DEPARTMENT OF THE INTERIOR
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BEDROCK GEOLOGY OF THE NARRAGANSETT PIER QUADRANGLE, RHODE ISLAND

by

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BEDROCK GEOLOGY OF THE NARRAGANSETT PIER

QUADRANGLE, RHODE ISLAND

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by
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ABSTRACT

The Narragansett Pier quadrangle is at the southwestern edge of the Narragansett Basin, a dominating structural feature of the bedrock of Rhode Island. Downfolded sedimentary rocks of Pennsylvanian age are sharply contrasted with older gneisses and schists, and with late or post-Pennsylvanian intrusives, along the western border of the basin.

Pre-Pennsylvanian rocks west of Narragansett Bay consist of metasedimentary quartz-biotite schist and granite gneiss. The quartz-biotite schist is correlated with the Blackstone series of pre-Cambrian(?) age. Conformable structures of the schist with the Scituate granite gneiss indicates that the latter is a product of granitization. The relation between the time of granitization, and the metamorphism of the Pennsylvanian rocks is uncertain. The Devonian(?) or earlier age assignment for similar gneisses in the North Scituate quadrangle is accepted pending further mapping in adjacent areas and a zircon-method age determination presently being made.

The Pennsylvanian rocks of the Narragansett Basin consist of conglomerate, sandstone, phyllite, and meta-anthracite, formed in a terrestrial basin of deposition. Late Pennsylvanian or post-Pennsylvanian granite, related pegmatites, and quartz veins intersect the Narragansett Basin strata on the west side of the bay. Minette dikes may be related to the granite intrusive series.

Details of the basin structure are not well known, owing to the absence of key beds suitable for mapping and to the widespread glacial cover. Numerous folds and faults in the continuous exposures along the shores suggest a complex structure in the covered areas. Dutch Island and Conanicut Island are located on the west limb of a major syncline. A major fault is postulated parallel to the axis of Mackeral Cove.

All the rocks in the area have been deformed to some extent. An early Paleozoic metamorphism converted sediments of the Blackstone series into the present schists. A late metamorphism, associated with the Appalachian revolution, metamorphosed the Rhode Island formation to schists and phyllites of the albite-epidote amphibolite facies, and may have produced the retrograde effects in the Blackstone series. Elongate pebbles suggest that directed stress was greatest near the border of the basin. Increased metamorphic grade in the southern part of the Narragansett Basin is probably due to the greater depth of burial with subsequent higher temperature and pressure, rather than to intrusion of the granite of the Narragansett Pier.

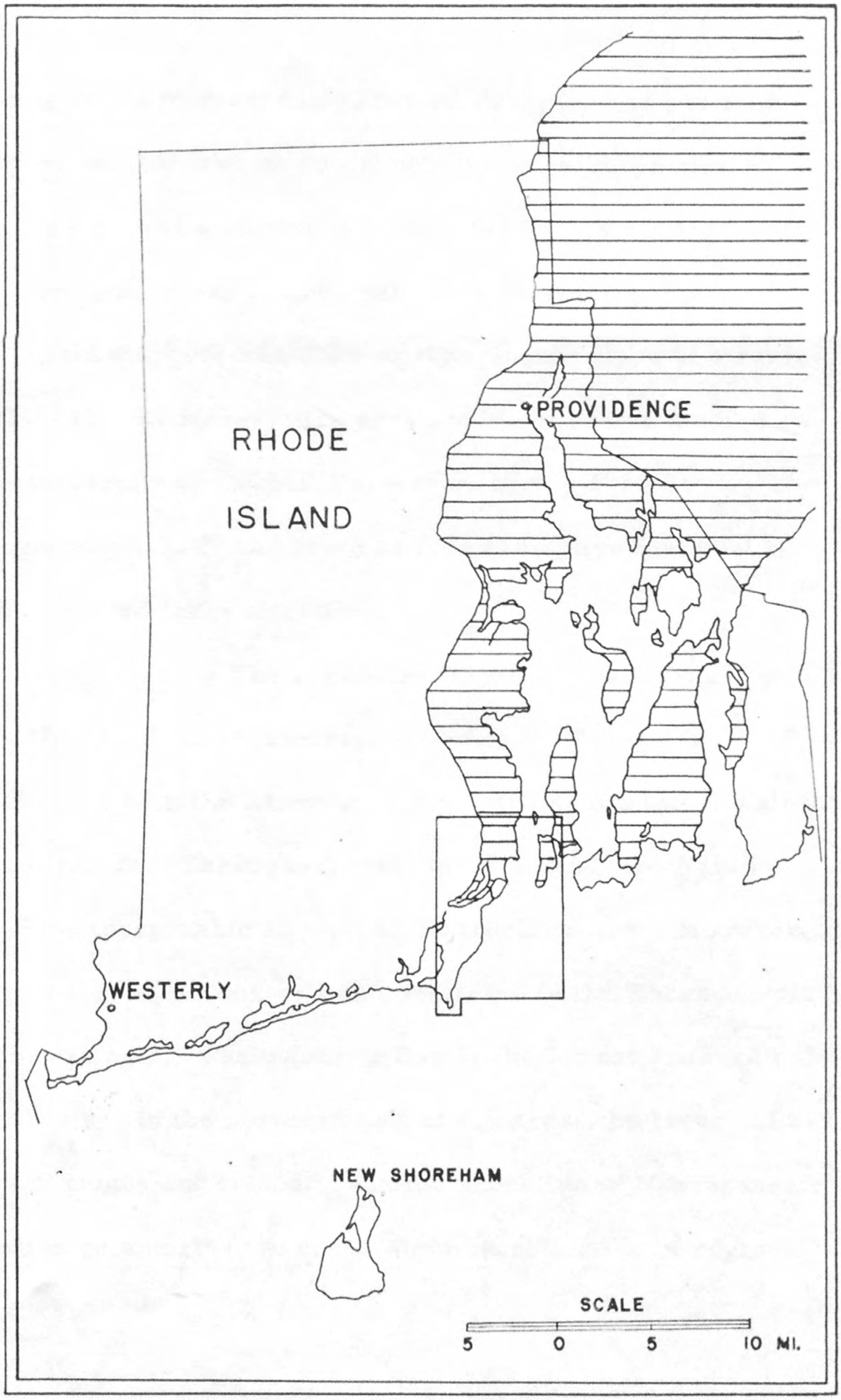
The Scituate granite gneiss and the granite of Narragansett Pier have been quarried for use in ocean piers and for local use as dimension stone. Two small graphite mines were operated many years ago. Sand and gravel deposits were being mined in 1953. Granite pegmatites represent a potential source of feldspar.

INTRODUCTION

General Statement. -- The Narragansett Pier 7 1/2 minute quadrangle is in southern Rhode Island at the entrance to Narragansett Bay (pl. 1). Narragansett Pier and Wakefield, the chief towns of the area, are about 29 miles south of Providence.

Pre-Pennsylvanian gneisses and schists which extend westward and northwestward into Connecticut, and late Pennsylvanian or post-Pennsylvanian granites and associated pegmatites underlie the western third of the area. Most of the remainder of the area is underlain by severely deformed Pennsylvanian sedimentary rocks of the Narragansett Basin (Emerson and Perry, 1907; Emerson, 1917; Shaler, Woodworth, and Foerste, 1899). The basin extends northeastward nearly to Boston Bay.

