W. Quinn, unpub. data.
Franklin	Quinn and Allen, 1950.
Georgiaville	Richmond, 1952; Richmond and Allen, 1951.
Hope Valley	Moore, 1958.
Kingston	Moore, 1964.
Narragansett Pier	Nichols, 1956.
Newport	G. E. Moore, Jr., unpub. data.
North Scituate	Quinn, 1951.
Oneco	Harwood and Goldsmith, 1971.
Pawtucket	Quinn and others, 1948, 1949.
Providence	Quinn, 1959.
Prudence Island	G. E. Moore, Jr., unpub. data.
Quonochontaug	Moore, 1959.
Sakonnet Point	G. E. Moore, Jr., unpub. data.
Slocum	Power, 1959.
Thompson	H. R. Dixon, unpub. data.
Tiverton	Pollock, 1964.

Quadrangle	*Reference*
Voluntown	Feininger, 1965b.
Watch Hill	Moore, 1967.
Wickford	Williams, 1964.

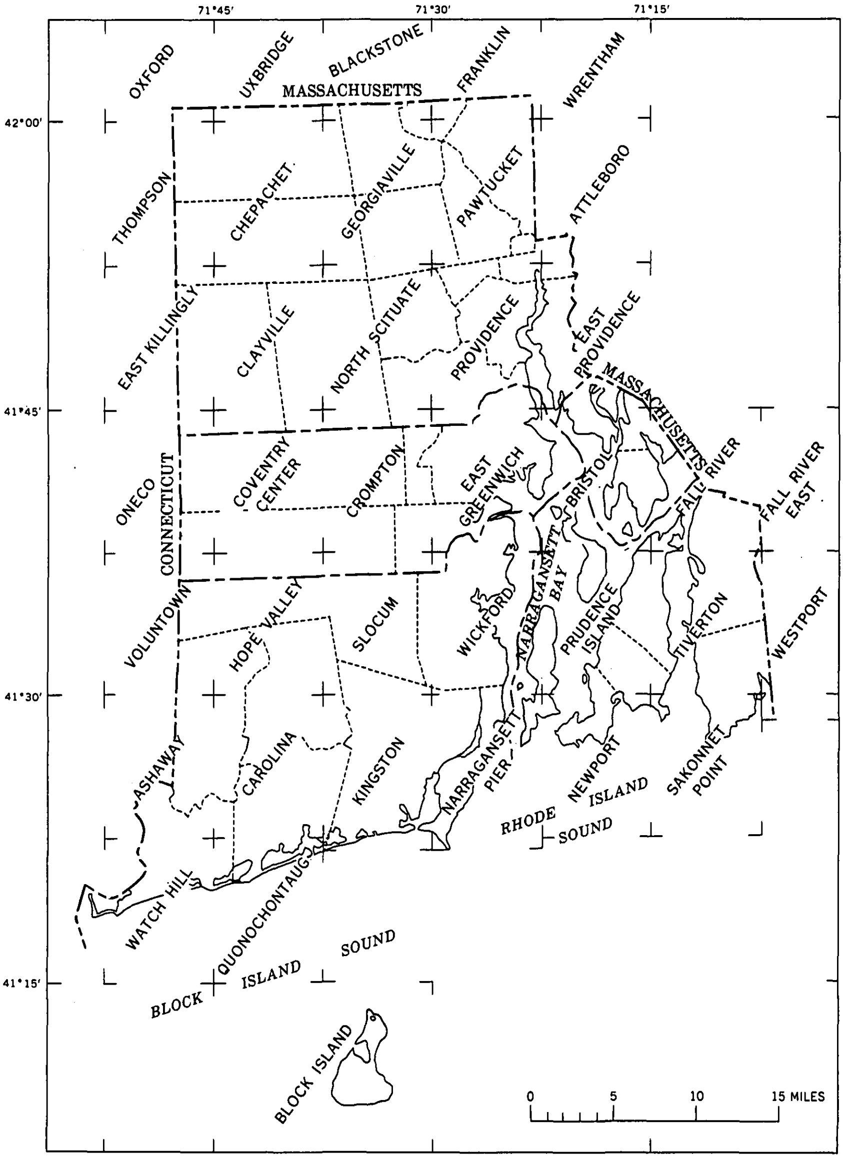

Figure 1.—Index map of Rhode Island showing location of quadrangles.

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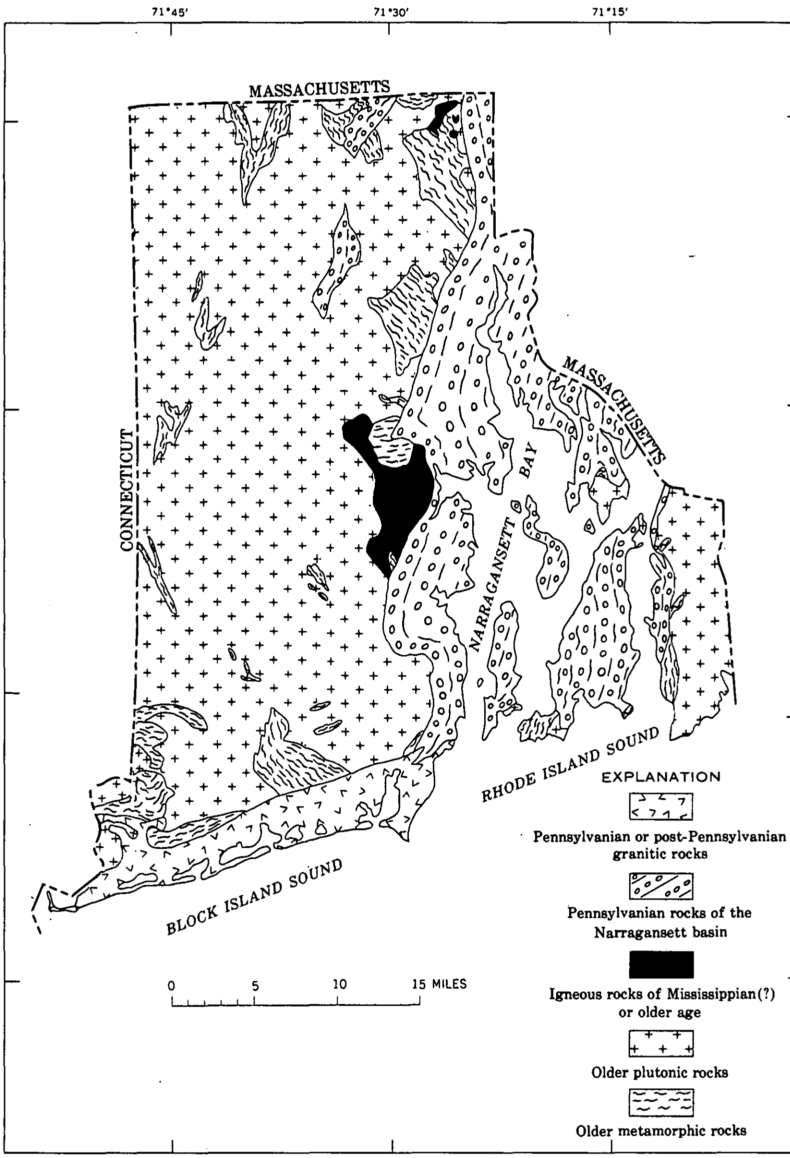

Figure 2.—Generalized geologic map of Rhode Island.

EARLIER GEOLOGICAL STUDIES IN RHODE ISLAND

Rhode Island geology received some attention at a rather early date, as the State was an area of early scientific development. In addition, certain unusual geological features aroused the interest of early scientists and naturalists; among these features were the meta-anthracite, the Purgatory Conglomerate, and a considerable variety of minerals.

The earliest reference to Rhode Island geology known to me is an 1808 article on the meta-anthracite; the author is not known, but may have been William Meade. (Providence Franklin Soc., 1887, p. 2, 3). The "Bibliography of the Geology of Rhode Island," compiled in 1944 and revised in 1950, lists all the published material known to the authors (Quinn and Swann, 1950). Many leading geologists of the last century made passing reference or significant contributions to Rhode Island geology. Among these were: W. O. Crosby, T. N. Dale, J. D. Dana, Amos Eaton, Ebenezer Emmons, A. F. Foerste, M. L. Fuller, C. H. Hitchcock, Edward Hitchcock, C. T. Jackson, J. F. Kemp, Leo Lesquereux, A. S. Packard, Jr., L. V. Pirsson, W. B. Rogers, S. H. Scudder, N. S. Shaler, C. U. Shepard, Benjamin Silliman, Gerard Troost, Warren Upham, Lardner Vanuxem, C. D. Walcott, J. D. Whitney, J. E. Wolff, and J. B. Woodworth.

The first geological study of the whole State was made by C. T. Jackson in 1840.

In 1887, the Providence Franklin Society published "Report on the Geology of Rhode Island." This contains an annotated list of earlier publications, including newspaper articles; lists of rocks, minerals, and fossils; descriptions of a number of special geological features; but no geologic map.

The next survey of a large part of the State was "Geology of the Narragansett Basin" by Shaler, Woodworth, and Foerste (1899). This is an old report, but some of the descriptions of exposures at specific localities are still of considerable use.

Professor C. W. Brown of Brown University organized a Natural Resources Survey of Rhode Island in 1909; he published preliminary reports in 1910 and 1911.

In 1917 B. K. Emerson published "Geology of Massachusetts and Rhode Island," which includes a geological map of the two States.

The present report is based in part on the above-mentioned early studies, but mostly on the series of quadrangle studies begun in 1944.

POSITION OF RHODE ISLAND IN THE APPALACHIAN MOUNTAIN SYSTEM

Rhode Island and most of the rest of New England are commonly considered to be within the northern Appalachians. Actually, Rhode Island is almost in the middle of the mountain system that extends from southern Alabama through Newfoundland. This mountain system has gone through a long and exceedingly complex sequence of events, involving geosynclinal sedimentation and volcanism, folding, thrust faulting, metamorphism, plutonism, uplift, and erosion. In some parts of the system some of these events have been repeated several times, and in some places the compression features of orogeny have been broken by later tensional features.

In Rhode Island sedimentation and orogeny took place in early or middle Paleozoic time and probably also during Precambrian time. There were at least two episodes of plutonic activity in early or middle Paleozoic time. The Narragansett basin of eastern Rhode Island and adjacent Massachusetts contains the only large mass of known Pennsylvanian rocks in this part of the mountain system. It also has the only unequivocal geologic evidence of Pennsylvanian or later compressional folding and plutonic activity in this part of the Appalachians. Rocks and orogenic structures of equivalent ages are known in Nova Scotia (Belt, 1964, 1965), but they are not known elsewhere in New England. Other parts of New England may have been affected by this orogenic episode, but definite evidence of it is lacking. L. W. Lundgren (oral commun., 1966) has suggested that some of the geological features of southeastern Connecticut, as well as the radiometric ages there, may be correlated with this late Paleozoic activity so well demonstrated in Rhode Island.

STRATIGRAPHIC UNITS

AGE RELATIONSHIPS

Age relationships of many of the rocks of Rhode Island, and of much of New England, are very uncertain because fossils are generally scarce, structural relations are complex, several episodes of metamorphism have affected parts of the area, lithologic characters are variable and gradational, and exposures are lacking in many critical places. A welcome exception to this uncertainty is the Narragansett basin (Quinn and Oliver, 1962) of eastern Rhode Island and adjacent Massachusetts. This is a complex synclinal mass containing several thousand feet of sedimentary rocks that contain plant fossils of Pennsylvanian age. This basin extends some 60 miles north through eastern Rhode Island and northeastward into Massachusetts; it is approximately 15 miles across.

Subject to the above uncertainties and excluding such minor rocks as mafic dikes and vein quartz, the rocks of Rhode Island are here divided into six groups.

1. Older metamorphic rocks. The ages of these rocks probably range from Precambrian to early Paleozoic. Important here are the rocks of the Blackstone Series of northern Rhode Island. Masses of somewhat similar rocks are scattered across the State to the southwest. Those near the southwest corner of the State have been correlated with Connecticut formations and assigned to the Cambrian and the Ordovician Systems (Feininger, 1965a,b). Other somewhat similar rocks east of the Narragansett basin are exposed in the Newport, Sakonnet Point, Tiverton, Fall River, and Bristol quadrangles. These are older than any other rocks in their vicinity, but there is no evidence concerning their relationships to the metamorphic rocks west of the Naragansett basin. Several gneissic rocks of northwestern Rhode Island have been assigned to this group, but relations of these are uncertain.
2. Older plutonic rocks. These are younger than the older metamorphic rocks and probably of early or middle Paleozoic age. This group includes several types of plutonic intrusive rocks, chiefly in the range of quartz diorite to granite. These rocks are areally the most extensive group. A few representatives of this group are the Scituate Granite Gneiss, the Hope Valley Alaskite Gneiss, the Esmond Granite, the Grant Mills Granodiorite, the Metacom Granite Gneiss, the Bulgarmarsh Granite, and the Ponaganset Gneiss. Present evidence is not sufficient to indicate whether these all belong to one plutonic or magmatic series or whether there are several such series. Again, rocks on the east side of the Narragansett basin cannot be certainly correlated with rocks on the west side.
3. Igneous rocks of Mississippian(?) or older age. This group includes the Quincy Granite and related rocks in northeastern Rhode Island and the East Greenwich Group of granitic, hypabyssal, and volcanic rocks.
4. Pennsylvanian rocks of the Narragansett basin and of smaller basins at North Scituate and at Woonsocket. These are chiefly clastic sedimentary rocks of continental origin, more or less metamorphosed.
5. Pennsylvanian or post-Pennsylvanian granitic rocks. These include the Narragansett Pier Granite and Westerly Granite and associated pegmatites.
6. Cretaceous clay and sand exposed on Block Island. These constitute the youngest group of rocks.

OLDER METAMORPHIC ROCKS

The oldest rocks in Rhode Island are metamorphic rocks in several different parts of the State. Evidence is insufficient to determine whether these are closely related to each other or whether they include members of widely different and unrelated groups of rocks. The Blackstone Series in northern Rhode Island constitute a fairly definite group. Correlated with the Blackstone Series are several small bodies of metamorphic rocks to the west and southwest. Another group, in the extreme southwest, has been correlated with Cambrian(?) and Ordovician(?) rocks of Connecticut (Feininger, 1965a, b). The relation of these to the Blackstone Series has not been firmly established. In southeastern Rhode Island, on the east side of the Narragansett basin, are several types of old metamorphic rocks whose relations to the rocks on the west side of the basin are unknown. The older gneissic rocks of northwestern Rhode Island are included in this group although their relations are not well known.

BLACKSTONE SERIES, PRECAMBRIAN(?)

GENERAL FEATURES

The name Blackstone Series was originally used by Woodworth (in Shaler and others, 1899, p. 8, 104–109), but it was dropped by Emerson (1917) and replaced with Marlboro Formation. In the Pawtucket quadrangle reports, the name Blackstone Series was revived (Quinn and others, 1948, 1949). This series includes quartzite, chlorite-quartz schist, quartz-mica schist, marble, and mafic volcanic rocks exposed in the valley of the lower Blackstone River in the Pawtucket quadrangle. We divided the Blackstone Series into a lowermost Mussey Brook Schist, a thick middle formation of massive quartzite, the overlying Sneech Pond Schist, and the Hunting Hill Greenstone. We accepted Emerson's correlation of the middle thick massive quartzite with the Westboro Quartzite, but subsequent studies have convinced me that we should have rejected this correlation. There now seems to be no good basis for deciding which, if any, of the several quartzites in Massachusetts is equivalent to this thick quartzite of the Blackstone Series of Rhode Island. Therefore, I here propose that this quartzite be named the Quinnville Quartzite for exposures just north of the village of Quinnville that extend north to the west end of the Blackstone River bridge on George Washington Highway, State Route 116 in the Pawtucket quadrangle. The quartzite is also well exposed at the west end of the bridge of proposed State Route 295, approximately 0.8 mile farther northwest. No other modification of this stratigraphic unit is proposed.

At many places in Rhode Island the rocks of the Blackstone Series cannot be assigned to specific formations but are referred to as Blackstone Series, undivided. Only the Quinnville Quartzite and the Hunting Hill Greenstone are readily distinguished lithologically. The other two formations both include interbedded mica schist, quartz-mica schist, chlorite-quartz schist, thin-bedded quartzite, and marble. The assignment of rocks to the Mussey Brook Schist or to the Sneech Pond Schist is mostly on the basis of whether they are above or below the Quinnville Quartzite.

Distribution.—The largest area of Blackstone Series rocks is along the valley of the Blackstone River in the Pawtucket quadrangle. Other areas of these rocks are a short distance northwest in the Georgiaville and Blackstone quadrangles and further northwest in the Chepachet and Uxbridge quadrangles. To the south in the Providence and North Scituate quadrangles is an area of rocks very similar to those of the Blackstone River valley. The Quinnville Quartzite is well developed there. Further south in the East Greenwich and Crompton quadrangles is an area of Blackstone Series rocks in which the Quinnville Quartzite is typical but in which the Sneech Pond Schist has more thin-bedded amphibolite than is usual. Blackstone Series rocks in two areas in the Clayville quadrangle probably were similar to the Sneech Pond Schist and the Mussey Brook Schist, but they have been much modified by migmatization. A considerable number of other areas to the south, southwest, and west across Rhode Island have metamorphic rocks similar to those of the Blackstone Series, but correlation is by no means certain. Feininger (1965, a, b) has correlated somewhat similar rocks of the Ashaway and Voluntown quadrangles with Cambrian(?) and Ordovician(?) formations in Connecticut. G. E. Moore, Jr. (oral commun., 1966) states that those metamorphic rocks east of the nearly north-south fault in the Ashaway quadrangle are more like rocks of the Blackstone Series than they are like the Cambrian(?) and Ordovician(?) rocks of Connecticut.

Age and correlation.—The age and correlation of the Blackstone Series constitute perhaps the most vexing problem in the geology of Rhode Island. Direct evidence is not definite. Indirect evidence involves correlations on lithologic characters of variable rocks in patches separated by younger plutonic rocks.

Within the East Greenwich area, the geologic relations indicate a considerable interval of geologic time between the deposition of the Blackstone Series and the deposition of the Pennsylvanian sediments of the Narragansett basin. First was the deposition of probably 15,000 to 20,000 feet of sandstone, shale, limestone, and mafic volcanic rocks of the Blackstone Series. These rocks were then folded and metamorphosed and later were intruded at depth by the Esmond Granite of the older plutonic series. This event was followed by a period of erosion long enough to expose the Esmond Granite. The Spencer Hill Volcanics were then formed, and some of the conglomeratic beds in these volcanic rocks contain cobbles of the Esmond Granite. After a considerable, but unknown, thickness of Spencer Hill Volcanics accumulated, there was a second plutonic intrusion, this time the Cowesett Granite and several related rocks. A second erosion interval followed, during which the Cowesett Granite was exposed before the deposition of the Pennsylvanian sediments of the Narragansett basin. These geologic events must have required a considerable length of time, so that the Blackstone Series probably was deposited in early Paleozoic or in Precambrian time.

Similar relations are exposed in northeastern Rhode Island, mostly in the Pawtucket quadrangle, and in nearby Massachusetts. There, the evidence indicates: (1) deposition of perhaps 10,000 feet of Blackstone Series, (2) deformation and metamorphism of the Backstone Series, (3) intrusion of Esmond Granite, Grant Mills Granodiorite, and related plutonic rocks, (4) intrusion of the Devonian(?) or older Quincy Granite and granite porphyry, (5) erosion which exposed the Quincy Granite and granite porphyry, and (6) deposition of the Pennsylvanian Pondville Conglomerate, exposed as "giant conglomerate" on the south border of the Blue Hills of Massachusetts (Chute, 1964). Here, also, the time involved for the sequence of events seems stone Series, (2) deformation and metamorphism of the Blackstone Series.

Indirect evidence suggesting a Precambrian, rather than a Paleozoic, age is found in the Hoppin Hill area in North Attleborough, Mass. Shale and limestone in that area are so little metamorphosed that they contain fossils, which have been identified as of Early Cambrian age (Shaw, 1950; Dowse, 1950). The rocks of the Blackstone Series are more metamorphosed than are these Cambrian rocks; therefore they were probably metamorphosed before the deposition of the Cambrian rocks. This argument is not strong, however, because the nearest Blackstone Series rocks are 4 miles distant from Hoppin Hill and the intervening area is covered by Pennsylvanian rocks and glacial drift.

Another indirect line of evidence on the age of the Blackstone Series has to do with the Northbridge Granite Gneiss of adjacent Massachusetts. Moorbath and staff (1962) made a rubidium-strontium investigation of the Northbridge and, on the basis of six samples, obtained an age of 535±15 m.y. (million years) Middle or Late Cambrian. This date was changed to 558±11 m.y. (Fairbairn and others, 1965, p. 5). The Northbridge Granite Gneiss includes a considerable variety of gneissic rocks that extend into similar rocks of the Ponaganset Gneiss of Rhode Island. The Ponaganset Gneiss of the Chepachet quadrangle is intrusive into and younger than the Blackstone Series. Therefore, if the Ponaganset and the Northbridge are correlative, as seems probable, the Blackstone must be early Cambrian or Precambrian. However, a complication in this correlation comes from the fact that Emerson (1917, p. 155) wrote of the Northbridge, "It is considered Archean because the Algonkian(?) quartzite overlaps it normally and the Milford granite cuts both rocks." The Algonkian(?) quartzite referred to by Emerson was the Westboro Quartzite. Emerson did not specify the locality of the supposed unconformity, or normal overlap; he may have inferred it from the general map pattern. In disagreement are exposures at a recent roadcut on Route 140, 0.73 mile south-southeast of Grafton, Mass., at the position where Emerson's map has a contact between the Westboro Quartzite and the Northbridge Granite Gneiss. These exposures show that the gneiss is younger than quartzite and schist layers of the Westboro. This relation is the same as that between the Ponaganset and the Blackstone Series in Rhode Island.

Altogether, it seems to me that no definite age assignment can now be made for the Blackstone Series but that the known evidence favors a Precambrian age.

Thicknesses.—At no place is it possible to measure or to estimate the total thickness of the Blackstone Series, because later intrusive rocks have removed some of the lower part of the Mussey Brook Schist and some of the upper part of the Sneech Pond Schist. The full thickness of the Quinnville Quartzite may be present along the Blackstone River in the Pawtucket quadrangle, but even in the most favorable places the possibility remains that folding or faulting has repeated or cut out some of the original layers of these formations.

The greatest remaining thickness of the Mussey Brook Schist is in the Providence quadrangle, where it is approximately 8,500 feet. The thickness of the Quinnville Quartzite along the Blackstone River is about 3,300 feet, but this quartzite seems to be at least 5,000 feet thick along the border between the Crompton and the East Greenwich quadrangles. A rather uncertain estimate of the thickness of the Sneech Pond Schist in the Pawtucket quadrangle is 8,500 feet. The Hunting Hill Greenstone is so irregular that an estimate of thickness would have little value. The total thickness of the Blackstone Series seems to be at least 15,000 feet, and it may be more than 20,000 feet.

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MUSSEY BROOK SCHIST

The type locality of the Mussey Brook Schist is in the Pawtucket quadrangle, where Mussey Brook leaves Handy Pond. This formation also occurs in the Georgiaville, the Providence, and the North Scituate quadrangles. It includes a considerable variety of rocks, chiefly greenish to gray fine-grained and thin-bedded chlorite-quartz schist and thin-bedded quartzite; similar rocks in the Georgiaville quadrangle have been altered by feldspathization. There are also thin beds of light-gray mica schist, dark-gray amphibole schist, greenstone, and white marble, and a few small lenses of serpentine and steatite.

Several of the thin beds of marble and lenses of steatite were worked in a small way during colonial times, and steatite was worked by Indians in prehistoric time in the Providence quadrangle at a point just north of Hartford Avenue and 400 feet west of the Providence City line.

Quartzite.—In the Providence quadrangle and extending into the North Scituate quadrangle is a layer of quartzite in the lower part of the Mussey Brook Schist. This layer, which is approximately 1,500 feet thick, is largely gray to light-gray, medium-grained to fine-grained, massive to thick-bedded quartzite, but it also includes beds of quartz-mica schist.

MARBLE

Layers of marble are sparsely interbedded through the Mussey Brook Schist and the Sneech Pond Schist. Most of these beds are too small to map, but two within the Pawtucket quadrangle are shown on the State map. One of these is at the now active quarry near Lime Rock (the old Harris quarry), and the other is at the abandoned quarry about a mile east (the old Dexter quarry). Several other beds in the Pawtucket quadrangle and in the Providence quadrangle were once quarried in a small way. The rock is white to light-gray, fine- to medium-grained marble and much of it is dolomitic. Common metamorphic minerals are tremolite, forsterite, diopside, talc, the bowenite variety of serpentine, and other lime-silicate minerals.

QUINNVILLE QUARTZITE

The Quinnville Quartzite is extensively exposed along the Blackstone River in the Pawtucket quadrangle and along the Woonasquatucket River in the Providence quadrangle. No explanation has been found for the courses of these two rivers in what appears to be resistant quartzite. The Quinnville is also found in the East Greenwich and Crompton quadrangles. It is largely light-gray or light-bluish, clean, massive, medium-grained quartzite, but in many places it contains thin beds of light-gray to greenish quartz-mica schist.

SNEECH POND SCHIST

The Sneech Pond Schist, named for exposures around Sneech Pond in the Pawtucket quadrangle, overlies the Quinnville Quartzite in the Pawtucket quadrangle, in the Providence quadrangle, and in an area along the border of the East Greenwich and Crompton quadrangles. This formation includes a great variety of metamorphosed sedimentary and volcanic rocks. It consists chiefly of gray to light-greenish, fine-grained quartz-mica schist, with many interbeds of quartzite, greenstone, quartz-chlorite schist, amphibole schist, feldspathic mica schist, marble, and serpentine.

HUNTING HILL GREENSTONE

The Hunting Hill Greenstone was named for exposures on Hunting Hill in the Pawtucket quadrangle. The formation is also exposed elsewhere in the Pawtucket quadrangle and in the Providence quadrangle; many bodies of this rock are too small to be shown even on a 1:24,000 map. The rock is largely dark-green, fine-grained greenstone that resulted from low-grade metamorphism of basaltic rock, although some may have had an andesite composition. Chief minerals are amphibole, plagioclase, and epidote, with minor chlorite, biotite, and quartz. Knots and veins of epidote are common. Some of the rock shows the texture of a pyroclastic rock, some seems to have formed as lava flows, some shows pillow structure, and some formed as shallow intrusives. It occurs at various stratigraphic positions throughout the Blackstone Series. This occurrence implies that volcanic and shallow intrusive activity took place during the time of deposition of several thousand feet of sandstone, shale, and limestone of the Blackstone Series.

A few small bodies of serpentine and of steatite occur in the Blackstone Series, mostly in association with the Hunting Hill Greenstone.

BLACKSTONE SERIES, UNDIVIDED

At several places in Rhode Island are bodies of metamorphic rock which are correlated tentatively with the Blackstone Series, but which cannot be assigned to specific formations within the series. Most of these bodies are surrounded by later intrusive granitic rocks. The lithologic types of these metamorphic rocks encompass the range of the Blackstone Series in the Pawtucket quadrangle—quartzite, mica schist, quartz-mica schist, chlorite schist, amphibole schist, and marble.

Most of them were metamorphosed at a higher intensity than that which prevailed in the Pawtucket quadrangle. In the Chepachet quadrangle, for example, are massive quartzite beds like the Quinnville Quartzite of the Pawtucket quadrangle, but mica schist beds contain staurolite and garnet, and mafic layers are amphibolite; schists in the Kingston quadrangle contain sillimanite. Most of the schists surrounded by granitic rocks are feldspathic, and much of the rock is gneissic. The variety of lithologic types is fully as great as might be expected from the great variety of rocks of the Blackstone Series that were subjected to different intensities of metamorphism and different degrees of metasomatism. Some of the common rocks that resulted are: quartzite, biotite schist, muscovite schist, garnet-sillimanite-muscovite schist, hornblende schist, biotite gneiss, muscovite gneiss, augen gneiss, and porphyroblastic gneiss.

MIGMATITE OF BLACKSTONE SERIES

In the Clayville quadrangle are two areas of migmatite formed from the Blackstone Series. Apparently before migmatization, the rocks were chiefly biotite schist and quartzite. These were then intimately invaded by stringers, sills, and dikes of granitic, aplitic, and pegmatitic material, and also by quartz veins, all probably derived from the adjoining Ponaganset Gneiss. Some contacts are sharp and some are gradational. The main minerals are feldspars, quartz, biotite, and muscovite. Other minerals, less abundant but in notable amount, include kyanite, staurolite, epidote, garnet, actinolite, scapolite, tourmaline, and apatite.

OLDER GNEISSIC ROCKS OF NORTHWESTERN RHODE ISLAND

In northwestern Rhode Island are several gneissic rocks whose relations to other rocks are not clearly revealed. These rocks are exposed rather extensively in the Georgiaville, North Scituate, Chepachet, and Clayville quadrangles. Formations included are the Nipsachuk Gneiss, the Absalona Formation, the Woonasquatucket Formation, and an unnamed light-colored gneiss. Richmond (1952; Richmond and Allen, 1951) named the first three of the above for exposures in the Georgiaville quadrangle.

These gneissic formations are older than the Scituate Granite Gneiss of the older plutonic group, as is shown by intrusive relations on Snake Hill in the Chepachet quadrangle. Richmond indicated that the gneisses are older than the Blackstone Series. The map pattern gives some support to his belief that the Blackstone Series lies unconformably over the gneisses. However, glacial drift covers the areas where the supposed unconformity might be exposed. On the basis of present knowledge, the gneisses may be older than, equivalent to, or younger than the Blackstone Series.

Their lithologic characters indicate that these gneisses probably formed as thick accumulations of graywacke, feldspathic sands, tuffs, ash flows, or lava flows, mostly of felsic composition. Richmond interpreted the structure of these rocks as a complicated overturned anticline, with the oldest rocks exposed in the middle. On this basis the total thickness of the gneisses would be at least 5,000 feet and might be 10,000 feet or more.

NIPSACHUCK GNEISS

The Nipsachuck Gneiss is exposed mostly in the Georgiaville quadrangle, but it extends westward into the Chepachet quadrangle. According to Richmond (1952; Richmond and Allen, 1951), it is exposed in the core of an anticline that is overturned toward the west. The rock is gray to light-tan fine-grained to medium-grained gneiss, with prominent lineation of biotite streaks and prominent foliation. Indistinct compositional layering appears to be bedding. The main constitutents are microperthite, albite-oligoclase, quartz, biotite, and muscovite. A typical mode is given in table 1. The composition, texture, and structure suggest that this rock was formed by the metamorphism of graywacke, feldspathic sandstone, or felsic volcanic rock.

TABLE 1.—*Typical modes of Rhode Island rocks*

Quartz	Potassium feldspar	Plagioclase	Biotite	Muscovite	Accessories	References
			Westerly Granite			
27.8	32.9	32.7	3.7	1.9	1.0	Chayes, 1950; (11).[1,2]
27.5	32.0	34.4	3.9	1.4	.8	L. W. Lundgren, unpub. data; (15).[1,2]
27.5	35.4	31.4	3.2	1.3	1.2	Fairbairn and others, 1951; (16).[1,2]
23.1	27.1	40.8	6.3	1.4	1.3	Chayes, 1950; (5).[1,3]
24.3	27.8	41.3	5.5	----------	1.1	Quinn, 1943; (6).[1,3]
23.2	27.7	42.1	4.9	----------	2.1	Moore, 1959.[3] Carolina-Quonochontaug quad.
27.1	33.9	33.6	1.8	2.5	1.2	Do.[3]
28.7	25.1	43.6	1.6	.3	.7	Do.[3]
			Narragansett Pier Granite			
29.2	27.9	34.7	5.9	----------	2.4	Moore, 1959. Carolina-Quonochontaug quad.
28.6	33.8	34.3	2.6	----------	.7	Quinn and Moore, 1968, p. 272. Carolina-Quonochontaug quad.
23.6	32.6	37.0	5.2	1.0	.6	Moore, 1964. Kingston quad.
31.0	28.4	34.7	3.5	1.3	1.1	A. W. Quinn, unpub. data Ashaway quad.
35.2	24.1	28.4	7.1	5.1	1.0	Quinn and others, 1957, p. 550. Narragansett Pier quad.
22.5	49.0	23.5	3.5	.5	.5	Feininger, 1964. Ashaway quad.
27.0	30.0	35.0	5.5	.5	1.0	Do.
34.0	36.0	25.0	----------	3.0	1.0	Do.
31.3	29.7	34.1	2.8	.6	1.5	Do.
25.8	33.4	38.6	.1	2.1	----------	Do.

See footnotes at end of table.

TABLE 1.—*Typical modes of Rhode Island rocks*—Continued

Quartz	Potassium feldspar	Plagioclase	Biotite	Muscovite	Accessories	References
Esmond Granite						
31.8	43.1	18.5	1.2	--	5.5	Quinn and Moore, 1968, p. 272. Pawtucket quad.
41.1	31.6	22.7	2.3	0.7	1.6	A. W. Quinn, unpub. data. North Scituate quad.
36.9	43.0	16.4	1.9	--	2.0	Quinn and Moore, 1968, p. 272. Providence quad.
27.1	45.9	24.8	1.3	.8	.1	A. W. Quinn, unpub. data. Crompton quad
35.3	35.9	27.0	.6	.8	.4	A. W. Quinn, unpub. data. Chepachet quad
Metacom Granite Gneiss						
31.8	38.0	4.2	16.2	4.0	5.8	A. W. Quinn, unpub. data. Bristol quad.
21.4	58.7	7.4	7.2	3.6	2.6	Do.
37.4	24.8	29.2	4.2	3.2	1.2	Do.
Woonasquatucket Formation						
70.9	19.4	1.0	0.3	8.0	0.7	A. W. Quinn, unpub. data. North Scituate quad.
22.7	72.0	1.3	1.3	1.2	1.5	Do.