Purpose and Methods of Study. -- Eleven weeks were spent during the summer of 1953 in detailed geologic mapping of the area. This project was conducted by the U. S. Geological Survey, in cooperation with the Rhode Island Development Council, as a part of the current systematic survey of the bedrock formations, surficial features, and ground water resources of Rhode Island. It was hoped that the age relationships of certain granites and gneisses, which underlie broad areas in western Rhode Island, would be revealed by detailed



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PENNSYLVANIAN SEDIMENTS
(NARRAGANSETT BASIN)

mapping in the Narragansett Pier quadrangle, and particular attention was focused on this problem. A small portion of adjacent Newport quadrangle is included in this report for the important structural and age relations provided in that area.

Field mapping was done on topographic maps at a scale of 1:31,680. Representative rock specimens were studied microscopically at Cornell University during 1953-1954. The geologic map (pl. 2) and much of the descriptive material is being prepared for publication.

Geography. -- The area is in the Seaboard Lowland section of the New England physiographic province (Fenneman, 1938, p. 345, 370) with the Atlantic Ocean in the southeastern half of the quadrangle. Throughout most of its extent, the Narragansett Basin is a topographic as well as a structural low. However, this relationship is not well demonstrated in the Narragansett Pier quadrangle. Narragansett Bay is the lowest drowned part of the basin. In the northern half of the area, the river valleys, elongate ridges and islands, and the shoreline of Narragansett Bay all have a northward trend which is reflective of regional structure.

Glacial striae and a boulder train indicate that ice movement was almost directly south (Flint, 1945). Much of the area is veneered with a thin glacial till, and some critical phases of the geology therefore are not exposed. The east end of a terminal moraine enters the area in the vicinity of Wakefield. South of Wakefield and Narragansett Pier is a low, rather level plain underlain by a thick series of fairly coarse glacial outwash. Outcrops are numerous along most of the ridges in the northern part of the quadrangle, and are particularly abundant along the coastline, where over 12 miles of magnificent exposures may be seen.

Previous Work. -- C. T. Jackson (1840) based the first geologic map of Rhode Island on a single season of reconnaissance study. In the accompanying report he mentioned the "deep valley or gorge" (Narragansett Basin) filled with "carboniferous rocks," and gave brief accounts of the intrusive granite of Conanicut Island and of the graphite mines on Tower Hill.

Many reports between 1884 and 1897 discussed the geology of Conanicut Island and Newport Neck. Particular attention was focused on the age and origin of the granite of Conanicut Island. T. N. Dale (1884) described this "protogene mass" as a metamorphic product. Collie (1894) and Crosby (1897) regarded the granite as pre-Pennsylvanian and Pirsson (1893) regarded it as younger than phyllites of Pennsylvanian age.

Monograph 33 of the U. S. Geological Survey (Shaler, Woodworth, and Foerste, 1899) represents the most complete study of the Narragansett Basin. Consideration of intimate structures and metamorphism of the rocks was omitted, and the rocks which border the basin were not differentiated but were indicated merely as pre-Carboniferous. Shaler states that the monograph, ".... should .... be considered as a contribution only to the stratigraphical and dynamic history of the area." A geologic map of the southern part of the Narragansett Basin at a scale of approximately 2 miles per inch includes much of the Narragansett Pier quadrangle.

Lahee (1912) discussed in some detail the relations of the degree of metamorphism to geological structure and igneous intrusion in the Narragansett Basin.

Loughlin (1910, 1912) mapped all the granites and gneisses of southwestern Rhode Island as members of a single series of igneous rocks, the Sterling granite, which formed a composite batholith. This series included the granite of Narragansett Pier as well as the Scituate granite gneiss, both of which he regarded as intrusive into the deformed Pennsylvanian sedimentary rocks.

Emerson (1917), as a result of reconnaissance mapping in Rhode Island and Massachusetts, supported Loughlin's conclusions and correlated the Sterling with the Andover granite of Massachusetts. Emerson's Rhode Island study was elaborated by Hawkins (1918), who separated the Westerly granite from the Sterling, placing the former as post-Pennsylvanian and the latter as pre-Pennsylvanian.

GEOLOGIC FORMATIONS

Blackstone Series

The Blackstone series was named by Woodworth (Shaler, Woodworth, and Foerste, 1899, p. 104-109) and redefined by Quinn (Quinn, Ray, and Seymour 1949) for a series of stratified rocks of pre-Cambrian(?) age exposed in a lower part of the Blackstone Valley between Woonsocket and Pawtucket, Rhode Island. It includes mica schist, amphibole schist, chlorite schist, quartzite, greenstone, and marble.

Quartz-biotite schist (qbs)

Location and description. -- Metamorphosed sedimentary rocks of the Blackstone series are exposed in the valley of Indian Run, between Saugatucket Road and Indian Run reservoir (pl. 2). An exposure was also observed on the east side of McSparran Hill. A limited number of outcrops, all approximately along the strike of the beds, are mostly light gray, fine-to medium-grained quartz-biotite schist. The schistosity and bedding are parallel and everywhere dip southeast. A lineation of elongate minerals plunges northeast.

The schist is composed chiefly of quartz (approximately 60 percent) and biotite (20 percent) and lesser amounts of orthoclase, chlorite, and moderately to extensively sericitized andesine. Microcline is absent in many exposures but becomes increasingly abundant as the Scituate granite gneiss is approached. (See Scituate granite gneiss; origin.) Minor constituents include muscovite, hornblende, magnetite, garnet, and zircon.

Elongate laths of biotite, muscovite, magnetite, and hornblende impart foliation to the rock. Biotite laths are mostly between 0.5 mm and 1.0 mm in length. Quartz and feldspar grains are generally equidimensional and average 0.15 mm in diameter. Garnet prophyroblasts, up to 3 mm in diameter, are generally rounded, but contain inclusions of quartz which are elongate parallel to schistosity of the rock. Fractures in the garnet are noticeably perpendicular to schistosity (fig. 1).

Locally beds of hornblende-epidote schist, up to 5 inches thick, are intercalated with the quartz-biotite schist. These beds are best exposed in a large outcrop 1500 feet slightly northeast of the north end of Indian Run reservoir. Many of these beds are discontinuous, having been stretched apart into

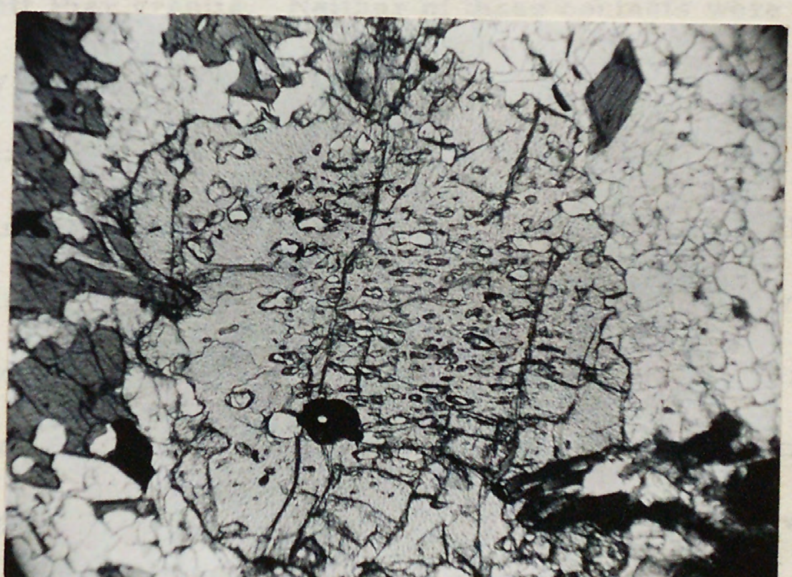

Figure 1. Relict garnet porphyroblast in quartz-biotite schist. Quartz inclusions are parallel to schistosity of the rock. Fractures are perpendicular to schistosity, and are filled with chlorite. Plane light, x43. Location, 1500 feet NNE of Indian Run reservoir.

lenticular boudinage from 1 to 3 feet long. Minor constituents of the hornblende-epidote layers are chlorite, quartz, altered andesine, zircon, rutile, and secondary calcite.