Quartz	Potassium feldspar	Plagioclase	Biotite	Muscovite	Hornblende	Accessories	References
Scituate Granite Gneiss							
24.8	45.4	27.2	1.7	0.2	--	0.7	Quinn and Moore, 1968, p. 272. North Scituate quad.
22.5	49.3	24.9	2.0	1.3	--	--	Do.
31.6	31.6	30.2	3.7	--	2.0	.8	Quinn and Moore, 1968, p. 272. Coventry Center quad.
19.3	45.1	21.4	11.5	1.9	--	.7	Do.
39.6	33.7	22.5	2.9	--	--	1.4	Do.
34.7	38.1	22.4	4.3	--	--	.5	Quinn, 1963. Crompton quad.
35.3	42.1	15.7	5.5	--	.4	1.0	Quinn and Moore, 1968, p. 272.
32.2	35.4	24.0	5.8	--	--	2.6	Do.
39.0	50.5	4.7	4.4	.5	--	.9	Quinn, 1967. Chepachet quad.

Quartz	Potassium feldspar	Plagioclase	Biotite	Accessories	References
Cowesett Granite					
21.8	49.2	23.8	3.3	1.9	Qiunn and others, 1957, p. 550. East Greenwich quad.
42.6	52.6	.7	3.7	.4	Quinn and Moore, 1968, p. 272. East Greenwich quad.
40.4	40.6	15.4	2.9	.7	Do.
46.9	49.8	--	3.0	.3	A. W. Quinn, unpub. data. Crompton quad.
47.7	43.8	3.1	5.0	.4	Do.
37.0	42.2	18.9	.7	1.5	Do.
Grant Mills Granodiorite					
35.3	14.2	45.7	4.3	0.5	A. W. Quinn, unpub. data. Pawtucket quad.
44.0	16.4	34.6	5.0	--	Do.

See footnotes at end of table.

TABLE 1.—*Typical modes of Rhode Island rocks*—Continued

Quartz	Potassium feldspar	Plagioclase	Biotite	Hornblende	Accessories	References
			Quartz diorite			
20.6	1.9	52.1	1.8	22.8	0.8	A. W. Quinn, unpub. data. Pawtucket quad.
28.5	7.3	61.3	2.5	----------	.4	Do.
24.5	----------	59.5	15.6	----------	.4	Quinn and Moore, 1968, p. 272. Pawtucket quad.
25.2	2.2	54.0	8.8	----------	9.8	A. W. Quinn, unpub. data. Providence quad.
			Hope Valley Alaskite Gneiss			
36.1	28.3	32.7	1.8	----------	1.0	Quinn and Moore, 1968, p. 272. Hope Valley quad.
34.1	31.9	31.9	----------	----------	1.7	Do.
31.3	34.4	31.3	2.5	----------	.5	Moore, 1959, Carolina-Quonochontaug quad.
43.0	34.2	19.6	1.4	----------	1.5	Quinn and Moore, 1968, p. 272. Carolina-Quonochontaug quad.
34.5	18.4	42.1	4.3	----------	.8	Do.
28.5	32.2	35.5	2.5	0.9	.4	Moore, 1963. Coventry Center quad.
24.2	39.9	33.1	1.9	----------	1.0	Moore, 1964. Kingston quad.
			Ten Rod Granite Gneiss			
30.4	28.6	35.0	5.0	----------	1.0	G. E. Moore, Jr., unpub. data. Hope Valley quad.
31.4	28.8	31.5	4.2	2.8	1.3	Do.
39.0	23.5	32.1	4.5	----------	.9	Do.
31.8	31.8	30.9	4.1	----------	1.4	Moore, 1963. Coventry Center quad.
34.2	30.6	27.6	6.8	----------	.8	Moore, 1963. Coventry Center quad.
31.9	22.1	38.9	6.1	----------	1.0	Moore, 1964. Kingston quad.
31.4	25.1	36.5	6.2	----------	.8	Do.

Quartz	Potassium feldspar	Plagioclase	Biotite	Hornblende	Epidote	Muscovite	Accessories	References
				Ponaganset Gneiss				
38.1	51.6	9.0	0.8	----------	----------	0.3	0.2	Quinn, 1967. Chepachet quad.
37.0	30.8	25.6	6.1	----------	----------	----------	.5	Do.
32.7	27.3	24.2	13.4	0.8	0.7	----------	.9	Do.
29.0	31.2	29.4	7.7	----------	----------	.2	2.5	Do.
39.3	22.5	31.9	5.0	----------	----------	----------	1.3	A. W. Quinn, unpub. data. Chepachet quad.
35.3	16.4	34.8	10.0	1.2	.6	.3	1.4	Quinn, 1967. Chepachet quad.
35.8	4.2	39.5	14.7	----------	.4	----------	2.6	Moore, 1963. Coventry Center quad.
36.5	----------	39.4	12.7	7.3	2.7	----------	1.4	Quinn, 1967. Chepachet quad.

Quartz	Potassium feldspar	Plagioclase	Biotite	Riebeckite	Aegirite	Accessories	References
				Quincy Granite			
37.0	55.5	----------	----------	2.4	3.8	1.2	A. W. Quinn, unpub. data. Pawtucket quad.
39.7	51.4	----------	----------	6.5	2.4	----------	Quinn and Moore, 1968, p. 272. Pawtucket quad.
75.3	14.6	----------	----------	9.8	----------	.3	A. W. Quinn, unpub. data. Pawtucket quad.
35.4	53.1	0.9	----------	----------	7.4	3.2	A. W. Quinn, unpub. data. Franklin quad.

See footnotes at end of table.

TABLE 1.—*Typical modes of Rhode Island rocks*—Continued

Quartz	Potassium feldspar	Plagioclase	Chlorite	Reference
				Porphyritic granite of Conanicut Island
35	32	27	6	D. R. Nichols, unpub. data. Narragansett Pier quad.

Quartz	Plagioclase	Hornblende	Biotite	Accessories	References
					Metadiorite
1.1	38.0	59.4	0.1	1.4	Quinn, 1967. Chepachet quad.
--------	12.5	86.0	----------	1.5	Do.
1.3	30.5	56.1	10.9	1.2	Do.
13.1	54.3	8.1	21.7	2.8	Do.
9.7	46.5	34.7	7.1	2.0	G. E. Moore, Jr., unpub. data. Clayville quad.
1.9	52.1	45.4	.6	----------	A. W. Quinn, unpub. data. North Scituate quad.

Plagioclase	Biotite	Olivine	Pyroxene	Magnetite, ilmenite	Apatite	Alteration products	Reference
							Gabbro
37.1	4.2	3.0	16.4	7.4	7.8	24.1	Moore, 1963. Coventry Center quad.

Quartz	Potassium feldspar	Plagioclase	Biotite	Carbonate minerals	Accessories	Reference
						Absalona Formation
37.8	41.6	4.3	12.4	2.1	1.8	A. W. Quinn, unpub. data. North Scituate quad.

Quartz	Potassium feldspar	Plagioclase	Biotite	Muscovite	Carbonate minerals	Accessories	Reference
							Nipsachuck Gneiss
50.6	31.2	0.8	14.6	1.0	1.5	0.3	A. W. Quinn, unpub. data. Chepachet quad.

[1] Number in parentheses indicates number of thin sections studied.
[2] Rocks from Smith quarries at Westerly.
[3] Rocks from quarries near Bradford.

ABSALONA FORMATION

The Absalona Formation, which appears to overlie the Nipsachuck Gneiss, is a dark-gray biotite schist or gneiss with prominent porphyroblasts, an inch or more across, of pink or light-gray microcline. Microcline, microperthite, albite, quartz, and biotite are the main constituents, but muscovite, epidote, and hornblende are common. A typical mode is given in table 1. Round grains of quartz are also common. In a few places some of these grains are bluish quartz and some are colorless quartz. This probably indicates a sedimentary origin, quartz grains having been derived from different sources. Foliation and lineation are well developed.

In the Georgiaville quadrangle, in addition to the dominant porphyroblastic biotite gneiss, G. M. Richmond mapped several layers of quartz-biotite schist, ampibolite, and feldspathic quartzite.

WOONASQUATUCKET FORMATION

The Woonasquatucket Formation is exposed in the Georgiaville and the North Scituate quadrangles. According to Richmond (1952; Richmond and Allen, 1951), it is younger than the Absalona Formation. The formation is chiefly light-gray, medium-grained, indistinctly foliated and layered gneiss and schist. Large round grains of bluish quartz and phenocrysts of microperthite are prominent. The main constitutents are microperthite, albite, quartz, muscovite, and biotite. Modes are given in table 1. Much of the formation appears to have originated as crystal tuff or as lava flows, but Richmond described conglomeratic layers and more schistose rock in the Georgiaville quadrangle.

LIGHT-COLORED GNEISS

In the Chepachet and the Clayville quadrangles are two areas of light-colored gneiss. One of these is enclosed by the Absalona Formation of the Chepachet quadrangle. The other is west of the Absalona Formation and extends southward into the Clayville quadrangle. The rock is light-gray to gray, fine-grained to medium-grained distinctly foliated gneiss. The main constitutents are microcline, oligoclase, quartz, biotite, and muscovite; hornblende porphyroblasts are prominent locally. At a few localities are layers of quartzite and feldspathic quartzite. The original unmetamorphosed rock probably was feldspathic and quartzose sediment or felsic volcanic debris.

METAMORPHIC ROCKS OF WESTERN AND SOUTHWESTERN RHODE ISLAND

Among the metamorphic rocks of western and southwestern Rhode Island are metavolcanic rocks in west-central Rhode Island and several formations in the extreme southwest that are continuous with Cambrian(?) and Ordovician(?) rocks of Connecticut (Feininger, 1965a,b).

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METAVOLCANIC ROCKS OF WESTERN RHODE ISLAND

An irregular mass of metavolcanic rocks and some metasedimentary rocks is exposed in the Coventry Center, Oneco, East Killingly, and Clayville quadrangles. These rocks are older than the enclosing plutonic rocks, but there is not sufficient evidence for any more specific age assignment. Much of the rock is light-gray to dark-gray, fine-grained, interlayered feldspathic gneiss, schist quartzite, amphibolite, and lime-silicate rock. The main constituents are feldspars, muscovite, biotite, quartz, and amphibole. Staurolite and sillimanite are present locally.

CAMBRIAN(?) PLAINFIELD FORMATION

Medium-grained feldspar-quartz-biotite gneiss.—In the Ashaway quadrangle are several metamorphic rocks that have been correlated with the Plainfield Formation of Cambrian(?) age of Connecticut (Feninger, 1965a). Medium-grained feldspar-quartz-biotite gneiss is one of the most voluminous of these rocks. Approximately 1 mile east of Ashaway is a synclinal structure with this gneiss as the lowermost formation. Structural complications and lack of outcrops in critical places prevent the estimation of the full thickness of the gneiss, but it appears to be greater than 2,000 feet. The rock is gray, medium-grained, feldspar-quartz-biotite gneiss and schistose gneiss. Compositional layering is well-developed, with feldspathic quartzite, biotite quartzite, and dark hornblende gneiss.

Fine-grained quartzite.—Fine-grained quartzite is exposed at several places in the Ashaway quadrangle. One layer of this quartzite is within the synclinal structure east of Ashaway, where it overlies the gneissic rocks assigned to the Plainfield Formation. This quartzite seems to underlie the same gneissic rocks, so that the quartzite probably forms different beds at different stratigraphic positions. The upper layer in the syncline appears to be approximately 700 feet thick. The rock is predominantly pale-tan to gray, fine-grained to medium-grained, vitreous, massive to lenticularly bedded clean quartzite. This unit also contains layers of mica schist and calc-silicate rock.

Medium- to coarse-grained calc-silicate rock.—Within the medium-grained feldspar-quartz-biotite gneiss of the Ashaway quadrangle are several lenses of medium- to coarse-grained calc-silicate rock. The longest of these extends almost east through Hopkinton for 2 miles, with an outcrop width of approximately 300 feet. The rock is gray to dark-gray and black, massive to weakly foliated calc-silicate quartzite and calc-silicate granofels. It is composed chiefly of quartz, andesine, actinolite-tremolite, epidote, and diopside. It includes bright-green epidote-rich gneiss southeast of Hopkinton.

Plainfield Formation, undivided.—Near the northwest corner of Rhode Island is a small area where material in the drift and somewhat uncertain outcrops suggest that the bedrock must be Plainfield Formation. Most of the rock seems to be thin-bedded quartzite and quartz-mica schist.

ORDOVICIAN(?) ROCKS

Within the Ashaway and the Watch Hill quadrangles are three formations that have been assigned tentatively to the Ordovician System (Feininger, 1965 a, b): layered felsic gneiss, pink facies of the layered felsic gneiss, and amphibolite.

Layered felsic gneiss.—In the southern part of the Ashaway quadrangle and extending into the Watch Hill quadrangle is a rather extensive area of layered felsic gneiss. Included here is mostly fine-grained to medium-grained, light- to medium-gray, strongly layered felsic gneiss. Most of the rock is composed of microcline, oligoclase, quartz, and biotite, but it also contains layers of biotite schist and amphibolite. The rock is intersected by many small irregular stringers of pink granite and pegmatite.

Pink facies of layered felsic gneiss.—Within the Watch Hill quadrangle is an area of rock like the layered felsic gneiss, except that it has more microcline and less biotite and is pink. The pink facies is overlain and underlain by the gray felsic gneiss.

Amphibolite.—In the Ashaway quadrangle are several areas of amphibolite. One of these is within the syncline east of Ashaway; the amphibolite there lies above the fine-grained quartzite of the Plainfield Formation. Other amphibolite bodies occupy different stratigraphic positions, however. This rock is predominantly medium-grained to coarse-grained, layered and foliated amphibolite whose main constituents are hornblende, plagioclase, quartz, and biotite. Locally, it is porphyroblastic. Included also are layers of dark biotite schist, feldspathic granofels, and quartzite.

METAMORPHIC ROCKS OF SOUTHEASTERN RHODE ISLAND

In the vicinity of Newport are two groups of older metamorphic rocks: (1) slate and quartzite and (2) volcanic tuff, conglomerate, and quartzite. On the east shore of the Sakonnet River are two other groups of older metamorphic rocks: (1) mica-chlorite schist of Sakonnet and (2) chlorite-biotite schist of Tiverton. A fifth type of older metamorphic rock in southeastern Rhode Island is the mica schist of Bristol. The relation of these rocks to other rocks of the older metamorphic group is unknown.

Slate and quartzite of Newport vicinity.—Slate and quartzite are well exposed on the shores of the western part of Newport Neck. Rocks included here are greenish-gray, very light gray, and purple, fine-grained to coarse-grained, thin-bedded slate and quartzite in alternating thin beds. Graded bedding and crossbedding are well developed at many outcrops. There are some thin beds of conglomerate and lenses of fine-grained marble. Discordance between bedding and cleavage is well exposed. Age relations of these rocks are not revealed, but general lithologic and structural characters suggest that they grade upward into the volcanic tuff, conglomerate, and quartzite of Newport Neck.

Volcanic tuff, conglomerate, and quartzite of Newport vicinity.—The shores of Newport Neck also expose a considerable mass of volcanic tuff, conglomerate, and quartzite. Other exposures of these rocks are on the southeastern part of Conanicut Island, Cliff Walk of Newport, the outer shore of Sachuest Point east of Newport, and Gould Island near the north end of Sakonnet River. The formation is mostly dark-gray, dense, flinty to fine-grained felsic metavolcanic rocks that weather light gray to greenish gray. Originally, the rocks were probably tuff, lapilli tuff, volcanic sandstone, and volcanic siltstone. Some of the more massive layers may have been flows. Near the base are conglomerate beds as much as 50 feet thick, which contain pebbles of quartzite, quartz, granite, and volcanic rocks. There are also a few lenses of white to gray marble near the base. These rocks are separated from the slate and quartzite of Newport Neck by a fault. Exposures on Cliff Walk show that these rocks were intruded by the porphyritic granite of Newport and Conanicut Island. The porphyritic granite is overlain unconformably by the Pondville Conglomerate on the east shore of Mackerel Cove of Conanicut Island.

Mica-chlorite schist of Sakonnet.—A rather large area of mica-chlorite schist is exposed along the shore north of Sakonnet Point in the Tiverton and Sakonnet Point quadrangles. This rock was intruded by the Bulgarmarsh Granite, which is Devonian(?) or older. Relations to other metamorphic rocks on the east side of the Narragansett basin are not known. The rock is mostly light-gray to greenish, fine-grained, thin-bedded mica-chlorite schist and is composed chiefly of muscovite, biotite, chlorite, and quartz. There are also many thin beds of marble and quartzite.

Chlorite-biotite schist of Tiverton.—Within the Tiverton quadrangle are two masses of chlorite-biotite schist that are almost surrounded by the Bulgarmarsh Granite. The granite is intrusive into the schist. The rock is mostly green to gray, fine-grained, poorly foliated chlorite-biotite schist and is composed mostly of chlorite, biotite, and quartz. There are also some beds of amphibolite and of quartzite.

Mica schist of Bristol.—Pre-Pennsylvanian basement is exposed in an area on Bristol Neck in the Bristol quadrangle. Within this area is schist that is older than the Metacom Granite Gneiss, which apparently formed in part at least by the granitization of the schist. Inclusions or relicts of schist are common in the gneiss. Both the gneiss and the schist are overlain unconformably by the Pennsylvanian rocks. The rock is pink to light-gray, thin-bedded, strongly lineated schist composed chiefly of muscovite, quartz, and biotite.

OLDER PLUTONIC ROCKS

WEST OF THE NARRAGANSETT BASIN

A major part of Rhode Island is underlain by plutonic granitic rocks, and a major event in the geological history of this area was the formation of these rocks. They range in structure from distinctly foliated gneisses to almost massive granites and in composition from diorite or quartz diorite to alaskite. These rocks extend northward into Massachusetts and a short distance westward into Connecticut; they apparently constitute a complex batholith. Evidence in Rhode Island suggests that these rocks, perhaps with the exception of cumberlandite and some gabbro, resulted from one episode, perhaps somewhat prolonged, of plutonic activity. However, so few reliable geological ages are known that the possibility of more than one plutonic episode still remains. The earliest of the plutonic rocks are so strongly foliated that they are interpreted as having been syntectonic. Some of the later plutonic rocks are almost massive. The more mafic rocks are generally more foliated, but there are exceptions to this; some granite gneiss in northwestern Rhode Island is more foliated than some quartz diorite in northeastern Rhode Island.

The Scituate Granite Gneiss, the Hope Valley Alaskite Gneiss, and the Ten Rod Granite Gneiss were formerly all included in the Sterling Granite Gneiss and were assigned a late Carboniferous or post-Carboniferous age (Loughlin, 1910; Loughlin and Hechinger, 1914). However, later mapping demonstrated that these several types of rocks can be distinguished. Furthermore, field relations indicate that these rocks are older than the Pennsylvanian rocks of the Narragansett basin (Quinn, 1951, 1952). Granitic rock that Loughlin observed to be intrusive into the Pennsylvanian rocks is the Narragansett Pier Granite. Recently, Goldsmith (1966) revived the name "Sterling," as the Sterling Plutonic Group in the New London area of Connecticut.

METADIORITE

Several bodies of metadiorite and schistose diorite are exposed at widely separated localities in the Chepachet, Thompson, Clayville, Providence, and Crompton quadrangles. Age relations are not known for all the metadiorites, but some of these are younger than the Blackstone Series, and some are older than granitic rocks of the older Plutonic series. The rocks are rather variable, even within small exposures. They vary from gray to dark gray and greenish, fine grained to coarse grained, and schistose and streaky to almost massive. The main constituents are hornblende, plagioclase, quartz, biotite, epidote, and chlorite. Retrograde alteration of these minerals is common. Typical modes are given in table 1. Angular and sharp inclusions of quartzite and schist, probably of the Blackstone Series, are exposed at several places. In the Crompton quadrangle the metadiorite seems to form dikes extending into the Blackstone Series. Most of these rocks probably formed as diorite intrusives, but some may have resulted from the metamorphism of sedimentary or volcanic rocks.

PONAGANSET GNEISS

The earliest of the granitic older plutonic rocks probably is the Ponaganset Gneiss of northwestern Rhode Island, which underlies a large area, chiefly in the Chepachet and Clayville quadrangles and also in the Uxbridge, Oxford, Thompson, East Killingly, Oneco, and Voluntown quadrangles. It is probably continuous into and equivalent to the Northbridge Granite Gneiss of Massachusetts, although, as stated earlier, a definite correlation involves confusion concerning ages. Detailed study of a considerable area in Massachusetts will be needed in order to determine how far the Ponaganset Gneiss extends into Massachusetts and what relationships it has to the metamorphic rocks and the granitic rocks there.

The Ponaganset Gneiss in Rhode Island includes a considerable variety of gneissic and granitic rock. The different types are arranged chiefly in north-trending lenses and layers, mostly too small to show even on a scale of 1 : 24,000. The rock is mostly gray to light gray, but some is pinkish, and some lenses are dark gray. The texture is mostly medium grained to coarse grained, but some rock is fine grained and some is strikingly porphyroblastic. All types are distinctly gneissic or foliated, and most are lineated. In most places the gneissic structure is steep and trends northward, and the lineation plunges northward. In some places a second foliation trends westward and dips gently northward. The chief minerals are potassium feldspar, plagioclase, quartz, and biotite. Minor minerals include hornblende and muscovite.

Most of the potassium feldspar is microcline with fine twinning, and some is perthitic. Composition of the plagioclase varies from An_{11} to An_{35}. The compositions of the rocks correspond to quartz diorite, grandodiorite, quartz monzonite, and granite. Typical modes are given in table 1.

Relationships along the contact between the Ponaganset and the Blackstone in the eastern part of the Chepachet quadrangle show clearly that the Ponaganset Gneiss is younger than the Blackstone Series. Some of this evidence indicates that the Ponaganset came in as liquid or partly liquid material that pushed schist and quartzite of the Blackstone Series aside and rotated blocks within this liquid. In other places there is clear indication of considerable granitization of the Blackstone Series. Evidence of these two processes, liquid intrusion and granitization, is present not only along the margin, but also well within the area of the Ponaganset Gneiss. An abandoned quarry just south of Pascoag in the Chepachet quadrangle shows clear examples of relicts. G. E. Moore, Jr., has observed rotated inclusions within the Clayville quadrangle (written commun., 1963).

This evidence is interpreted to mean that a mass of sedimentary rock, probably graywacke or other feldspathic sediments, was heated until some became liquid or partly liquid so that it intruded higher rocks. Some water-rich solutions also invaded the higher rocks. This all occurred under considerable stress, and these rocks are syntectonic.

At Escoheag Hill in the Voluntown quadrangle is a dark-gray coarse-grained and markedly porphyritic foliated quartz diorite gneiss. Textural layers are prominent. Tan microcline phenocrysts as much as 3 inches long give the rock an unusual appearance; many of these are discordant to the foliation. Chief minerals are oligoclase-andesine, quartz, microcline, and biotite. Magnetite is common and hornblende is present locally. Feininger (1965b) described this as magmatic in origin. Harwood and Goldsmith (1971) have called this unit the porphyritic facies of the Ponaganset Gneiss in the Oneco quadrangle.

PORPHYRITIC GRANITE GNEISS

In the Voluntown quadrangle are a few areas underlain by porphyritic granite gneiss of rather heterogeneous character. The rock ranges from light gray to pink, most is medium grained but some is fine grained, and foliation is well developed at most places. Platy microcline phenocrysts are mostly parallel to, but some are discordant to, the foliation. Layering is prominent at many outcrops and is emphasized by sills of Hope Valley Alaskite Gneiss in some areas. The porphyritic granite gneiss is composed of almost equal proportions of microcline, oligoclase, and quartz; biotite is the main mafic constituent.

This gneiss was intruded by both the Scituate Granite Gneiss and the Hope Valley Alaskite Gneiss. It is probably most closely related to the Ponaganset Gneiss. Feininger (1965b) described it as magmatic and syntectonic.

SCITUATE GRANITE GNEISS

The Scituate Granite Gneiss is one of the most widely exposed formations in Rhode Island. The largest area of exposure is in the North Scituate, Clayville, Crompton, Coventry Center, Slocum, and Hope Valley quadrangles, but smaller areas of this rock are exposed in most of the other quadrangles west of the Narragansett basin.

The Scituate Granite Gneiss is grouped with other members of the older plutonic rocks for reasons discussed earlier in this report. Especially clear is the evidence that it is closely related to the Hope Valley Alaskite Gneiss and the Ten Rod Granite Gneiss. The Scituate Granite Gneiss is gradational into the Hope Valley Alaskite Gneiss in the Hope Valley quadrangle. The Ten Rod Granite Gneiss is intrusive into the Scituate in the Hope Valley quadrangle. The Scituate Granite Gneiss probably is younger than the Ponaganset Gneiss, as is suggested by the greater development of foliation in the Ponaganset. Evidence in the North Scituate quadrangle seems to show that the Scituate Granite Gneiss is older than the Esmond Granite.

The Scituate Granite Gneiss is pink, tan, or gray, medium grained to coarse grained, and commonly has a lineation marked by splotches of biotite. Locally, it is also foliated. The main constituents are microcline and microperthite, albite-oligoclase, smoky quartz, and biotite; commonly, hornblende and magnetite are megascopically visible. The splotches of biotite commonly also contain unusual concentrations of such accessory minerals as sphene (keilhauite; Young, 1938), magnetite, zircon, epidote, and apatite. Typical modes are given in table 1.

At most outcrops the origin of the Scituate Granite Gneiss is not shown, but at several places in the North Scituate and the Hope Valley quadrangles there is evidence of its magmatic intrusion into the Blackstone Series and other rocks. There is no evidence that any large part of this rock was formed by granitization.

HOPE VALLEY ALASKITE GNEISS

The Hope Valley Alaskite Gneiss was named by Moore (1958) for extensive exposures in the Hope Valley quadrangle. It is also exposed widely in the Carolina and other quadrangles in the southern part of the State and in the Thompson and Oxford quadrangles near the southwest corner of the State. Moore (1958) discovered that the Hope Valley Alaskite Gneiss is gradational into and of the same age as the Scituate Granite Gneiss.

The Hope Valley Alaskite Gneiss is mostly pink or light tan, but also gray, medium-grained, lineated alaskite gneiss. Lineation consisting of rod-shaped aggregates of smoky and gray quartz is a conspicuous character of the rock, as is the scarcity of biotite. Magnetite grains are common. The main constituents are microcline, albite-oligoclase, quartz, and magnetite. Typical modes are given in table 1.

Fine-grained Hope Valley Alaskite Gneiss.—A few small areas are underlain by rock that is like the Hope Valley Alaskite Gneiss, except that the grain size is smaller. Some of those are shown on the map.

TEN ROD GRANITE GNEISS

The Ten Rod Granite Gneiss was named for exposures on Ten Rod Road in the Hope Valley quadrangle (Moore, 1958). One rather large area of this rock is within the Slocum, Kingston, Wickford, and Narragansett Pier quadrangles. Smaller areas of this rock have been mapped in the Coventry Center, Hope Valley, and Carolina quadrangles.

The Ten Rod Granite Gneiss is pinkish-gray to medium-gray, medium-grained to fine-grained, porphyritic or porphyroblastic granite gneiss. The chief minerals are microcline, albite-oligoclase, quartz, and biotite. It generally has a well-developed foliation and some lineation. Large crystals of pinkish to tan microline give this rock a distinctive appearance. Typical modes are given in table 1.

Moore (1958) described evidence indicating that the Ten Rod Granite Gneiss is younger than the Scituate Granite Gneiss and the Hope Valley Alaskite Gneiss and that it has a magmatic origin. However, Nichols (1956) in the Narragansett Pier quadrangle and Power (1959) in the Slocum quadrangle believed that this "augen gneiss" resulted from granitization of masses of older rocks such as the Blackstone Series.

Nonporphyritic facies of Ten Rod Granite Gneiss.—In the southwest corner of the Wickford quadrangle is a nonporphyritic facies of the Ted Rod Granite Gneiss, which Williams (1964) mapped separately. It is gradational into Ten Rod Granite Gneiss that has the usual porphyritic or porphyroblastic texture. The nonporphyritic facies differs also by containing muscovite.

FINE-GRAINED GRANITE RELATED TO SCITUATE GRANITE GNEISS AND TEN ROD GRANITE GNEISS

Throughout the areas of Scituate Granite Gneiss and Ten Rod Granite Gneiss are numerous granitic instrusives, some of which are large enough to be shown on the map. These commonly appear to have approximately the same composition as the surrounding coarse gneiss,

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but they are finer grained and they commonly show less foliation and lineation. In some places, foliation is parallel to the margins of the finer grained rock. In the North Scituate and Crompton quadrangles, the finer grained rock seems to have been formed as late-stage intrusives into the coarser rock.

POTTER HILL GRANITE GNEISS

The Potter Hill Granite Gneiss was named for a village in the Ashaway quadrangle (Feininger, 1965a). Feininger mapped a considerable area of this rock in Rhode Island and nearby Connecticut. The rock is light orange to pink, fine grained to medium grained, equigranular to locally porphyritic, and very strongly foliated. Most outcrops are weathered, deeply stained, somewhat crumbly, and generally slabby. The rock is composed chiefly of microcline, oligoclase, quartz, biotite, magnetite, and minor muscovite. Feininger (1965a) described it as largely magmatic, but locally containing many inclusions of gneiss of the Plainfield Formation. He used the foliation to delineate the shapes of the several Potter Hill intrusives. This rock grades into the Hope Valley Alaskite Gneiss.

QUARTZ DIORITE, SEVERAL TYPES

There are several bodies of quartz diorite in the Providence, Pawtucket, and Franklin quadrangles. The rock in an individual body is somewhat variable and streaky, and separate bodies differ somewhat for each other. Most of them are probably approximately the same age, but within the Pawtucket quadrangle there is evidence of at least two different ages. Generally the quartz diorite seems to be older than the associated more granitic rocks.

Most of the quartz diorite is dull gray, medium grained to coarse grained, and variably foliated. Some is porphyritic. The chief minerals are oligoclase or andesine, quartz, biotite, locally occurring hornblende, and minor microcline. Much of the plagioclase has been altered to more sodic composition, with resulting formation of epidote and muscovite. Typical modes are given in table 1. Most of the quartz diorite seems to be of magmatic origin, but replacement of mafic metamorphic rocks is also indicated for some quartz diorite in the Pawtucket quadrangle.

GRANT MILLS GRANODIORITE

Grant Mills Granodiorite, which was named for a former settlement in the Franklin quadrangle (Warren and Powers, 1914), is exposed in several moderate-sized areas in the Franklin, Pawtucket, and Providence quadrangles.

This granodiorite is gray to greenish gray, strikingly porphyritic, with a medium- to coarse-grained matrix, and massive to foliated and streaky. It consists chiefly of albite-oligoclase, microcline microperthite, quartz, and biotite. The phenocrysts are microcline microperthite. Much of the plagioclase has been changed to albite, epidote, and muscovite, and some of the biotite has been altered to chlorite. Typical modes are given in table 1.

Evidence of magmatic intrusive origin has been described in reports on the Pawtucket and the Providence quadrangles. Intrusive relations show that the granodiorite is younger than some of the quartz diorite in the Pawtucket quadrangle. Also in the Pawtucket quadrangle, the Grant Mills Granodiorite grades into the Esmond Granite, which presumably means that these two rocks are of the same age.

ESMOND GRANITE

The Esmond Granite was named (Quinn and others, 1948) for the Esmond district just beyond the southwest corner of the Pawtucket quadrangle. Formerly there was a rather large granite-quarrying industry there. The Esmond Granite is also exposed in the Franklin, Blackstone, Chepachet, Georgiaville, North Scituate, Providence, East Greenwich, and Crompton quadrangles. This granite was correlated with the Milford Granite of Massachusetts by Emerson (1917, p. 165, 166), but the lithologic resemblance is not very strong, and intervening areas have not been studied in much detail.

Much of the Esmond Granite is light pink to light gray, light tan, and greenish, medium to coarse grained, and massive. However, some is distinctly foliated. The greenish color characteristic of much of this rock is due to the presence of much fine-grained epidote. The rock consists chiefly of microperthite, albite, quartz, and biotite. Much of the plagicoclase has been altered to albite, epidote, and muscovite, and some of the biotite has been altered to chlorite. Typical modes are given in table 1.

At several places sharp angular and rotated inclusions of Blackstone Series and other rocks within the Esmond Granite give evidence of a magmatic origin for the granite; such evidence has been described in the Providence, Pawtucket, Chepachet, and North Scituate quadrangle reports. There is also some evidence of granitization, especially in the Georgiaville quadrangle. Intrusive relations show that the Esmond Granite is younger than the Blackstone Series. Near the north margin of the North Scituate quadrangle it appears to be intrusive into and younger than the Scituate Granite Gneiss. As indicated above, it appears gradational into the Grant Mills Granodiorite in the Pawtucket quadrangle. Intrusive relations in the Pawtucket quadrangle show that the Esmond is older than the Quincy Granite.

FINE-GRAINED GRANITE RELATED TO ESMOND GRANITE

Fine-grained granite related to the Esmond Granite is exposed in several areas too small to show on this State map and in one larger area shown in the Pawtucket and Georgiaville quadrangles. Except for the fine grain, this rock is very similar to the Esmond Granite. In the Pawtucket quadrangle there seems to be some gradation into the Esmond Granite, but in the Georgiaville quadrangle some dikes of the fine-grained rock intrude the Esmond Granite.

The rock is light gray to gray and pink, fine grained, and massive to faintly foliated. It consists of microperthite, albite, quartz, biotite, and muscovite. Plagioclase and biotite are altered in the same way as in the Esmond Granite.