Relations to other rocks. -- The quartz-biotite schist is bounded on the east by metamorphosed sedimentary rocks of the Narragansett Basin and is cut off on the south by the younger Narragansett Pier granite. Neither of these contacts were observed directly. Apparent conformity with the Pennsylvanian rocks has led Foerste (Shaler, Woodworth, and Foerste, 1899, p. 247) and Loughlin (1910, p. 452) to map the schist exposures with the Rhode Island formation of the Narragansett Basin. However, the rocks west of Narragansett Bay are generally conglomeratic and nowhere rich in lime. On the north and west, the quartz-biotite schist grades into the younger Scituate granite gneiss, which was apparently granitized before the Pennsylvanian period.

Correlation. -- North of the area, in the North Scituate quadrangle, the Blackstone series grades into Scituate granite gneiss, and in places is intruded by a more massive variety of the gneiss (Quinn, 1951). West of the area, in eastern Connecticut, the Putnam gneiss, considered by some[1] to be equivalent to

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1. Some geologists do not agree with this correlation. H. E. Gregory, (Rice and Gregory, 1906, p. 129-140) dated the Putnam gneiss as late Carboniferous or post-Carboniferous; G. F. Loughlin (1912, p. 16) believed the northward continuation of the Putnam gneiss into Massachusetts was represented by the Bolton gneiss assigned to the Carboniferous by Emerson (1917, p. 219).

the Blackstone (Martin, 1925, p. 24; Hawkins, 1918, p. 445-446; Foye, 1949, p. 73) is definitely older than gneissic rocks (Martin, 1925, p. 14; Perhac, 1952, p. 37, 44) that are similar to the Scituate granite gneiss of the North Scituate quadrangle. Inclusions of schist and quartzite scattered in the Scituate granite gneiss in intervening areas (oral communications from G. E. Moore and W. R. Power of the U. S. Geological Survey) permit correlation of the quartz-biotite schist of the Narragansett Pier quadrangle with rocks of the Blackstone series of the North Scituate quadrangle.

Greenstone (gs)

Massive greenstone crops out discontinuously on the east shore of Conanicut Island for about half a mile north of Bull Point (pl. 2). The inland extent was approximated. The rock was studied in the field and laboratory only in sufficient detail to obtain age relations of certain rocks of the Narragansett Pier quadrangle. In this connection the greenstone is discussed in the section on the porphyritic granite.

The greenstone is dense (specific gravity about 2.95) with only a slight development of schistosity. It is very fine-grained and consists chiefly of sericite, with chlorite and fine-grained epidote giving the dark green color to the rock. Quartz and plagioclase are aggregated in small pods in the fine-grained matrix. Collie (1894, p. 204) reports that in some places the greenstone is conglomeratic, consisting of clastic, partly felsitic material, clearly of volcanic origin. On the Newport Harbor islands and on Newport Neck, all within 1 1/2 miles of Bull Point, similar pre-Carboniferous green or purple rocks contain thin layers of limestone (Shaler, Woodworth, and Foerste, 1899, p. 381).

The greenstone is provisionally correlated with rocks of the Blackstone series since the greenstones of the Blackstone series are also intercalated with limestones in the Pawtucket quadrangle (Quinn, 1949), and the greenstones of both areas were formed and metamorphosed before the intrusion of a pre-Pennsylvanian granite. Further studies in the Newport quadrangle are needed to verify this age assignment.

Age

Rocks of the Blackstone series are intruded by pre-Pennsylvanian granites and other plutonics in the Pawtucket quadrangle (Quinn, Ray, and Seymour, 1949), and are overlain unconformably by Narragansett Basin sedimentary rocks in the East Greenwich quadrangle (Quinn, 1952). A pre-Cambrian age is suggested for the series since it is more metamorphosed than the fossiliferous Lower Cambrian rocks in North Attleboro, Massachusetts (Shaler, Woodworth, and Foerste, 1899, p. 105). A peculiar ultrabasic rock (cumberlandite; Johnson, 1908), intrudes the series near the northeastern corner of Rhode Island. The age of the magnetite of this intrusive was determined as 1500 million years by the helium method (Hurley and Goodman, 1943). This would place the Blackstone series far back in the pre-Cambrian. The long interval between the formation of the Blackstone series and the deposition of Pennsylvanian sediments included folding and metamorphism of the Blackstone, intrusion of several igneous masses, and a period of erosion long enough to uncover some of the intrusives.

The reliability of the helium method is not accepted by many geologists. However, from these several evidences, it is probable that the Blackstone series is pre-Cambrian, although it could be early Paleozoic.

Porphyritic Granite (pg)

Location. -- Coarse porphyritic granite is exposed at the south end of Conanicut Island. About one-fifth is in the Narragansett Pier quadrangle, the main mass lying in adjacent Newport quadrangle. Outcrops are numerous on irregular knobs and steep cliffs of the rugged, broken landscape (fig. 2a). On the east shore of Mackeral Cove, a sharp bluff marks the contact between the granite and the easily eroded conglomerate lying to the north.

Petrography. -- In the Narragansett Pier quadrangle shearing and alteration of the granite is striking. Extensive chloritization of the feldspars gives the rock a grayish-green, massive appearance. Comparatively fresh samples were collected on the east side of the island near Bull Point where major constituents of the grayish-pink granite may be recognized in hand specimen.

Phenocrysts of moderate orange pink orthoclase, up to 2 inches across, are characteristic of the rock. Although many of the crystals are idiomorphic, irregular grain boundaries are revealed in thin section. Earlier grains of quartz, plagioclase, and chlorite are included in the phenocrysts. The chlorite inclusions are particularly abundant.

The groundmass is coarse equigranular with grains averaging 5 mm in diameter. Milky to semitransparent quartz is a major constituent, accounting for 35 percent of the rock volume. Orthoclase is also found in the groundmass, and with the phenocrysts accounts for about 32 percent of the rock. Pale yellowish-green albite (27 percent), irregular patches of dark green chlorite

Figure 2a. Typical rugged landscape produced by resistant porphyritic granite at the southwest end of Conanicut Island. In background note contrasting gentle low-lying topography across Mackeral Cove where weak phyllites are the bedrock.