GABBRO, PROBABLY OF SEVERAL AGES

At three places in Rhode Island are gabbroic rocks of sufficient extent to show on the State map. There rocks are widely separated and there is little evidence concerning their ages and their relationships to each other.

The northernmost gabbro body is near the Massachusetts State line in the Pawtucket and Franklin quadrangles, just west of the cumberlandite at Iron Mine Hill. In addition to the Pawtucket reports (Quinn and others, 1948, 1949), a report on Woonsocket (Quinn and Allen, 1950) describes this gabbro briefly and gives references to earlier reports. The rock is dark gray, medium grained to coarse grained, and massive. It is composed chiefly of labradorite, altered ferromagnesian minerals, and magnetite. Within Rhode Island the only evidence concerning the age of this rock is that inclusions of it are contained in the cumberlandite. Warren and Powers (1914, p. 450) reported that at Sheldonville, Mass., a similar gabbro was intruded by biotite granite that probably is related to the Esmond Granite.

Two masses of gabbroic rock are near the southern margin of the Georgiaville quadrangle. This rock was coarse grained and porphyritic, but it has been much altered, and the grain size has been reduced. It had platy phenocrysts of plagioclase, but these have been altered. It now consists chiefly of chlorite, albite, epidote, and magnetite, with small amounts of amphibole and quartz. Apparently it is younger than the Woonasquatucket Formation and the Absalona Formation and older than the Pennsylvanian Bellingham Conglomerate of the North Scituate basin.

A third area of gabbro is chiefly in the Coventry Center quadrangle (Moore, 1963), although it extends short distances into the Clayville, East Killingly, and Oneco quadrangles. The rock is uniformly coarse grained, dark gray to grayish purple, with platy crystals of grayish-purple andesine-labradorite, and lesser amounts of augite, olivine, biotite, magnetite, and apatite. A typical mode is given in table 1. The rock has a well-developed foliation which appears to be a primary flow structure. This rock is intrusive into the surrounding metamorphic rocks. It shows no effects of the regional metamorphism that has affected even the Pennsylvanian rocks in Rhode Island, so that this is probably a Pennsylvanian or younger rock. In this respect it appears to differ from the other gabbroic rocks of Rhode Island.

CUMBERLANDITE

Cumberlandite, the titaniferous magnetite rock at Iron Mine Hill in the Franklin quadrangle, has been known for 250 years or more. The peculiar character of the rock and the possibility of its economic use as an iron ore have attracted the attention of many people. As a result, many articles have been written about the rock, the most useful being those by Johnson (1908), Wadsworth (1881, 1882), and Singewald (1913).

The rock is black to brown with scattered white or greenish platy crystals (originally of labradorite) as much as half an inch long. The matrix is fine grained to medium grained, and in places the platy crystals are alined, probably as a result of flow. The rock is very heavy and is also weakly magnetic. The fresh rock consists of magnetite-ilmenite intergrowth, olivine, labradorite, and spinel. Fresh rock is rare, however; in most cumberlandite, the olivine and labradorite have been replaced by sepentine, actinolite, and other alteration products. This rock is peculiar to Rhode Island, although a somewhat similar rock has been described at Taberg, Sweden (Singewald, 1913, Iron Minehill, p. 40–46).

The original hill has been described as 1,200 feet long and 600 feet wide, but perhaps half of it has been quarried away. No contact with other rocks is exposed, but the cumberlandite contains a few inclusions of the gabbro that crops out to the west. Schist of the Blackstone Series is exposed a few hundred feet to the northeast, but the relationship is not known. Hurley and Goodman (1943) obtained an age of 1,500 m.y. for the cumberlandite, by using the helium method on magnetite, but this method is of doubtful value. The mineral composition and the presence of inclusions of gabbro suggest an igneous origin of the cumberlandite.

The cumberlandite meets the requirements of an ideal glacial boulder train: there is only one source, the source is small but large enough to supply an adequate amount of material, the rock is readily recognized, and it is resistant to weathering. As a consequence, this boulder train was described long ago (Shaler, 1893). The train extends a little east of south, mostly on the east and central parts of Narragansett Bay to Newport and beyond. Cumberlandite boulders have been discovered on Block Island and on Martha's Vineyard.

SOUTHEASTERN RHODE ISLAND

Several older plutonic rocks are exposed in southeastern Rhode Island. There is no strong lithologic resemblance or other evidence for correlating these rocks with pre-Pennsylvanian rocks on the west side of the Narragansett basin, nor with Dedham Granodiorite (Emerson, 1917).

METACOM GRANITE GNEISS

The Metacom Granite Gneiss was named for exposures on Metacom Avenue in the Bristol quadrangle (Quinn and Springer, 1954). Other exposures are on the northeast part of Aquidneck Island and on the mainland to the east, in the Tiverton and Fall River quadrangles.

The gneiss is gray to pink, medium grained, locally porphyritic, strongly lineated with oval patches of biotite, and foliated locally. It is composed chiefly of microcline, microperthite, albite, quartz, biotite, and muscovite. Typical modes are given in table 1. Small aplite dikes and quartz veins are common. Oriented inclusions of mica schist, and gradation of the gneiss into the adjacent mica schist of Bristol are evidence that the gneiss originated by granitization of the schist.

The mica schist and the gneiss, together with the Bulgarmarsh Granite, constitute the basement on which the Pennsylvanian sediments of that part of the Narragansett basin were deposited.

PORPHYRITIC GRANITE AT NEWPORT AND CONANICUT ISLAND

Porphyritic granite is exposed on Newport Neck in the Newport quadrangle and on Conanicut Island in the Newport and Narragansett Pier quadrangles.

The rock is gray, pink, and greenish, coarse grained, contains pink phenocrysts of microcline, and is generally massive. It consists chiefly of microcline, microperthite, orthoclase, albite-oligoclase, quartz, biotite, hornblende, and chlorite. Locally, the mineral grains are much strained and crushed; in these places, alteration has produced chlorite, epidote, and sericite. A typical mode is given in table 1.

On the Cliff Walk on Newport Neck and on Conanicut Island the granite is intrusive into and younger than the volcanic tuff, conglomerate, and quartzite. On the east shore of Mackerel Cove in the Narragansett Pier quadrangle is an exposure showing that Pennsylvanian conglomerate lies unconformably on the granite. No similar porphyritic granite is known on the west side of the Narragansett basin.

BULGARMARSH GRANITE

The Bulgarmarsh Granite was named for exposures on Bulgarmarsh Road in the Tiverton quadrangle (Pollock, 1964). It is widely exposed in the Tiverton, Fall River, and Sakonnet Point quadrangles and in adjacent Massachusetts.

The Bulgarmarsh Granite is pink to gray, coarse grained, and foliated to massive. It is composed chiefly of microcline, microperthite, albite, quartz, biotite, chlorite, and muscovite. Plagioclase and biotite are somewhat altered.

The granite intruded the chlorite-biotite schist of Tiverton in a manner indicating a magmatic origin of the granite. It is overlain unconformably by Pennsylvanian conglomerate of the Narragansett basin in the Fall River and Tiverton quadrangles.

IGNEOUS ROCKS OF MISSISSIPPIAN(?) OR OLDER AGE

Igneous rocks of considerable variety that appear to be younger than the older plutonic rocks of Rhode Island and older than the Pennsylvanian rocks of the Narragansett basin occur in the Pawtucket and Franklin quadrangles of northeastern Rhode Island and in the East Greenwich and Crompton quadrangles of central Rhode Island. The northeast group has been correlated with the Quincy Granite of Massachusetts, which had been assigned a Carboniferous (Emerson, 1917, p. 188) or a Mississippian(?) age (Quinn and others, 1948, p. 16), but is now considered to be Devonian(?) in age (Chute, 1969). Correlation of the Quincy Granite and the granite porphyry with the East Greenwich Group seems probable, although evidence for this is not strong.

QUINCY GRANITE AND GRANITE PORPHYRY

The Quincy Granite is gray to light gray, medium grained, and mostly massive but has flow structure along the contacts. Microperthite, quartz in small grains, riebeckite, and aegirite are the main constituents. Patches and veins of bright-purple fluorite are common. Typical modes are given in table 1.

The granite porphyry is gray to dark gray, fine grained with round phenocrysts of quartz and squarish phenocrysts of microperthite, and generally has flow structure. Bright-purple fluorite is common, as are inclusions of schist.

The Quincy Granite and granite porphyry form several hills in the northern part of the Pawtucket quadrangle and also in the Franklin quadrangle to the north. The intrusive bodies are moderate sized to small, and some of them include both granite and granite porphyry.

The granite of the quarry area of Quincy, Mass., has such a distinctive composition (perthitic feldspar, granular quartz, riebeckite, and aegirite) that the similar rocks of northeastern Rhode Island are correlated with it with some assurance. The association of the granite with granite porphyry in both places is further evidence. In the Blue Hills area of Massachusetts, a pre-Pennsylvanian age seems well established by the presence of boulders of the Blue Hill Granite Porphyry in the "giant conglomerate" of the Pennsylvanian Norfolk basin, at Routes 28 and 128 (Chute, 1964).

Chute (1966, p. B28) has described evidence that the Blue Hill Granite Porphyry of the Norwood, Mass., quadrangle is not closely related in age to the Quincy Granite, but Chute (1969) considers Blue Hill and Quincy to be Devonian(?) and the Blue Hill to be younger than Quincy. (See "Igneous rocks of Mississippian(?) or older age.") The evidence in Rhode Island is that the granite porphyry in Rhode Island is closely related in age to the Quincy Granite of the Pawtucket quadrangle. The Quincy Granite and associated rocks seems to be somewhat younger than rocks of the Boston vicinity that have been assigned to the Devonian System (Emerson, 1917, p. 188). However, the Devonian age of the older rocks is not well established, and, therefore, this limit to the age of the Quincy Granite is not well established by geological relations. In the Pawtucket quadrangle, the rock mapped as Quincy Granite is intrusive into the Esmond Granite. The rubidium-strontium whole-rock age of 305±14 m.y. for the Quincy Granite as mapped in Massachusetts (Bottino, 1963) is not quite in agreement with a Mississippian age. More recently, R. E. Zartman and others (U.S. Geological Survey, 1967, p. A166–A167) have obtained radiometric ages that suggest an Ordovician age for the same Quincy Granite (nine samples, Rb-Sr whole-rock age, 340–400 m.y.; four samples, K-Ar hornblende age, 430–457 m.y.). Zartman favors the greater hornblende age.

EAST GREENWICH GROUP

The name, East Greenwich Group (called "East Greenwich Granite Group" on their map), was originated by Emerson and Perry (1907, p. 58–70). It has also been discussed in the East Greenwich Quadrangle report (Quinn, 1952). The rocks of this unit appear to constitute a closely related group of extrusive, shallow intrusive, and plutonic rocks. Some of the volcanic rocks contain boulders that appear to be Esmond Granite. These volcanic rocks were intruded by the Cowesett Granite. The whole group appears to be overlain unconformably by the Pennsylvanian rocks of the Narragansett basin. This evidence leaves some uncertainty about the age of the East Greenwich Group, but a Mississippian or earlier age is plausible. The perthitic character of the granitic rocks and the association of volcanic, hypabyssal, and plutonic rocks gives some support to a correlation of the East Greenwich Group with the Quincy Granite and associated rocks. Riebeckite and aegirite are absent from or rare in the group in the East Greenwich quadrangle but are sparingly present in the Crompton quadrangle. The table of radiometric ages (table 2) lists lead-alpha ages on zircon from the Cowesett Granite ranging from 257 to 275 m.y. These are in disagreement with the pre-Pennsylvanian age, which seems well established.

SPENCER HILL VOLCANICS

The Spencer Hill Volcanics were named in the East Greenwich quadrangle report for exposures on Spencer Hill near the west margin of the quadrangle. These rocks extend eastward a considerable distance in the East Greenwich quadrangle and westward a short distance into the Crompton quadrangle. They include rhyolitic rocks that appear to be flows and a great amount of volcanic tuff, breccia, and conglomerate. They are gray, dark gray, pink, greenish, and purplish. Rhyolites are mostly fine grained and some are porphyritic. Flow structure is well developed. The composition is mostly felsic, but some appears to be as mafic as andesite. Chief minerals are microcline, microperthite, plagioclase, quartz, biotite, and muscovite. The pyroclastic rocks contain poorly sorted pebbles and other fragments. Most fragments are 2 or 3 inches in diameter, but some are as much as 2 feet across. The fragments include a considerable variety of rock types, such as rhyolite, quartzite, schist, and granite. The trend of flow structure and irregular bedding is mostly east, and the dips are moderate to steep northerly. New roadcuts in 1966 on U.S. Route 95 made good exposures of the Spencer Hill Volcanics.

MASKERCHUGG GRANITE

East and southeast of the Spencer Hill Volcanics is an area of Maskerchugg Granite, named in the East Greenwich quadrangle report for exposures along Maskerchugg River. This granite appears to be intrusive into the Spencer Hill Volcanics and to have been intruded by Cowesett Granite and by granite porphyry. It is overlain unconformably by the Pennsylvanian rocks of the Narragansett basin.

The rock is gray to light tan, fine grained with a few small phenocrysts, and streaky with a well-developed flow structure. The main constituents are microcline, microperthite, micropegmatite, quartz, and biotite. Phenocrysts include microperthite, micropegmatite, and quartz.

GRANITE PORPHYRY ASSOCIATED WITH COWESETT GRANITE

A small round area of granite porphyry transects the contact of the Spencer Hill Volcanics with the Maskerchugg Granite in the East Greenwich quadrangle. The granite porphyry appears to be intrusive into both the Spencer Hill Volcanics and the Maskerchugg Granite, but exposures are sparse and relations are uncertain.

The granite porphyry is gray, bluish gray, to pink, fine to medium grained, porphyritic, and massive. The main constituents are microcline, microcline-microperthite, oligoclase, quartz, and biotite. The phenocrysts are chiefly pink microcline, microcline-microperthite, gray to bluish-gray quartz, and biotite.

COWESETT GRANITE

The most extensive member of the East Greenwich Group is the Cowesett Granite, named for Cowesett Road in the East Greenwich quadrangle; it extends also into the Crompton, Slocum, and Wickford quadrangles. It is intrusive into rocks of the Blackstone Series, the Spencer Hill Volcanics, and the Maskerchugg Granite. It appears to be overlain unconformably by Pennsylvanian rocks of the Narragansett basin. Contacts with quartzite of the Blackstone Series are sharp, and some blocks of the quartzite were rotated in the Cowesett Granite magma.

The Cowesett Granite is light gray to pink, medium grained to coarse grained, subporphyritic, and mostly massive but has flow structure along contacts. The main constituents are microcline, microperthite, albite, quartz, and biotite. Typical modes are given in table 1.

PERTHITIC COWESETT GRANITE

Along the west side of the Cowesett Granite area of the Crompton quadrangle are two areas of perthitic Cowesett Granite. It appears to be gradational into the Cowesett Granite.

The granite is gray where fresh, but tan or brown where weathered. It is coarse grained to medium grained, subporphyritic, and has oval clusters of biotite and some flow structure. The main constituents are glassy feldspar, quartz, and biotite. The feldspar is chiefly microperthite, containing only very minor plagioclase in separate grains. Riebeckite is present in a few places in this rock, and purple fluorite is common. The presence of riebeckite and purple fluorite add some further support to correlation of the Cowesett Granite with the Quincy Granite.

FINE-GRAINED GRANITE RELATED TO COWESETT GRANITE

In the East Greenwich quadrangle near the northern margin of the Cowesett Granite area is a dikelike intrusive mass of dark fine-grained granite, intrusive into the Cowesett Granite.

The rock is gray to dark gray, fine grained and porphyritic, and mostly massive but has flow structure along the margins. It consists chiefly of microperthite, micropegmatite, oligoclase, quartz, and biotite.

PENNSYLVANIAN ROCKS

The Narragansett basin which contains a large mass of Pennsylvanian rocks, is the most prominent geologic feature in eastern Rhode Island and adjacent Massachusetts. Two smaller masses of probably Pennsylvanian rocks, contained in the Woonsocket and North Scituate basins are exposed a few miles west of the Narragansett basin. These Pennsylvanian rocks are in marked contrast to the adjacent older rocks; they lie unconformably on the older rocks, trend in different directions, include many layers of fossiliferous rocks and some unmetamorphosed rocks, and are generally lithologically dissimilar.

The most recent general description of the Pennsylvanian rocks in this area is by Quinn and Oliver (1962). A massive report was published in 1899, by Shaler, Woodworth, and Foerste. The following published quadrangle reports (see "Introduction") treat at least small areas of Pennsylvanian rocks: Georgiaville, Pawtucket, North Scituate, Providence, Crompton, East Greenwich, Kingston, Bristol, Tiverton, and Narragansett Pier.