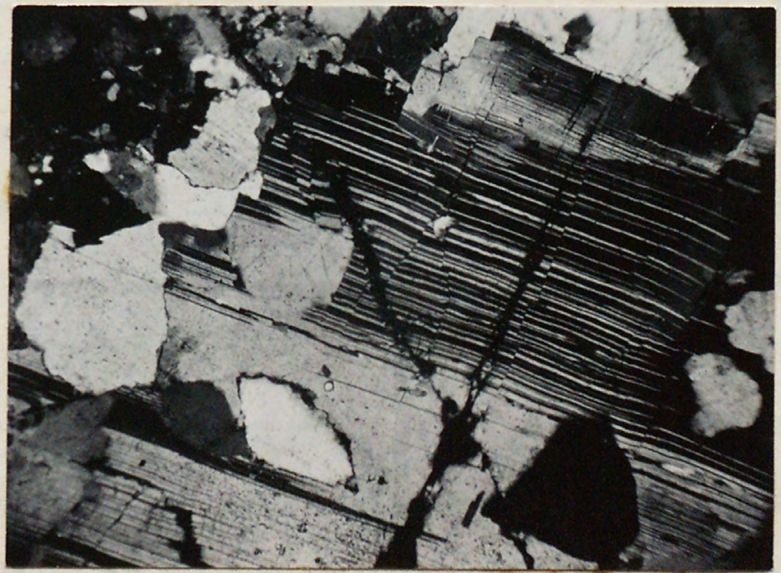

Figure 2b. Faulted feldspar grain in porphyritic granite. Feldspar is partly replaced by quartz. Epidote vein diagonally cuts across twin lamellae. Crossed nicols, x 38. Location, east side of Mackeral Cove.

(6 percent) and grayish-brown sphene (less than 1 percent) are also conspicuous in hand specimens. Small veins and flakes of limonite are disseminated throughout the rock and contribute to its altered appearance.

In thin section, extensive deformation and alteration is evident, particularly in specimens from the west side of the island. Cleavage and twinning lines of the feldspars are bent, wavy extinction is well developed in quartz, and fracturing and faulting of grains is common (fig. 2b). Veins of chlorite and limonite occupy many fractures. Chlorite is secondary. Although the original ferromagnesium mineral was not observed, Collie, (1894, p. 207) reports green biotite in sparing amounts, almost invariably altered to chlorite. The chlorite, in grains up to 2 mm in diameter, encloses stubby or rounded grains of apatite. Most of the euhedral grains of albite are extensively sericitized, rendering twin lamellae indistinct. In addition to chlorite and limonite impregnations, the plagioclase is replaced by separate grains of epidote. Anhedral quartz is commonly fractured into mosaics. It replaces the plagioclase but is veined along grain boundaries by orthoclase. Orthoclase is not as greatly altered as the plagioclase, but displays bent cleavage lines and wavy extinction. Disseminated limonite gives a dull brown tint to much of the quartz and feldspar. Sphene, commonly twinned, is the most abundant accessory mineral. Magnetite, garnet, and rutile are rare.

Age. -- On the east side of Mackeral Cove, the granite supplies boulders and pebbles to the unconformably overlying Pennsylvanian Pondville conglomerate. This clearly establishes the granite as pre-Pennsylvanian, a view adopted by Collie (1894, p. 208), Crosby (1897, p. 235-236), Foerste (Shaler, Woodworth, and Foerste, 1899, p. 233-234), and Lahee (1912, p. 251). At Bull Point the granite intrudes greenstone (see Greenstone) which has been regarded by Pirsson (1893, p. 369) and Jackson (1840, p. 91) as a thermally metamorphosed equivalent of phyllites of Pennsylvanian age. However the foregoing precludes such a possibility.

The greenstone, extending northward for half a mile beyond the granite contact, retains its massive, dark green, and somewhat flinty character throughout, showing no transition toward the lithologically dissimilar Pennsylvanian phyllites which are exposed but a few hundred feet to the north. Similarly, on the west side of the island the phyllites, which are exposed less than 600 feet north of the granite, show none of the characteristics of the greenstone. In addition, the likely existence of a belt of arkose between the greenstone and phyllite (see Pondville conglomerate) eliminates the possibility of a gradation between these two formations.

Intrusive contact. -- The intrusive granite contact is well exposed at Bull Point where the granite and greenstone are firmly welded together along a rather irregular but nearly vertical contact of knife-edge sharpness. The granite is finer grained at the contact and contains a few inclusions of greenstone. Pink aplites, extending perpendicular to the contact, cut the greenstone as narrow dikes.

The field occurrence of the porphyritic granite is limited to Conanicut Island and Newport Neck to the southeast (Jackson, 1840, p. 90; Crosby, 1897, p. 231, 232; Shaler, Woodworth, and Foerste, 1899, p. 316), and it resembles no other granite in Rhode Island. Its age relation to the Scituate granite gneiss is unknown, but the extensive mechanical deformation in the porphyritic granite as compared with that in the granite gneiss, suggests that the Scituate granite gneiss is younger.

Scituate Granite Gneiss (sga, sgal)

The Scituate granite gneiss was named by Quinn (1951) for extensive exposures of medium- to coarse-grained, gray to pink gneiss in the North Scituate quadrangle. It was formerly included with other gneisses and granites in the Sterling granite of late Carboniferous or post-Carboniferous age (Rice and Gregory, 1906, p. 134; Emerson, 1917, p. 229; Loughlin, 1910, p. 247). Two distinct facies of the Scituate granite gneiss are exposed in the Narragansett Pier quadrangle.

It is difficult to place the boundaries between the Scituate granite gneiss and quartz-biotite schist of the Blackstone series. The contact is gradational over a distance of 500 to 1000 feet as estimated from limited exposures.

Augen gneiss (sga)

Augen gneiss underlies approximately 5 square miles in the northwest corner of the quadrangle. Fresh exposures of the light gray rock are provided in the quarry 0.5 miles southwest of Mooresfield and in several small pits 0.35 miles northwest of Indian Run reservoir. Elsewhere outcrops are extremely scarce. Prominent foliation in the gneiss near Peace Dale trends northeast and near Mooresfield trends northwest. Foliation is conformable with that in the quartz-biotite schist of pre-Cambrian(?) age.

Petrography.-- The rock is medium- to coarse-grained and highly gneissoid, with biotite abundant along the planes of foliation (fig. 3e). Mafic schlieren are drawn out in the plane of foliation and appear as dark shadows on the otherwise light colored surface. Augen of pink microcline are drawn out between the layers of biotite. Biotite, microcline, quartz, oligoclase, magnetite, and garnet, and occasionally pyrite are visible to the unaided eye.

Most of the augen are aggregates of microcline, although true metacrysts also occur. The augen average 1 to 2 cm long and seldom exceed 2.5 cm, and the length is generally about three times the width. Crystal borders are irregular and groundmass inclusions are oriented with the foliation of the rock (fig. 3f). This attests to a late growth of the microcline. A slight bending of biotite flakes around the augen indicates some forceful growth of microcline.

Smoky to glassy quartz is a major constituent (40-50 percent), considerably in excess of the amount found in many granites. The quartz content of the augen gneiss recorded in other areas ranges from 25 percent (Loughlin, 1912, p. 121) to 60 percent (Perhac, 1952, p. 16). The quartz is slightly elongate in the plane of foliation. Fracturing is present but not abundant and undulatory extinction is common. Quartz crystallization began early and continued during and after the crystallization of plagioclase and microcline.

Potash feldspar comprises about 28 percent of the rock; this is mostly microcline although microperthite is also present. Microcline, in addition to forming the augen, is an integral part of the groundmass. In both occurrences the microcline has the same origin and age relations. All of the microcline crystals are notably free of deformation effects; hence the lenticular augen probably do not owe their existence to shearing. Oriented inclusions of quartz, plagioclase, and muscovite are common.

Grayish- to yellowish-white oligoclase comprises about 22 percent of the rock. The grains are somewhat altered to sericite. Biotite (7 percent) is early and is replaced to some extent by younger minerals. Minor constituents include magnetite (some crystals 1 mm or more in diameter), garnet, muscovite, chlorite, zircon, apatite, and yttrian sphene (keilhauite; Young, 1938, p. 149-152). Zircon grains vary in shape from euhedral to anhedral; the latter at least are earlier than the feldspar. The amber sphene was recognized in heavy mineral separates by its low index of refraction (Nx = 1.85) and a rather large optic angle (approximately 40 degrees).

Alaskite gneiss (sgal)

Exposures of alaskite gneiss are numerous on the ridge east and northeast of Hazard reservoir. Fresh exposures are provided in road cuts along Route R.I. IA. The contact with augen gneiss is buried beneath swamps and glacial cover in the lowland around Hazard Reservoir. Foliation of the alaskite gneiss is parallel with that in the Pennsylvanian strata to the east, the augen gneiss to the west, and the quartz-biotite schist in the valley of Indian Run.

Petrography. -- The alaskite gneiss (fig. 3g) is medium- to coarse-grained, grayish-pink, and differs from the augen gneiss chiefly in degree of foliation, in texture, and in amount of biotite.

The alaskite gneiss is practically free of mafic minerals. A moderately to poorly developed foliation is produced by alternating quartz-rich and feldspar-rich layers. Quartz grains are rod-like, producing a lineation in the plane of foliation. Biotite flakes are oriented in the plane of foliation. The pink microcline crystals have a more uniform distribution than in the augen gneiss, although a tendency toward aggregation (fig. 3h) results in a texture somewhat similar to the augen gneiss. In western Rhode Island Perhac (1952, p. 45) finds the alaskite grading insensibly into the augen gneiss. The mineral assemblage is similar with that of the augen gneiss. In the alaskite, quartz, microcline, and albite are the major constituents. Biotite (0-2 percent) is much less abundant than in the augen gneiss and the muscovite content is increased up to 6 percent. Accessories are the same as in the augen gneiss.

Origin

The structure of the Scituate granite gneiss seems to be inherited from the older schists of the Blackstone series. The structures of augen and alaskite gneiss, that is, strikes, dips, and lineation, are perfectly conformable with those of the quartz-biotite schist. Mafic schlieren drawn out in the plane of foliation of the gneiss probably represent unreplaced remnants of the schist. No evidence was seen of forceful emplacement by a liquid magma.

Figure 3. GRANITIZATION

Figures 3a, 3b. Slightly feldspathized quartz-biotite schist.

Figures 3c, 3d. Schist (altered) from transition zone between quartz-biotite schist and alaskite gneiss. Note rod-like development of smoky quartz in the hand specimen.

Figures 3e, 3f. Augen gneiss; photomicrograph shows prominent microcline augen.

Figures 3g, 3h. Alaskite gneiss; photomicrograph illustrates tendency of aggregation of microcline crystals.

M - microcline; B - biotite; Q - quartz; P - plagioclase

Figure 3a.

Figure 3b.

Figure 3c.

Figure 3d

Figure 3e

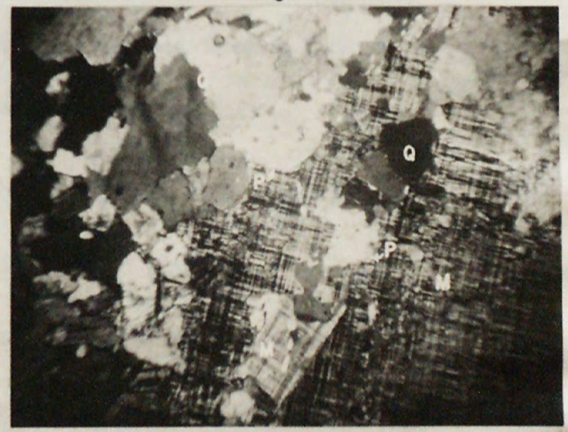

Figure 3f

Figure 3g

Figure 3h

Photomicrographs 1 mm.
Hand specimens approximately actual size

FIGURE 3. GRANITIZATION

Petrographic data support structural observations. Major changes, in passing from schist to gneiss, are the increase of potash feldspar, decrease of biotite, and general increase of grain size (fig. 3). Foliation becomes less prominent due to the decrease in amount of biotite. Potash feldspar increases from 5 percent in the schist to as much as 46 percent in the gneiss. Biotite decreases from approximately 20 percent in the schist to 7 percent in the augen gneiss and to none in some of the alaskite gneiss. Quartz grains in the quartz-biotite schist are equidimensional and average 0.15 mm in diameter. Grains are elongate in the gneiss and average 3 mm in diameter, though grains up to 6 mm long are not uncommon. The grain size in the transition rock is intermediate and pencils of quartz have started to develop. Biotite laths, which average 0.5 to 1 mm in length in the schist, are generally less than 0.5 mm in length in the gneiss.

The conversion of quartz-biotite schist to granite gneiss involves feldspathization and increase in grain size. Many of the constituents of the gneiss were present in the quartz-biotite schist. In the absence of chemical analyses, percent potash was calculated from modal andyses. These reveal about 2 to 3 times as much potash in the gneisses as in the schist (percent potash in quartz-biotite schist - approximately3 percent; in augen gneiss - 5 percent;

in alaskite gneiss - 8 percent). The granitization involved not only reconstitution of the quartz-biotite schist, but also an addition of potash.

The difference between augen gneiss and alaskite gneiss is mainly textural; also biotite is more abundant in the augen gneiss. The writer is not able to explain these differences. Both types include schlieren of quartz-biotite schist and apparently replace that type rock. It has been postulated (Perhac, 1952, p. 37-44) that the augen gneiss represents replacement of quartz-biotite schist, and alaskite gneiss represents replacement of quartzite.

Evidence in other areas. -- Much of the evidence in other areas supports this thesis of replacement origin. Perhac (1952, p 37-46) describes a granitization origin for similar augen and alaskite gneisses, in western Rhode Island and eastern Connecticut, on much the same grounds as described above. W. R. Power (1953, oral communication) also believes that the gneisses in the Slocum quadrangle, immediately northwest of the Narragansett Pier quadrangle, are of replacement origin. Quinn (1951), in describing the Scituate granite gneiss, states that "... over much of the area... the structure may have been inherited from an older schist or quartzite" since "... the bedding and schistosity of the quartzite.. extend into the foliation of the gneiss without any change of direction." Foye (1949, p. 60) in describing the augen variety, states that "The porphyritic texture of much of the Sterling orthogneiss appears to be due to the growth of microcline feldspar crystals along the foliation planes of the ancient schist (Putnam series). Hence the porphyritic gneiss is not a purely igneous rock but a hybrid produced by the recrystallization of schists under the influence of the Sterling granite magma."