NARRAGANSETT BASIN

The Narragansett basin occupies the area of Narragansett Bay, trending northward in eastern Rhode Island and extending northeastward into Massachusetts. Actually, more of the Narragansett basin is in Massachusetts than in Rhode Island, but exposures are better in Rhode Island, and much of what is known about these rocks has been learned there. This basin is a complex synclinal mass of clastic sedimentary rocks. It is almost 55 miles long and about 15 to 25 miles wide. The western margin of the basin is in the western part of Providence, R.I., and the east margin runs through Fall River, Mass. The northeast extremity is near Hanover, Mass. Exposures of older rocks on Conanicut Island and on Newport Neck suggest that the southern end of the basin is near the mouth of Narragansett Bay. The drowned-valley system now occupied by the bay has been eroded in the less resistant rocks of the Narragansett basin.

The rocks of the Narragansett basin are predominantly clastic nonmarine sedimentary rocks of graywacke and arkosic composition that range from coarse conglomerate to shale. Sharp and irregular variations, both vertical and lateral, in lithologic character, together with probably complex structure, combine to make the study of these rocks difficult. Total thickness has been estimated at approximately 12,000 feet (Shaler and others, 1899, p. 134), but the evidence for this is weak. The greatest measured stratigraphic thickness, apparently without duplication, is in a tunnel in the Providence quadrangle where a thickness of 2,260 feet was measured. This section appears to be only a small part of the whole. Scattered exposures reveal many folds and some faults, but, in the absence of stratigraphic units that can be traced more than a few hundred feet, the character and amount of the folding and faulting are not known in satisfactory detail.

The Pennsylvanian age of these rocks has been determined on the basis of numerous plant fossils that have been found at scattered localities within the basin. No recent study of the fossils has been made, but an Allegheny age seems to be established (Knox, 1944). A few insect and other animal fossils have also been found (Lesquereux, 1899; Scudder, 1893).

The coarseness of the sediments, the presence of much unweathered feldspar and rock fragments, and the character of the bedding suggest that these sediments were deposited in a lowland surrounded by an upland area of considerable relief. The presence of coal beds indicates that there were also fairly extensive swampy areas somewhat removed from the sources of sediments (Mutch, 1968).

On both the west and east margins are exposures showing an unconformable relationship, some of the Pennsylvanian conglomerate having been derived from the nearby underlying older rocks. Such a relationship is exposed in the Providence, Crompton, East Greenwich, Narragansett Pier, and Tiverton quadrangles. For the most part, however, the Pennsylvanian sediment appears to have been derived from a more distant source, probably from the northeast (Towe, 1959).

Although the lithologic character of the Pennsylvanian rocks of the basin varies in an irregular way, it has been possible to divide these rocks into several somewhat vaguely defined mappable units—the Pondville Conglomerate, the Wamsutta Formation, the Rhode Island Formation, conglomerate in the Rhode Island Formation, the Dighton Conglomerate, and a felsite at Diamond Hill.

PONDVILLE CONGLOMERATE

The Pondville Conglomerate was named for Pondville Station in Massachusetts (Shaler and others, 1899, p. 134–139). This name is applied to conglomeratic layers lying directly on the older rocks at the base of the Pennsylvanian rocks. This unit is discontinuous, being absent at many places where sandstone or shale of the Rhode Island Formation or of the Wamsutta Formation lies directly on the older rocks. Its thickness is approximately 160 feet near Natick, Mass., and may be almost 500 feet in the Tiverton quadrangle.

In most places the Pondville Conglomerate is gray to greenish coarse conglomerate with abundant sandy matrix, and there is much irregular interbedding with sandstone and lithic graywacke. Pebbles and cobbles are commonly 6 inches or more in diameter, and some are as much as 2 feet across. Most of the pebbles are quartzite, but in a few places there are pebbles of granite and schist derived from nearby exposed sources. In the Tiverton quadrangle and to the south the basal Pennsylvanian beds are light-gray to dark-gray granule conglomerate, containing pebbles of smoky quartz as much as 5 millimeters in diameter.

WAMSUTTA FORMATION

The Wamsutta Formation was named for a proposed but not adopted name for Attleboro, Mass. (Shaler and others, 1899, p. 141). It is a large mass of red rocks that lie mostly in North Attleborough, and Attleboro, Mass.; the unit extends into Rhode Island only in the Pawtucket and Franklin quadrangles.

The formation includes a considerable thickness of interbedded red coarse-grained conglomerate, lithic graywacke, sandstone, and shale. Crossbedding and interfingering of layers are characteristic. The conglomerate layers contain many pebbles of felsite. Some of the conglomerate in the Pawtucket quadrangle contains boulders as much as 4 feet in diameter. A very few lenses of limestone, one flow of red rhyolite, and several sheets of basalt are exposed in adjacent Massachusetts but not in Rhode Island.

The Wamsutta Formation is partly equivalent to the Pondville Conglomerate, for locally it lies directly on the pre-Pennsylvanian rocks. It is also partly equivalent to the Rhode Island Formation, for red layers of the Wamsutta Formation interfinger with gray and black layers of the Rhode Island Formation to the south. A few plant fossils have been discovered in the Wamsutta Formation (Knox, 1944).

RHODE ISLAND FORMATION

The most extensive and thickest (perhaps 10,000 feet) of the Pennsylvanian formations in Rhode Island is the Rhode Island Formation, originally called Rhode Island Coal Measures (Shaler and others, 1899, p. 134, 159). By far the largest part of the Narragansett basin is underlain by it. Included here are fine to coarse conglomerate, sandstone, lithic graywacke, graywacke, arkose, and shale, and a small amount of meta-anthracite. Most of the rock is gray, dark gray, and greenish, but some is black especially the shale and the meta-anthracite. These are interbedded in a most irregular way; crossbedding is common. Field examination seems to show that the sediments were derived from the northeast and were carried to the south and southwest because there seems to be more shale to the south and southwest and more conglomerate to the north and northeast. Furthermore, microscopic examination seems to show that quartz is more abundant (the sediment more mature) to the south and southwest (Towe, 1959). This conclusion is given further support by directions of crossbedding, alinement of plant stems, and other sedimentary features.

In the north, the rocks of the Rhode Island Formation are strong and well indurated but not metamorphosed. To the south, however, they are progressively metamorphosed, as is shown by the successive appearance of metamorphic minerals of higher grade, by such structural features as metamorphic cleavage and schistosity, and by the elongation of pebbles (Quinn and Glass, 1958). These more intensely metamorphosed rocks include quartz-mica schist, feldspathic quartzite, garnet-staurolite schist, and some quartz-mica-sillimanite schist.

Coal in the Rhode Island Formation has long been known (Ashley, 1915). Most of it is meta-anthracite, but some is anthracite (Quinn and Glass, 1958). Numerous beds of meta-anthracite have been mined or otherwise exposed at many places in the Narragansett basin. Most of these beds have not been traced very far, and most are thin, but the bed at the Cranston mine was as much as 35 feet thick in places. Some of this thickness may have been caused by deformation. The meta-anthracite is dark gray to black. Some has the blocky fracture of lower rank coal, but much of it looks like sheared and slickensided graphite. The ash content is high. Vein quartz and fibrous quartz, which is a replacement of aphrosiderite (Richards, 1925), commonly are associated with the coaly layers, as is pyrite.

Conglomerate of the Rhode Island Formation.—Conglomerate layers occur throughout the Rhode Island Formation, but only a few of them are thick and extensive enough to show on the State map. These layers are shown in the Bristol, Wickford, Prudence Island, Tiverton, and Newport quadrangles.

These conglomerate layers are gray to greenish, mostly very coarse, with stones as much as a foot or a few feet long, and interbedded with sandstone and graywacke. These stones are predominantly quartzite. In the vicinity of Newport, stones of porphyritic felsite are common, and in the same area some of the quartzite stones contain Cambrian and Ordovician brachiopods (Walcott, 1898). Increasingly to the south, the pebbles and cobbles have been elongated as a result of tectonic forces. Purgatory Chasm, approximately 2 miles east of Newport, has long been known for its "stretched pebbles."

These conglomerate layers are somewhat more resistant to erosion than are the surrounding rocks, so that they stand higher topographically.

DIGHTON CONGLOMERATE

The Dighton Conglomerate was named for Dighton, Mass. (Shaler and others, 1899, p. 184–187).

Within the town of Dighton, and also west of Taunton and west of Attleboro, Mass., are bodies of conglomerate that appear to have synclinal structures. According to this interpretation, these rocks are the youngest in the Narragansett basin. These have been correlated with each other and have been placed in one formation, the Dighton Conglomerate. The structure of intervening areas is too little known to make these correlations or age assignments firm. The maximum thickness has been estimated at 2,000 feet (Shaler and others, 1899, p. 184). Only the southwest end of the conglomerate of Dighton extends into Rhode Island.

This formation includes gray conglomerate and lithic graywacke and sandstone, irregularly interbedded. Most of the conglomerate is coarse, with quartzite clasts in a sandy matrix.

The presence of this coarse conglomerate at the top of the section and at places now several miles from the margins of the basin implies a very vigorous transportation over considerable distances.

FELSITE AT DIAMOND HILL

At Diamond Hill in the Pawtucket and Franklin quadrangles is a small mass of felsite that is much altered and cut through by the vein quartz of Diamond Hill. A rhyolite flow and some basalt layers are enclosed by the Wamsutta Formation in Attleboro, Mass., to the southeast. The Diamond Hill felsite appears to be intrusive but probably was almost contemporaneous with the extrusions in Massachusetts.

The felsite at Diamond Hill is gray, greenish gray, and reddish purple, fine grained, and porphyritic with phenocrysts of quartz and altered feldspars. In places it shows flow structure, but much of it is massive. The composition of the phenocrysts suggests that the fresh rock was nearly dacite.

NORTH SCITUATE AND WOONSOCKET BASINS

BELLINGHAM CONGLOMERATE

The probable Pennsylvanian rocks in the Woonsocket and the North Scituate basins have been correlated with rocks at Bellingham, Mass. (Mansfield, 1906, p. 99). These rocks are exposed in the Blackstone, Franklin, Georgiaville, and North Scituate quadrangles. No fossils have been found in these two basins, but a correlation with the Narragansett basin is strongly supported by the general lithologic and structural similarity and by strong discordance of the basins to structures in the older rocks.

Rocks included are gray to green conglomerate, sandstone, lithic graywacke, and phyllite, all irregularly interbedded. Along State Route 146 southwest of Woonsocket the pebbles are greatly elongated, and the rocks have a distinct schistosity. Further south, especially in the North Scituate basin, conglomerate is less abundant, sand-size grains are predominant, and pebbles are less elongated.

PENNSYLVANIAN OR POST-PENNSYLVANIAN GRANITIC ROCKS

At the mouth of Narragansett Bay and extending westward along the shore at least as far as Westerly are granitic rocks that intrude the Pennsylvanian rocks of the Narragansett basin. This is one of the very few places where geological relations demonstrate that there are Pennsylvanian or later granitic intrusive rocks in New England. The Narragansett Pier Granite is readily distinguished from the Westerly Granite, and the Westerly Granite is definitely younger, but the two probably are closely related and of almost the same age.

NARRAGANSETT PIER GRANITE

The Narragansett Pier Granite was named for extensive exposures on the shore just south of Narragansett (then called Narragansett Pier) in the Narragansett Pier quadrangle. It is the same as the "red Westerly Granite" of the Westerly quarry area. The rock is shown on the map as a continuous mass, but much of this area is covered by end moraine and outwash plain, and exposures there are sparse. It is exposed in the Narragansett Pier, Kingston, Carolina, Quonochontaug, Watch Hill, and Ashaway quadrangles.

The rock is mostly pink or tan, but also light gray, equigranular, medium grained, locally porphyritic, and massive to weakly foliated, the foliation apparently being flow structure. It is quartz monzonite to granodiorite and consists chiefly of microcline, oligoclase, quartz, biotite, and minor muscovite. Typical modes are given in table 1. It has a rather uniform composition: microcline, 30–35 percent; oligoclase, 30–35 percent; quartz, 25–30 percent; and biotite, 3–5 percent. At Quonochontaug, Kemp (1894) described several boulders of orbicular granite. No bedrock source of these boulders is known. Some of the matrix of these boulders is very similar to the Narragansett Pier Granite, however, so it seems probable that the orbicular rock is a facies of the Narrangansett Pier Granite and that the source is under the drift a short distance north of Quonochontaug.

Granitic sills and dikes that intrude Pennsylvanian sedimentary rocks of the Narragansett basin are exposed at the south end of Tower Hill in the Narragansett Pier quadrangle. The granite is light gray, but otherwise is very similar to the Narragansett Pier Granite. Exposures are not complete, but this rock seems to extend into the type area of the Narragansett Pier Granite. Therefore, this is interpreted as the Narranganset Pier Granite, and the granite is assigned a late Pennsylvanian or post-Pennsylvanian age.

Wave-cut cliffs expose large masses of pegmatite and granite that intrude the Pennsylvanian sedimentary rocks in the Narragansett Pier quadrangle, southward from Wesquage Beach for a mile or more. Pegmatite is predominant at the north, and granite is more abundant to the south. The pegmatite is mostly simple in composition; feldspars, perthite, graphic granite, quartz, muscovite, and biotite constitute most of the rock. Small garnet crystals are common; there are a few crystals of beryl as much as 6 inches across and a few crystals of apatite.

WESTERLY GRANITE

The Westerly Granite is exposed chiefly in the Westerly area—in the Ashaway, Watch Hill, Carolina, and Quonochontaug quadrangles. Most of this rock is in east-trending dikes that dip south, but there are also small irregular intrusive masses. The dike just south of Bradford is 1.6 miles long and approximately 65 feet thick, and it dips about 28° S. Other dikes are somewhat shorter and most are thinner. Dale (1908, p. 190), who had opportunity to see more quarries in operation then than now, stated that the dikes of Westerly Granite range in thickness from 50 to 150 feet.

The Westerly Granite is mostly gray to light gray, but workers in the stone industry recognized several color varieties, such as white statuary, blue, blue white, old blue, pink, light pink, pink gray, and pink statuary. The texture is mostly equigranular and fine. The structure is mostly massive, but a faint foliation can be detected in places. The rock is quartz monzonite to granodiorite in composition, and the main constituents are oligoclase, microcline, quartz, biotite, and minor muscovite. Modes are given in table 1.

The fine grain and uniform composition of this rock have long been known in the stone industry, and it has had extensive use for statuary and monuments. More recently, the fine grain and uniform composition have resulted in the selection of this rock as a standard for chemical, mineralogical, and other analyses and measurements. As a result, many analyses of different kinds have been published; new ones appear from time to time and in many different publications. Probably this rock is more thoroughly known than is any other rock in the world. Sample G–1 (Westerly Granite) was taken from the Smith quarries in Westerly (Fairbairn and others, 1951). Later, as the first sample was nearing exhaustion, a second sample was taken from the quarries just south of Bradford (Chayes and Suzuki, 1963). The rock within any one dike has unusual uniformity, although small differences can be detected. Differences between different dikes are somewhat larger, but even these differences are small compared with differences in most other granitic rocks. "A rather detailed study of small samples of the granites of Westerly and Bradford, Rhode Island, indicates that these granites are remarkably homogeneous in composition" (Chayes, 1950, p. 403).

Geological relations show only that the Westerly Granite is intrusive into and younger than the Narragansett Pier Granite, which is younger than the Pennsylvanian rocks of the Narragansett basin. The two granites probably are closely related and of almost the same age.

MAFIC DIKES AND SILLS

Mafic dikes and sills are widely scattered in Rhode Island. Approximately 40 have been discovered in the following quadrangles: Blackstone (Quinn and Allen, 1950), Franklin, Georgiaville, Pawtucket, North Scituate, Crompton, Ashaway, Voluntown, Narragansett Pier, Newport, Sakonnet Point, and Watch Hill. Only a few dikes are shown on the State map, so that the quadrangle reports should be consulted for locations and descriptions. After the report was printed, one dike in the Georgiaville quadrangle was uncovered in a new excavation on State Route 146, approximately 900 feet southeast of Pound Hill Road. Most of the dikes are small, only a few inches or a few feet across, but one in the Blackstone quadrangle is 40–60 feet wide and almost a mile long.

The dikes are dark gray to black and fine grained. Some have the composition of ordinary basalt, diabase, and olivine diabase, and others are of less common types. The dikes on Beavertail in the Narragansett Pier quadrangle have been called minette, although they are somewhat altered. Two dikes (possibly two exposures of one dike) in the Watch Hill and Ashaway quadrangles appear to be lamprophyre, possibly monchiquite. Several of the older dikes are so altered that their original compositions are not known.

These dikes are of more than one age. In the Pawtucket quadrangle, some were altered by the regional metamorphism that affected the Blackstone Series. Others there are fresh and unaltered, presumably because they were intruded after the metamorphism. The large dike in the Blackstone quadrange intersects sedimentary rocks of probable Pennsylvanian age, and the minettes on Beavertail in the Narragansett Pier quadrangle also intersect Pennsylvanian rocks. The dike in the Blackstone quadrangle is ordinary diabase, which makes plausible a correlation with Triassic diabase of the Connecticut Valley.

It seems probable that each of the several episodes of plutonic and tectonic activity was accompanied by some dike intrusion and that the compositions of the intrusive rocks varied. The Connecticut Valley Triassic igneous and tectonic activity was also probably represented by dikes in Rhode Island.

VEIN QUARTZ

Two masses of vein quartz are large enough to be shown on the State map—at Diamond Hill in the Pawtucket and Franklin quadrangles and on Bristol Neck in the Fall River quadrangle.

The prominent western face of Diamond Hill is part of a mass of vein quartz more than 1,000 feet wide and a mile long. This occurrence is probably along a fault between Pennsylvanian rocks of the Narragansett basin on the east and pre-Pennsylvanian rocks on the west. Some of the quartz appears to have replaced the felsite of Diamond Hill, but much of it was open-space filling. The many intersecting veins indicate that the quartz was deposited during repeated fracturing along this zone. Open cavities with quartz-crystal terminations are common. Considerable hematite and goethite were deposited, some in the form of botryoidal masses, some as thin coatings, and some as specular hematite flakes. Cryptocrystalline quartz and jasper with both massive and layered structure form a minor part of the deposit. "Negative crystal" cavities have been found in a few places.

A considerable mass of vein quartz crops out on the eastern part of Bristol Neck and on the east slope of Mount Hope (in the Fall River quadrangle, but described in the Bristol quadrangle report). This mass is probably along a fault between the Metacom Granite Gneiss on the west and Pennsylvanian sedimentary rocks on the east. The quartz is mostly milky and massive, only a few cavities containing quartz crystals. In a few places, especially near the south end of the vein on the shore, some of the quartz of the cavities is amethystine.

The amethyst was once much sought, and very little can now be found. A very few pieces containing fluorite have been found in this vein. Unlike Diamond Hill, there is little staining by hematite and goethite.

UPPER CRETACEOUS RARITAN FORMATION(?) OF BLOCK ISLAND

In a few places the bluffs of Block Island expose unconsolidated Cretaceous rocks, including red, white, gray, and black clay and white sand. The black clay contains fragments of lignite and nodules of pyrite and siderite. These rocks have been correlated tentatively with the Raritan Formation (C. A. Kaye, written commun., 1965). All these layers have been involved in complex folding, presumably by glacial push.

No consolidated bedrock is exposed on Block Island. It apparently is 1,000 feet or more below sea level (Tuttle and others, 1961; Hansen and Schiner, 1964, p. 7). Most of the island is composed of glacial drift, which is exposed prominently on several wave-cut bluffs. The drift includes a considerable thickness and a wide variety of till, gravel, sand, and clay, probably representing more than one glaciation.

STRUCTURAL GEOLOGY

OLDER METAMORPHIC ROCKS

The masses of Blackstone Series and other older metamorphic rocks now exposed are only small remnants of the original masses. Very large parts of these original masses of the metamorphic rocks must have been removed or displaced by the intrusions of the plutonic rocks that now occupy a large part of Rhode Island. Other parts of the metamorphic rocks were covered by the Pennsylvanian rocks of the Narragansett basin.

The large body of Blackstone Series in the Blackstone River valley between Pawtucket and Woonsocket has a broadly simple structure—northwest strikes of bedding and schistosity and moderate northeast dips. The patch of Blackstone Series just west of Providence and that west of Natick are similar, except that west of Natick the strikes are more to the west. Some of the smaller structures of these rocks are more complex. The trends in these rocks are not in line with the general north and northeast trends of Appalachian structure in the nearby parts of New England. Schistosity and bedding generally are parallel in the Blackstone Series.

The Cambrian(?) and Ordovician(?) rocks in the southwest part of the State are fragmentary, but mapping in Connecticut may tie them into major structures to the west and northwest.

The structures of the older gneissic rocks (Nipsachuck, Absalona, Woonasquatucket, and light-colored gneisses), chiefly in the Georgiaville quadrangle, seem even less related to regional structure. These structures may be more complex continuations of the structures in the Blackstone Series, or they may be at least in part remnants of more ancient structures, as was suggested in the Georgiaville quadrangle reports.

The small bodies of metamorphic rocks on the east and southeast side of the Narragansett basin are even more fragmentary than those on the west side. However, this fragmentary character leaves the possibility that these metamorphic masses are isolated pieces of a once-systematic major structure.

OLDER PLUTONIC ROCKS

Most of Rhode Island west of the Narragansett basin is underlain by granitic plutonic rocks. These may make up one magmatic series, in which case the whole body of rocks constitutes a complex batholith. In a broad way this is a discordant intrusion, cutting sharply across the Blackstone Series and other metamorphic rocks. The plutonic rocks range from strongly gneissic for the early syntectonic members to almost massive for the latest. In the northwest part of the State, in the Chepachet quadrangle, a north-trending foliation and lineation are strongly developed. In that quadrangle there is also a later westerly foliation dipping moderately northward. A similar later foliation is present more sparingly in the more southern areas of the older plutonic rocks.

IGNEOUS ROCKS OF MISSISSIPPIAN(?) OR OLDER AGE

The Quincy Granite and granite porphyry in the Pawtucket quadrangle were intruded as sills and irregular partly concordant bodies. One intrusive body seems to be along a fault.

The Spencer Hill Volcanics in the East Greenwich and Crompton quadrangles strike eastward and dip northward.

NARRAGANSETT BASIN

The Narragansett basin is strikingly discordant to the adjacent older rocks. Contact lines of the older rocks and such smaller structural features as foliation are cut sharply by the margins of the Narranganset basin. The two smaller basins, at North Scituate and at Woonsocket, also are sharply discordant to the older structures, which is part of the evidence for their Pennsylvanian age. This unconformity indicates clearly that the older rocks were deformed and then eroded to a considerable depth before the Pennsylvanian sediments were deposited.

The structure within the Narragansett basin is complex, but the scarcity of outcrops and the irregular variability of the Pennsylvanian sedimentary rocks in the basin have prevented discovery of much of the details of structure. The major structure of the basin is synclinal; this syncline trends north through eastern Rhode Island and bends northeastward into Massachusetts. Three masses of Dighton Conglomerate in Massachusetts have been intercepted as three smaller synclines within the basin. At several localities in Rhode Island and Massachusetts certain beds can be traced for a few hundred feet. These and observations on some single outcrops show clearly that there are many folds and faults. The exposures of pre-Pennsylvanian rocks surrounded by Pennsylvanian rocks on Bristol Neck and on the northeast end of Aquidneck Island are due to folds and faults.

To the south, especially on Beavertail in the Narragansett Pier quadrangle, a pronounced slaty cleavage has been developed. The cleavage is axial-plane cleavage, and it is, therefore, generally discordant to the beds. Another consequence of the deformation of the Pennsylvanian rocks is the distortion of clasts in conglomerate. Clasts in conglomerate in the northern parts of the State have approximately their original shapes, but they are progressively distorted to the south. At Purgatory Chasm, a little more than 2 miles east of Newport, the clasts are triaxial in shape, and the ratio of dimensions is 4.1 : 1.5 : 1 (Agron, 1963, p. 22). The two longer dimensions are in the axial planes of folds. In the Woonsocket basin, clast dimension ratios are more extreme, 13.5 : 2.5 : 1 (Hall, 1963, p. 54).

The west margin of the Narragansett basin at Diamond Hill is along a fault. A similar relationship is indicated by the vein quartz at Mount Hope, described in the Bristol quadrangle report. There is some evidence that the east margins of the Woonsocket and North Scituate basins may be faults in the Georgiaville and North Scituate quadrangles. Probably there are many other faults not revealed by existing exposures.

How far the Narragansett basin extends southward out to sea is unknown. The presence of pre-Pennsylvanian rocks on Newport Neck and on the southeast part of Conanicut Island (Newport, Prudence Island, and Narragansett Pier quadrangles) gives some evidence that the basin may come to an end near the mouth of Narragansett Bay.

PENNSYLVANIAN OR POST-PENNSYLVANIAN GRANITIC ROCKS

The Narragansett Pier Granite is intrusive into the Pennsylvanian rocks at the southwest extent of the Narragansett basin. This granite appears to form a body extending westward some 20 miles or more along the south shore. Such a west-trending structure is not in line with most recognized structures in nearby parts of New England. In support of the reality of this west-trending structure are the dikes of Westerly Granite, most of which strike west and dip moderately south.

METAMORPHISM

Rhode Island was affected by two or more episodes of regional metamorphism in pre-Pennsylvanian time and by one in Pennsylvanian or post-Pennsylvanian time. There was also some minor contact metamorphism, caused by the intrusion of plutonic rocks.

PRE-PENNSYLVANIAN METAMORPHISM

The Blackstone Series and others of the older rocks were involved in regional metamorphism. Evidence is not clear whether this all occurred at one time or at several times. Because of the scattered and patchy distribution of these rocks, the drawing of isograds seems not to be feasible. However, some variations may be detected. The large mass of Blackstone Series rocks in the Blackstone River valley (Pawtucket and Georgiaville quadrangles) shows low intensity of metamorphism, about the quartz-albite-epidote-almandine subfacies of the greenschist facies. Approximately the same intensity prevails in the Providence and North Scituate quadrangles. To the northwest (Chepachet quadrangle) and south and southwest (Crompton, Hope Valley, and Coventry Center quadrangles) the intensity rises to the lower part of the almandine-amphibolite facies. Further south and southwest (Kingston, Carolina, Ashaway, and Voluntown quadrangles) the intensity has risen to the sillimanite-almandine-muscovite subfacies of the almandine-amphibolite facies. The metamorphism of rocks east and southeast of the Narragansett basin is mostly of low intensity, about the quartz-albite-epidote-biotite subfacies of the greenschist facies.

In a few places, contact metamorphism has affected these older rocks. The marble at Lime Rock in the Pawtucket quadrangle has been intruded by quartz diorite of the older plutonic rocks. Away from the contact, the marble contains tremolite as a result of regional metamorphism. At the contact, forsterite and diopside were caused by the higher temperature. Some of these minerals have been altered down to serpentine, bowenite variety. Several small mineral deposits in the vicinity of Sneech Pond, also in the Pawtucket quadrangle, are contact metamorphic deposits (Quinn and Young, 1937).

Regional metamorphism of the Blackstone Series and other older metamorphic rocks occurred before the intrusion of the older plutonic rocks, as is shown by rotated schist inclusions in the plutonic rocks. The plutonic rocks also show effects of metamorphism, which indicates a second episode. In the west and southwest areas, Moore (1958, 1959, 1963, 1964) discovered granulation, a metamorphic foliation, and late porphyroblasts in the Scituate Granite Gneiss, the Hope Valley Alaskite Gneiss, and the Ten Rod Granite Gneiss. The second foliation of the Ponaganset Gneiss in the Chepachet quadrangle is also evidence of a later metamorphism.

PENNSYLVANIAN OR POST-PENNSYLVANIAN METAMORPHISM

The Pennsylvanian rocks of the Narragansett basin provide a good illustration of progressive regional metamorphism, as was described by Lahee (1912, 1914) and later by Quinn and Glass (1958). These three papers described gradual and systematic change from nonmetamorphosed rocks in the north to more intensely metamorphosed rocks to the south. Subsequent work has made it feasible to draw isograds that show an increase of metamorphic intensity to the south and an increase toward the margins, particularly the west margin, of the basin where the rocks must have been under the greatest thickness of cover. This area of most intense metamorphism is also near the intrusive bodies of Narragansett Pier Granite.

Well-indurated but very weakly metamorphosed rocks occur at the northeast corner of the State. Going southward, the change of intensity of metamorphism is shown by the appearance of biotite, then garnet, and then staurolite. The pattern and rate of increase of metamorphism suggest that the rocks at the south end of Tower Hill in the Narragansett Pier quadrangle are at the sillimanite grade. No sillimanite has been discovered there, but the original rocks probably did not have the right composition to yield sillimanite. To the west, in the Kingston quadrangle, are sillimanite-bearing rocks that have been assigned to the Pennsylvanian. Along with these mineralogical indications of increasing metamorphism are textural changes. The mineral grains become more and more interlocking. More striking is the increasing deformation of pebbles, cobbles, and boulders in conglomerate described above. Still another effect of this progressive metamorphism is the increase in rank of coal. Quinn and Glass (1958) showed that the rank of coal increases from high anthracite near the Providence-Pawtucket line to meta-anthracite at the Cranston mine, near the south margin of the Providence quadrangle.

A remarkable fact is that plant fossils in graphitic shale interbedded with garnet-staurolite schist layers have been found at shore exposures on Conanicut Island 1,500 feet south of the east end of the Jamestown Bridge.

The probable Pennsylvanian rocks of the basins at North Scituate and Woonsocket have been metamorphosed to the intensity that they contain much biotite and scattered garnet crystals. Apparently they are at about the quartz-albite-epidote-almandine subfacies of the greenschist facies.

A puzzling feature of both metamorphism and structure of the pre-Pennsylvanian rocks in Rhode Island is that they show so little of the effects of the Pennsylvanian or post-Pennsylvanian deformation and metamorphism.

RADIOMETRIC AGES

Radiometric ages of rocks in Rhode Island and nearby Massachusetts are assembled in table 2. The ages must be considered with respect to methods of determination, but even so, they do not all agree with ages indicated by geological evidence.

The first published ages were made by the lead-alpha method (Quinn and others, 1957). Most of these ages seemed reasonable according to the time scale accepted at the time of the determinations (older plutonic rocks, Devonian; Quincy Granite, Mississippian; Narragansett Pier and Westerly Granites, Late or post-Pennsylvanian). However, subsequent lengthening of the geologic time scale (Kulp, 1961; Faul, 1960) places most of these dates in the Pennsylvanian Period or later. This placement probably is wrong; it seems very doubtful that the older plutonic rocks were intruded at depth during Pennsylvanian time and then exposed by erosion before the formation of the volcanic and plutonic rocks of the East Greenwich Group and that those in turn were exposed by a second period of erosion, all before lower or middle Allegheny time, which is the age indicated by the fossils of the Wamsutta Formation (Knox, 1944).

TABLE 2.—*Radiometric ages of rocks in Rhode Island and nearby Massachusetts*

Sample	Method [1]	Material	Age (m.y.) [2]	Reference
Narragansett Pier (npg) **and Westerly** (wg) **Granites**				
Q55–4 (wg)	Pb-α	Monazite	220	Quinn and others, 1957.
S47 (wg)	Pb-α	Zircon	243	Do.
B–3042(wg)	Rb-Sr	Biotite	259±10	Bottino, 1963.
G–1 standard (wg)	Rb-Sr	Whole rock	299±40	Do.
B–3814(wg)	K-Ar	Biotite	240±12	Hurley and others, 1960.
Q55–3(npg)	Pb-α	Zircon	208	Quinn and others, 1957.
S46(npg)	Pb-α	do	225	Do.
Q55–1(npg)	Pb-α	do	235	Do.
53S–49(npg)	Pb-α	do	274	Do.

See footnotes at end of table.

TABLE 2.—*Radiometric ages of rocks in Rhode Island and nearby Massachusetts*—Continued

Sample	Method [1]	Material	Age (m.y.) [2]	Reference
Narragansett basin and North Scituate basin rocks and metamorphic minerals				
Wamsutta rhyolite	Rb-Sr	Whole rock	211±23	Bottino, 1963.
R-3917	K-Ar	Slate	253±13	Hurley and others, 1960.
R-3920	K-Ar	do	230±12	Do.
R-3818	K-Ar	do	260±13	Do.
R-3817	K-Ar	Impure biotite	275±15	Do.
B-3817A	K-Ar	Biotite	250±12	Do.
B-3817A	Rb-Sr	do	244±15	Do.
B-3815 [3]	K-Ar	do	237±11	Do.
B-3816 [3]	K-Ar	do	230±11	Do.
B-3815 [3]	Rb-Sr	do	244±12	Do.
16	K-Ar	do	200	Harakal, 1964.
Cowesett Granite (cg) and Quincy Granite				
Q48-3(cg)	Pb-α	Zircon	272	Quinn and others, 1957.
			272	
			257	
QG-1	Pb-α	do	275	Do.
			273	
Quincy Granite	Rb-Sr	Whole rock	305±14	Bottino, 1963.
Older plutonic rocks—Scituate Granite Gneiss (sg), Hope Valley Alaskite Gneiss (hva), Ten Rod Granite Gneiss (trg), and Northbridge Granite Gneiss (ngn)				
Q53-38(trg)	Pb-α	Zircon	289	Quinn and others, 1957.
Q53-39(hva)	Pb-α	do	303	Do.
Q50-17(sg)	Pb-α	do	299	Do.
Q53-37(sg)	Pb-α	do	337	Do.
			303	
1(sg)	K-Ar	Biotite	245	Harakal, 1964.
2(sg)	K-Ar	do	200	Do.
3(sg)	K-Ar	do	225	Do.
5(sg)	K-Ar	do	200	Do.
23(sg)	K-Ar	do	230	Do.
23(sg)	K-Ar	Muscovite	250	Do.
25(sg)	K-Ar	Biotite	230	Do.
4849(ngn)	Rb-Sr	Whole rock	538	Moorbath and staff, 1962.
4850(ngn)	Rb-Sr	do	550	Do.
4851(ngn)	Rb-Sr	do	517	Do.
4852(ngn)	Rb-Sr	do	529	Do.
4853(ngn)	Rb-Sr	do	458	Do.
4144(ngn)	Rb-Sr	do	535	Do.
(ngn)	isochron		535±15	

[1] Published or recalculated ages based on the following decay constants:
Rb-Sr .... $\lambda = 1.47 \times 10^{-11}$ yr^{-1}
K-Ar .... $\lambda_\beta = 4.72 \times 10^{-10}$ yr^{-1}
$\lambda_\epsilon = 0.585 \times 10^{-10}$ yr^{-1}

[2] Part of time scale according to Kulp (1961):

	Million years
Jurassic	181
Triassic	230
Permian	280
Pennsylvanian	310
Mississippian	345

[3] This is listed as being from or associated with granite intrusive into Pennsylvanian rocks and appears to be a feldspathic sandstone.