A magmatic origin of the same rocks has been advocated by other geologists. Loughlin (1912, p. 35-38) considers most of the Sterling granites as intrusive sheets or batholithic bodies. However he (1912, p. 45) notes the gradation of the porphyritic rock (augen gneiss) into schists, and the presence of minor contortions in the gneiss identical with those in the sedimentary rocks. Gregory (1911, p. 23) believes the gneisses are of igneous origin. Dale (1908, p. 190) thinks the gneisses were originally granites and have received their present structures by shearing. With regard to the Stonington region of Connecticut, Martin (1925, p. 33) states, "... the Sterling granites... are not true gneisses. They are gneissoid, or 'flow granites,' the orientation and banding of the constituents being a primary and not a secondary structure." However, Martin (1925, p. 14-15) also states, "...granite injection is very marked (near the border of the schist area) and has much changed the original character of the rock (Putnam schists)..." and "...Feldspathic beds are an important component of the series at some localities. Some of them most probably are recrystallized arkose deposits, but others are highly granitized schists ... granitization of the schists is a rather common phenomenon in this region, making it difficult to say ... whether certain rocks should be considered sedimentary or igneous." Although Quinn (1951) admits a metasomatic origin for some of the rocks in the North Scituate quadrangle, he states, "most of the Scituate granite gneiss that underlies a large part of the quadrangle is marked by a schistosity that probably is due to magmatic flowage." He also reports that a massive variety of the Scituate granite gneiss is intrusive as small dikes and sills into schist and quartzite beds of the Blackstone series.

Correlation

The correlation of gneisses in the Narragansett Pier quadrangle with those in the North Scituate quadrangle is based on similar lithology (substantiated by field visits by W. R. Power, G. E. Moore, and A. W. Quinn who have mapped the Scituate granite gneiss in other quadrangles), and on the presence of yttrian sphene in both areas. Continuity of structures may be revealed by mapping the intervening areas.

Age

Discussion of age of the Scituate granite gneiss in the Narragansett Pier quadrangle refers to the time of granitization.

The age of the Scituate granite gneiss has been a major problem in Rhode Island and Connecticut geology. In this respect the Narragansett Pier quadrangle has been of considerable importance since both the Scituate granite gneiss and sedimentary rocks of the Pennsylvanian period are exposed here. Many geologists have drawn conclusions as to the relative ages from evidence provided in this area. Loughlin (1910, p. 447) argued that all the granites in southeastern Connecticut and southwestern Rhode Island are parts of one composite batholith (Sterling), a granite of which intrudes Pennsylvanian strata south of Wesquage beach. However, this correlation appears to be incorrect, inasmuch as the area mapped as Sterling granite is composed of granites, gneisses, and migmatites of different ages. Of these, only the later granites that are intrusive into the gneissic types (Kemp, 1899, p. 370; Martin, 1925, p. 36) are similar to the post-Pennsylvanian intrusives along the shore of Narragansett Bay.

Unfortunately the contact between the Scituate granite gneiss and the Rhode Island formation was not observed, but other evidence is as follows:

1. Structures in the gneiss are generally conformable with those in the adjacent Rhode Island formation. This includes both strike of foliation and strike and direction of dip of lineation.

2. Pennsylvanian sedimentary rocks on the hillside southwest of Bridgetown have been severely deformed: a) elongate quartzite pebbles indicate extreme stretching (some pebbles are 8 inches by 0.6 inches by 1 inch); b) meta-anthracite beds are brecciated and slickensided, and brecciated graphite boulders are strewn about the hillside.

   The gneisses, exposed no more than 0.45 miles away from any of these occurrences does not show granulation or effects of shearing commensurate with this amount of deformation.

3. Quartzite pebbles of unknown origin are abundant in the sedimentary rocks, whereas no pebbles of Scituate granite gneiss were found.

The evidence may be interpreted in favor of either of these conclusions:

1. The gneissic structures were developed before the Pennsylvanian sediments were deposited. Conformity of structures is fortuitous. Granulation and shearing effects are absent in the gneiss since it served as a resistant strut that transmitted the deforming forces, and the major yielding was in the less competent sedimentary rocks. Pebbles of the Scituate granite gneiss may be present but have not been observed, or pebbles may be absent due to conditions of sedimentation or to a fault contact.

2. Granitization that produced the gneiss took place during the metamorphism that affected sedimentary rocks of the Narragansett Basin (during the Appalachian revolution). This would explain conformity, lack of shearing, and lack of gneissic pebbles.

The facts available are probably more in favor of the second conclusion - a late or post-Pennsylvanian age for the granitization, although no definite conclusions can be drawn.

In the North Scituate quadrangle (Quinn, 1951), the Esmond granite (Devonian? or earlier) intrudes a part of the Scituate granite gneiss regarded as magmatic. In this area and in the Narragansett Pier quadrangle, similar gneisses of granitization origin were probably developed at the same time as the intrusive granite, and hence must be Devonian(?) or earlier. This age determination is accepted for the gneisses in the Narragansett Pier quadrangle pending further mapping in the Wickford quadrangle and a zircon-method age determination presently being made by the U. S. Geological Survey. Since the zircon was probably inherited from the Blackstone series, the determination may show the age of an igneous rock from which the Blackstone series was derived. Determination on zircon from the magmatic gneiss in the North Scituate quadrangle will be more reliable.

Pennsylvanian Series

Much of the Narragansett Pier quadrangle is underlain by sedimentary rocks of Pennsylvanian age, which have been divided into the Pondville conglomerate and the Rhode Island formation (Emerson, 1917, p. 54-55).

Pondville conglomerate (Pp)

The Pondville conglomerate was named by Shaler (Shaler, Woodworth and Foerste, 1899, p. 134-135) for basal Carboniferous arkose beds exposed at Pondville in the Norfolk County Basin of

Massachusetts. Essentially similar products of decayed granitic land surface are found as basal beds in many parts of the Narragansett Basin, and such beds are named Pondville conglomerate because of their lithologic character and stratigraphic position. The thickness is variable owing to folding or faulting, or to the topographic irregularity of the floor on which the Pennsylvanian sediments were deposited.

Distribution. -- Bluish-gray arkosic conglomerate, with a thickness of at least 300 feet, is exposed on the east shore of Mackeral Cove in contact with the porphyritic granite of Conanicut Island. Conglomerate boulders distributed northward along the shore indicate that the bed may be 500 or more feet thick. Crosby (1897, p. 235) reports an abundance of the same dark conglomerate boulders on the east side of the island separating the nearest outcrops of greenstone and Pennsylvanian phyllite, and estimates a thickness of 400 feet for the arkose on the east shore. Collie (1894, p. 208) states, "the outcrop of arkose at the shore (of Mackeral Cove) is not a local exposure. It is everywhere present, lying between the granite and the overlying schist (phyllite). Well diggers state that in all parts of the island they invariably come upon a layer of 'rotten granite' before the hard granite is reached." Foerste (Shaler, Woodworth, and Foerste, 1899, p. 308) describes Carboniferous arkose on Rose Island east of Conanicut Island. From these several lines of evidence, it seems probable that the conglomerate extends across Conanicut Island as a continuous bed with an outcrop width of about 400 feet. On the west side of Narragansett Bay no outcrops of the conglomerate are known south from Natick (Quinn, 1952) which is about 15 miles north of the Narragansett Pier quadrangle.

At the contact with the porphyritic granite the basal beds are chiefly coarse conglomerate, composed of large pebbles and boulders clearly derived from the adjacent granite, with intercalated lenses of cross-bedded gray sandstone. Boulders of conglomeratic material give way abruptly to green phyllites of Pennsylvanian age at a small stream entering Mackeral Cove. Since no gradation exists between the two rock types, a fault contact is suspected.

Lithology. -- Conglomerate boulders near the contact with the porphyritic granite are composed of detritus derived from the granite and are cemented by sericitic material derived from the alteration of feldspar of the granite. Half inch orthoclase grains, which form prominent phenocrysts in the granite, are abundant near the contact. Further north the conglomerate boulders are composed chiefly of bluish, semi-transparent quartz with occasional grains up to one-half inch in diameter. The rounded shapes of these grains indicate transport as separate grains. The feldspar is mostly altered to sericite. Small irregular grains of leucoxene are disseminated throughout the sericitic groundmass and more grains 1 mm in length are pseudomorphic after sphene, the predominant accessory of the nearby porphyritic granite. Muscovite and epidote are minor constituents.

The rock is highly deformed. The quartz grains are extensively fractured and peripheral granulation is common. Some irregular, granulated zones have developed in grain interiors.

Age. -- No fossils were found in the conglomerate, but the rock is considered basal Pennsylvanian because of its lithologic and stratigraphic similarity with other basal arkoses of the Narragansett Basin. The interbedded gray sandstone resembles no other rock in Rhode Island so closely as the sandstone of the Rhode Island formation.

Rhode Island formation (IPris, IPrip)

The Rhode Island formation, which is the thickest and most widespread formation of the Narragansett Basin (Emerson, 1917, p. 54), underlies much of the Narragansett Pier quadrangle. Exposures are numerous on the shorelines of the islands and mainland, but are sparse inland. In its unmetamorphosed state, the Rhode Island formation consists of conglomerate, sandstone, shale, and some beds of coal. The rocks appear to have been formed in a terrestrial basin of deposition, as indicated by the rapid change of texture - both along and across the strike, the abundant cross bedding, the many fossils of land plants (Knox, 1944; Lesquereux, 1899), and the absence of anything marine. Conglomerate beds are found across much of the basin and indicate shallow water during deposition. The considerable thickness of the Rhode Island formation indicates that the basin must have downfolded during sedimentation.

Foerste (Shaler, Woodworth, and Foerste, 1899, p. 331-364) subdivided the Rhode Island formation into the Kingstown series, representing the Pennsylvanian rocks on the west side of the bay and on Dutch Island, and the Aquidneck shales, for the fine-grained sedimentary rocks underlying much of Conanicut Island. Separate mapping of these two distinct units seems desirable, and they are here represented (pl. 2) as (1). sandstone and conglomerate (IPris), and (2). phyllite (IPrip). A gradational contact between the two passes across Fox Hill.

Sandstone and conglomerate (IPris). -- From the present data, it is impossible to separate the Pennsylvanian strata west of Narragansett Bay and on Dutch Island into divisions of geological value. Shoreline exposures and a few inland exposures indicate that they consist of frequent alternations of sandstones, conglomerates, muscovite schists, and a few beds of meta-anthracite. All of these rocks have been metamorphosed and have a schistose structure. Bedding and schistosity are parallel or nearly so in all exposures.

Sandstone.-- The sandstones are generally light gray, coarse grained (0.5-1.5 mm), and are rather glossy due to the abundant development of muscovite. The thickness of the sandy layers varies from 2 to 12 feet in shoreline exposures. Cross bedding is common. The texture is no longer clastic, owing to the recrystallization of quartz grains and the presence of metamorphic muscovite, but is rather a metamorphic texture with an alignment of muscovite laths interstitial to and intersecting irregular, elongate quartz grains. Minor constituents of the sandstones are biotite, plagioclase, garnet, chlorite, zircon, and graphite. Microcline was found only in a sample taken south of Saugatucket Road and just east of Indian Run. Microcline is the predominant feldspar of the nearby Scituate granite gneiss, which may have been the source of the microcline in the sedimentary rocks.

Conglomerate.-- Interbedded with the sandstones are coarse quartzite conglomerates with pebbles as large as 1 by 8 inches. These beds are exposed on the ridge southwest of Bridgetown, along the southeast and south sides of Tower Hill, on the east side of Dutch Island, and on Fox Hill at the northern end of Beaver Neck. Along the west shore of the bay, the pebbles have been smeared out into ghosts, and are hardly recognizable as pebbles. The matrix is extremely fine grained and is composed of sericite and chlorite, with minor amounts of biotite, graphite, and apatite. The pebbles have been stretched into spindle-shaped or disc-shaped forms (figs. 12a, 12b).

The source of the quartzite pebbles is unknown. C. D. Walcott (1898, p. 327), after a study of Upper Cambrian or Lower Ordovician brachiopods in the quartzite pebbles from the Narragansett Basin, suggests derivation of the fragments from an area of erosion in the vicinity of Newfoundland, and subsequent glacial transportation.

Muscovite schist. -- Coarse muscovite schist is exposed in several places along the ridge west of Pettaquamscutt River. Poor exposures prevent determination of thickness of the schistose section and its relation with other rocks. Fine-grained quartz is present in varying amounts and garnet metacrysts are commonly developed. The schists represent shaly layers in the original sediments, in some exposures only 600 feet from the present border of the basin.

Meta-anthracite. -- Thin seams of meta-anthracite are exposed in 2 small mines west of Pettaquamscutt River. They are stratigraphically above the muscovite schist just described. The beds are extremely graphitic, and are extensively slickensided and brecciated.

Thickness. -- Foerste (Shaler, Woodworth, and Foerste, 1899, p. 334-339) estimated a thickness of approximately 11,500 feet for the Pennsylvanian strata west of Fox Hill. This estimate includes the exposures west of Indian Run which are here mapped (pl. 2) as pre-Cambrian(?). The widely varying dips in observed outcrops, the broad areas covered by water or glacial deposits, and the presence of a broad fold west of Jamestown bridge and 2 miles north of the Narragansett Pier quadrangle, indicate the impossibility of estimating the thickness even approximately.

Phyllite (Prip). -- Soft, fissile phyllites constitute the principal formation of Conanicut Island. Eastward dips indicate that these rocks overlie the sandstone and conglomerate series to the west. The phyllites comprise a considerable thickness of the Rhode Island formation. They are far more uniform in texture and in composition than the underlying rocks.

General features. -- The phyllites range in color from black to light gray or grayish-green and have a silvery luster along cleavage surfaces. Schistosity is so well developed that it commonly obliterates the bedding, and renders accurate observations impossible. In fact bedding cannot be observed in many parts of the island. In its best exposures, the bedding has a ribbon-like appearance (fig. 4a). These exposures are limited, but are numerous enough to indicate that the beds on Beaver Neck and on the east side of Mackeral Cove have a general easterly dip with only local overturning. The schistosity is usually at an angle to bedding and dips west in most exposures. From many small folds, it is clear that the schistosity is axial plane cleavage (fig. 11b). Wave erosion of the shorelines has been directed by cleavage.

Description. -- The phyllites are of two principal kinds - a light gray or greenish-gray phyllite with a bright micaceous luster, and a black phyllite with large amounts of graphite. The structures of the two are similar, the chief difference being in the amount of carbonaceous matter. The two alternate in bands as narrow as one-half inch. The light greenish-gray or silvery phyllites are the predominant types in the Narragansett Pier quadrangle. Grains of pyrite and almandite, mostly less than 2.5 mm in diameter, are scattered throughout much of the formation. The grains have altered to limonite and give the rock a speckled appearance. The phyllites usually have smooth, shiny, cleavage surfaces, but minor crenulations are developed in some areas (fig. 4b), where they give a lineation to the rock.