Early rubidium-strontium whole-rock determinations (table 2) are compatible with geologic evidence. The Northbridge Granite Gneiss, which is correlated with the Ponaganset Gneiss, is believed to be of early Paleozoic age. In 1968, however, Day obtained an age of 638±42 m.y. for the Hope Valley Alaskite Gneiss, the Ten Rod Granite Gneiss, and probably the Scituate Granite Gneiss of Rhode Island. This additional evidence supports a Precambrian age for the Blackstone Series. However, the rubidium-strontium method gave a Triassic age for the rhyolite flow of the Wamsutta Formation, but the Allegheny age referred to previously was of rocks that almost certainly overlie and are younger than this rhyolite. The rubidium-strontium whole-rock determination of the Westerly Granite (G–1) gives an Early Pennsylvanian age. The Westerly Granite is intrusive into Narragansett Pier Granite, which is intrusive into the Pennsylvanian rocks of the Narragansett basin. Therefore, the geological evidence gives a Late Pennsylvanian or a post-Pennsylvanian age for the Westerly Granite. The three rubidium-strontium age determinations (table 2, B–3042, B–3817A, and B–3815) on individual minerals give approximately the same age for the metamorphism of the Pennsylvanian rocks and the crystallization of the Westerly Granite; this similarity seems geologically probable.

Potassium-argon determinations appear to give ages younger than the time of formation of the rocks on which they were made, because the age given is probably the time at which both the igneous minerals and the metamorphic minerals cooled to a temperature at which the radiogenic argon was retained within these minerals. This time may have been considerably later than the crystallization of the rock.

In addition to the ages shown in table 2 is an age of 1,500 m.y. for cumberlandite by the helium method on magnetite (Hurley and Goodman, 1943). This method now appears to be unreliable.

More recent age determinations on the Quincy Granite in Massachusetts have been discussed earlier (p. 34).

GEOLOGICAL HISTORY

The earliest geologic event shown by the rocks of Rhode Island is the deposition of the Blackstone Series, probably in Precambrian time. A large part of this series is clean quartzite, quartz-mica schist, and marble. This series originated as sediments deposited in a body of water, probably marine. Interlayered with these sediments were lava flows and pyroclastic rocks. The basin of sedimentation was receiving sediment from the erosion of a landmass, and it was also receiving extrusive material from nearby volcanoes. This time of sedimentation and volcanic activity must have been very long, as the thickness of the Blackstone Series may have been 15,000 to 20,000 feet.

The other metamorphic rocks both to the west and to the east and southeast of the Narragansett Bay show a somewhat similar history, although they are not exactly the same lithologically and the present remains are not so thick. Whether they were contemporaneous with the Blackstone Series is not known.

Presumably after the deposition of the Blackstone Series came the deposition of materials forming the Cambrian(?) and Ordovician(?) rocks in the southwest part of Rhode Island. These rocks, too, resulted from the deposition of a large thickness of sediments and the extrusion of volcanic material.

All these sediments and volcanic rocks were buried to a considerable depth and were involved in tectonic activity that included regional metamorphism. It is not known whether all these rocks were involved in one episode of tectonism and metamorphism or whether different groups were affected by different tectonic-metamorphic events. The intensity of the metamorphism seems to have been less in the northeastern part of Rhode Island.

In the waning stages of the metamorphism, the intrusion of the older plutonic rocks began. Large masses of liquid or partly liquid granitic material were squeezed upward into the metamorphic rocks. This material may have been derived from melting or partial melting of the just-accumulated geosynclinal sediments and volcanic rocks, or it may have been derived from the underlying sialic crust. The intrusion continued beyond the tectonic climax, so that the syntectonic intrusive rocks that have pronounced foliation and lineation were followed by posttectonic rocks that are more nearly massive. During the development of this intrusive complex there was also some change from more mafic to less mafic rocks, but this change is not very well defined. The principal rock units included in this large intrusive sequence are the Ponaganset Gneiss, the Scituate Granite Gneiss and associates, and probably the Grant Mills Granodiorite and the Esmond Granite and associated intrusives. Again there is no good evidence concerning relations with rocks on the east side of Narragansett Bay. These intrusions probably were emplaced in middle or early Paleozoic, or, if Day's (1968) rubidium-strontium ages are correct, in Precambrian time.

These older plutonic rocks, having coarse textures, must have solidified at depth. The next recorded event in the geological history of the State is that the plutonic rocks were uncovered during a long period of erosion. This is shown by the fact that eroded boulders of the Esmond Granite are in the Spencer Hill Volcanics of the East Greenwich quadrangle.

The East Greenwich Group, which is tentatively correlated with the Quincy Granite and granite porphyry, reveals an episode of volcanic activity associated with and followed by small hypabyssal intrusions and larger plutonic intrusions. This activity may have been in the Mississippian Period, but recent radiometric ages indicate an earlier time of formation.

After the East Greenwich Group was formed, erosion again attacked the area and in time exposed the Cowesett Granite and the Quincy Granite before the beginning of sedimentation in the Pennsylvanian Period.

The sedimentation of the Pennsylvanian Period appears to have been entirely nonmarine and to have been in an area of high relief. Erosion was rapid and weathering was largely physical, so that feldspars were not completely destroyed in the weathering. Vigorous streams attacked the high surrounding areas and strewed the clastic sediments in an intermontane lowland. Some parts of the lowland were far enough away from the sediment-laden streams for quiet swamps to escape sedimentation for a time. During this time, plants grew in profusion, indicating a mild climate, and large masses of vegetation accumulated. These masses later became the beds of meta-anthracite. The clastic sedimentation continued long enough for several thousand feet of sediments to accumulate. Late in this time some of the streams must have rejuvenated, which resulted in the deposition of the coarse Dighton Conglomerate.

The Pennsylvanian sedimentation came to an end when the area was again uplifted and caught in intense tectonic action. The Narragansett basin sedimentary rocks were tightly folded, faulted, and metamorphosed. Near the south end of the present Narragansett Bay, the Narragansett Pier Granite was intruded into the Pennsylvanian rocks and also into older granitic rocks along the position of the present south shore. The Westerly Granite was intruded along a few south-dipping fractures.

A few mafic dikes were intruded after the Westerly Granite. Possibly some of the dikes and faults are Triassic.

The Cretaceous rocks of Block Island are a very small part of a considerable thickness of marine sediments deposited along the east coast of the United States in Cretaceous and Tertiary time. These sediments constitute the Coastal Plain, which is submerged in the north except for such scattered areas as Long Island, Block Island, Martha's Vineyard, and Nantucket.

Otherwise, the succeeding time has been a period of erosion, probably a period during which stream-cut valleys were drowned to form Narragansett Bay, and a period of glaciation.

Thus, the evidence in Rhode Island is in general agreement with other evidence pointing to great complexity in the formation of a mountain range and specifically to the recurrence of various types of structural and igneous activity for a long time during the development of the Appalachians. In Rhode Island, at least one and perhaps several episodes of deformation and metamorphism followed the deposition of materials of the Blackstone Series and other older metamorphic rocks, in Precambrian or early Paleozoic time. Then, at least one and perhaps more than one episode of plutonic activity formed the older plutonic rocks, in Paleozoic or possibly in Precambrian time. This period was followed by erosion and the volcanism, plutonic activity, and deformation that formed the Quincy Granite and the East Greenwich Group in Mississippian(?) or earlier time. Another period of erosion exposed these rocks, and then the materials of the Pennsylvanian rocks were deposited in great thickness. Finally, these rocks were deformed, metamorphosed, and cut by intrusive rocks in Pennsylvanian or post-Pennsylvanian time. This last activity, the "Appalachian Revolution," is better demonstrated in Rhode Island than in any other New England State. The greatest possible simplification of these events leaves a long and complex orogenic sequence in the development of this part of the Appalachian Mountain system.

ECONOMIC GEOLOGY

CARBONATE ROCKS

Carbonate rock, limestone, has been of economic use in Rhode Island since a very early date. Bishop (1861, v. 1, p. 218) stated, "The earliest mention of its [lime's] manufacture that we have seen, was in Rhode Island, where in January 1662, a Mr. Hacklet, of Providence, applied to the town for liberty to burn lime, and to take stone and wood from the commons for that purpose, which was granted him for a limited time." Evidence concerning the location of this early quarry is conflicting. Published data point to a small quarry in Manton just northwest of Providence (Quinn, 1954). On the contrary, Mr. Ed Conklin, of the Conklin Limestone Co., maintains that early deeds indicate that this earliest quarry was at Lime Rock, at the site of the present operating quarry.

Marble beds within the Blackstone Series are the carbonate rocks quarried here. The two largest beds are in the Pawtucket quadrangle, the "Harris" quarries (including the present operating Conklin quarry) at Lime Rock about 7 miles northwest of the center of Providence and the "Dexter" quarry about a mile east of the "Harris" quarry. The layer of marble at the "Harris" quarry is at least half a mile long and somewhat more than 400 feet thick. Several other marble beds are known in the Pawtucket and Providence quadrangles, but most of them are too small to be of value now and some of them have been almost worked out. Earlier use of these rocks was for mortar, plaster, and so forth, but the present use is largely agricultural. Much of this marble is dolomitic, so that it is not suitable for portland cement.

DIMENSION STONE

GRANITE

Granite has been one of the most valuable geological materials in Rhode Island. Many small quarries are scattered about the State and there are also a considerable number of large quarries. Most are now abandoned.

The Quincy Granite of the northern part of the Pawtucket quadrangle and the southern part of the Franklin quadrangle was once worked rather extensively. The quarries have been abandoned for many years.

The Esmond Granite was once quarried extensively in many quarries in the Esmond-Graniteville area near the corner of the Georgiaville, Pawtucket, North Scituate, and Providence quadrangles. A notable fact about this area is that it supplied the 12 large 3- by 22-foot monolithic columns for the Arcade building in Providence. These are reported to have been the largest granite monoliths in the world in 1828 when the Arcade was built. These quarries are also now abandoned.

The Ponaganset Gneiss, the Scituate Granite Gneiss, the Hope Valley Alaskite Gneiss, the Ten Rod Granite Gneiss, and the porphyritic granite of Newport all have been quarried at several places; most of the quadrangles west of the Narragansett basin have at least a few abandoned quarries.

Probably the most important granite quarry area in the State is the Westerly area, which still has some quarry activity (Dale, 1908, 1923; Macomber, 1958). Some of these quarries are in the Watch Hill and Ashaway quadrangles near Westerly, and some in the Carolina quadrangle near Bradford. These quarries worked either the Narragansett Pier Granite or the Westerly Granite; both rocks were taken from a few quarries. The dike form added to the difficulty of working the Westerly Granite. The quarry south of Bradford was extended back a considerable distance underneath the overlying Hope Valley Alaskite Gneiss. The fine grain and uniform composition make the Westerly Granite especially suited for statuary and monuments. The Narragansett Pier Granite ("red Westerly granite") is used more in buildings. In recent years, the waste blocks of these quarries have had large use in building breakwaters along the nearby shores. Only one quarry now is in use at Westerly and one at Bradford.

OTHER ROCKS

Only minor use for dimension stone has been made of such rocks as marble and Pennsylvanian sandstone. Very minor use has been made of soapstone in lenses of the Blackstone Series. The sandstone at Woonsocket was used for making "ten thousand dozen" whetstones in 1840 (Jackson, 1840, p. 71).

CRUSHED STONE

Crushed stone has been quarried in large amounts at several places and in such different rocks as greenstone of the Blackstone Series, Metacom Granite Gneiss, several other granites and gneisses, sandstone and conglomerate of the Narragansett basin, and cumberlandite.

METAL DEPOSITS

Rhode Island, like other New England States, has several old prospect pits and the remains of small mines. There is generally very little information about when the deposits were worked, the extent of the mining, or even what was sought. Below is a list of seven of these deposits, the first six of which have been referred to in the quadrangle reports:

- Durfee Hill gold mine, Chepachet quadrangle
- Furnace Hill iron deposits, North Scituate quadrangle
- Snake Den gold mine, North Scituate quadrangle
- Bald Hill gold mine, East Greenwich quadrangle
- Gold mine southeast of Victory Highway and Plainfield Pike, Coventry Center quadrangle
- Copper Mine Hill deposits, Pawtucket quadrangle
- Foster ("Homestrike") gold mine, half a mile northeast of Cucumber Hill, East Killingly quadrangle

In the Pawtucket quadrangle, mostly east and northeast of Sneech Pond, are several prospects and small abandoned mine holes. Jackson (1840, p. 55) wrote, "no less than fifty different ancient mine holes in this hill." The area was once known as Copper Mine Hill. These are high-temperature hydrothermal deposits, containing tremolite, diopside, garnet, quartz, magnetite, scheelite, molybdenite, pyrite, chalcopyrite, galena, sphalerite, covellite, chalcocite, and other minerals. The mining was probably for copper, although some of the work may have been for gold. Nearby are also a few small deposits of manganese silicates and oxides.

CUMBERLANDITE

The cumberlandite of Iron Mine Hill in the Franklin quadrangle has been used for iron ore and for crushed rock. It has also been considered as a possible source of titanium. It is reported to have been mixed in 1703 with iron ore from Cranston (Furnace Hill Brook limonite) and used to make cannon for the siege of Louisburg in 1745 (Johnson, 1908). The iron content is low; Warren (1908, p. 24) gives the following analysis: SiO_2, 22.35 percent; Al_3O_3, 5.26 percent; Fe_2O_3, 14.05 percent; V_2O_3, 0.18 percent; Cr_2O_3, trace; FeO, 28.84 percent; MgO, 16.10 percent; CaO, 1.17 percent; Na_2O, 0.44 percent; K_2O, 0.10 percent; H_2O, 0.42 percent; CO_2, 0.02 percent; TiO_2, 10.11 percent; P_2O_5, 0.02 percent; S, 0.38 percent; MnO, 0.43 percent; Zn, 0.71 percent; Cu, 0.08 percent; Co and Ni, 0.08 percent; Pb, trace. The average of 10 analyses gives Fe, 33.49 percent and TiO_2, 9.75 percent. The presence of titanium makes smelting difficult. The intergrowth of magnetite and ilmenite is so fine (Singewald, 1913) that separation is difficult.

Johnson (1908, p. 6) estimated the surface dimensions of this rock as 1,200 by 600 feet. With this area there would be 8 million tons of rock for 100 feet of depth, and the rock probably extends down a considerable distance. The area is probably larger beneath the cover of drift, and the body of rock is probably large enough to justify large-scale mining if an economic method of separating the iron and titanium can be found.

META-ANTHRACITE

Ashley (1915) recounted the history of mining Rhode Island coal. The earliest use recorded by him was by British soldiers in Newport in pre-Revolutionary time. One of the few extended and successful uses was in Portsmouth from 1860 to 1883 for smelting copper ore from Cuba and South America. Some of the slag can still be seen on the shore. Other mines were opened in Valley Falls, Cumberland, Bristol, Providence, and Cranston, and in Mansfield, Mass. The material from the Cranston mine, operated until 1959, was last used for foundry graphite but was earlier used for fuel. It is even reported that 250 to 300 tons a week of Rhode Island coal was shipped to Pittsburgh, Pa., in 1887 (Ashley, 1915, p. 11).

The coal beds are fairly common in parts of the Rhode Island Formation, and some are as much as 35 feet thick. Two main difficulties in the use of this material are (1) that the ash content is high in most of the coal, and (2) that metamorphism has changed much of the coal to the meta-anthracite rank, in which the volatile combustible content is too low for good use (Quinn and Glass, 1958; Toenges and others, 1948). These characteristics of the meta-anthracite, together with the general trend away from some uses of coal, make a situation very unfavorable to the use of Rhode Island coal.

QUARTZ

At Diamond Hill in the Pawtucket and Franklin quadrangles is a mass of vein quartz approximately 1,000 feet wide and a mile long. This might constitute a source of silica, but the iron content is much too high for many uses of silica. Hematite, goethite, and limonite are abundant throughout the mass of veins as stains, coatings, and botryoidal masses in vugs.

The large quartz vein on Mount Hope (described by Quinn and Springer, 1954) has some iron, but less than that at Diamond Hill. I do not know of any systematic sampling or economic study of this mass of quartz.

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