The phyllites are composed principally of sericite, chlorite, and fine-grained quartz. Minor constituents include biotite, magnetite, ilmenite and its decomposition product leucoxene, graphite, epidote, muscovite, apatite, albite, chloritoid, rutile, and hematite.

Figure 4a. Ribbon-like phyllites on Conanicut Island. Overturning is indicated by bedding dipping more steeply than axial plane cleavage. Scale given by 1 man rubber raft. Location, west side of Beaver Neck.

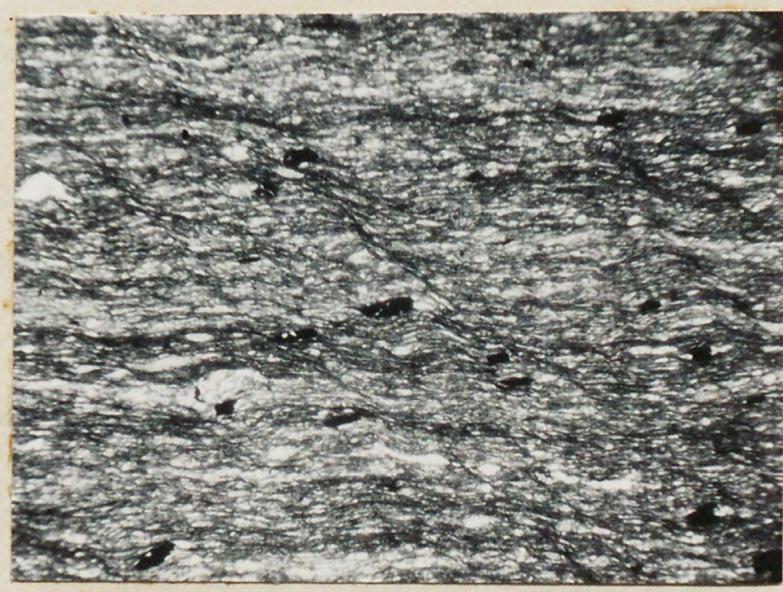

Figure 4b. Crenulated phyllite; minor folds are at angle to schistosity; rock composed chiefly of sericite, chlorite, and fine-grained quartz. Dark grains are leucoxene. Crossed nicols, x 28. Location, Fox Hill.

Alignment of irregular grains of sericite, chlorite, magnetite, ilmenite, and quartz, produces the excellent cleavage. This alignment shows no relation to bedding except where bedding and schistosity happen to be parallel. Lenticular augen in the light phyllite are made of coarser sericite than that of the groundmass. The augen may represent original larger grains of feldspar which have been altered to sericite.

Quartz grains may be aggregated in lenticular streaks parallel to schistosity. Small grains are also preserved in the protective shadows of garnet porphyroblasts. Veins of quartz are conspicuous along the axes of minor crenulations. In places, lenticles of chlorite, consisting of one or more flakes, are parallel to the schistosity whereas the flakes comprising the lenticles are commonly set transversely to schistosity. Graphite is particularly abundant in these rocks as irregular patches or fine disseminations between the micaceous minerals.

Thickness. -- Assuming an average eastward dip of 45 degrees, the phyllite series on Beaver Neck has a maximum thickness of 2800 feet. However local tight folding and possible faulting may substantially reduce this figure. Since the bedding on the east side of Mackeral Cove is exposed only along the shore, no estimate can be given for the main part of Conanicut Island.

Origin. -- The phyllites are of fresh water origin, but unlike the underlying rocks, they represent quiescent conditions of deposition. The phyllites may be traced northward into horizons bearing ferns and other land plants (Shaler, Woodworth, and Foerste, 1899, p. 231). The banded character of these rocks also suggests deposition in a terrestial basin of deposition.

Relations to other rocks. -- The phyllites overlie the sandstone and conglomerate series to the west. They generally dip eastward toward Mackeral Cove and the older granite of Conanicut Island. To account for this condition, a steep fault is postulated parallel to the axis of Mackeral Cove. A northeastward continuation of this same fault is postulated to explain the lack of gradation between the phyllites and the Pondville conglomerate.

Age. -- Plant fossils from several places in the Narragansett Basin are the basis for assignment to the Pennsylvanian period (Knox, 1944; Lesquereux, 1889). Knox (1944, p. 130) believes that the age of the flora of the contemporaneous Wamsutta formation is probably lower Alleghany.

Granite of Narragansett Pier (npg)

Name. -- A granite underlies broad areas in the southern half of the quadrangle which is typically exposed along the shore south of Narragansett Pier. In a manuscript in preparation for publication, the name Narragansett Pier will be proposed as a formal name for this granite. It was formerly included with the Sterling granite by many geologists (see Scituate granite gneiss). Since it intrudes folded Pennsylvanian strata, it served to date a considerable variety of granites, gneisses, and migmatites in western Rhode Island and eastern Connecticut, including the Scituate granite gneiss. However, the granite is also intrusive into the gneissic types, many of which are now considered pre-Pennsylvanian.

Distribution. -- Outcrops are numerous on Boston Neck, Little Neck, and on the low bluffs along the southwest side of Pettaquamscutt Cove. Outcrops are lacking on the southwest end of Tower Hill and the contact is inferred. South of Narragansett Pier exposures are almost wholly confined to the coastline. Drill holes 1 1/2 miles north of Point Judith strike reddish, broken and badly decayed "binary granite" below glacial outwash as much as 95 feet thick (U. S. Army Corps of Engineers, 1940).

Petrography. -- The normal granite is reddish, medium- to coarse-grained with rather inconspicuous linear and occasional planar structure. The texture is extremely variable with irregular patches of pegmatitic and aplitic material dispersed through the medium-grained granite. Sharply defined pegmatite and aplite dikes, numerous schist inclusions, and irregularly spaced joints further dissect the granite.

Mineral composition was determined by at least 1700 point counts on each of seven specimens. The rock varies from granite to quartz monzonite. The main constituents include pink orthoclase and microcline (26-34 percent), oligoclase (31-36 percent), quartz (24-34 percent), and biotite (1-6 percent). Minor constituents and accessories include muscovite, magnetite, pyrite, and spessartite garnet.

The texture is xenomorphic granular. Biotite and plagioclase formed early and are partially replaced. The greenish-white oligoclase crystals are zoned with outer rims slightly more sodic than the commonly sericitized interiors. Vermicular and in places graphic intergrowths of quartz in oligoclase are common. Of the potassium feldspars orthoclase predominates. Carlsbad twinning is displayed in both orthoclase and microcline. Quartz is smoky to glassy and is somewhat elongate. Disseminated pyrite, partly altered to limonite, and euhedral crystals of zircon are common accessories.

Schist inclusions are abundant and some are sharply rotated. Biotite in the granite is in greater concentration near the schist inclusions and gneissic structure is developed parallel to the contacts of the inclusions. The granite is commonly pegmatitic and seldom fine-grained at the contact.

North of Narragansett Pier, a border phase of the red granite is light yellowish gray. However outcrops are insufficient to delimit this border phase. The minerals, textural relations, and paragenesis are identical with the normal granite although mineral proportions vary considerably. Significant changes are the increase in potash feldspar (40 percent) which is here creamy white as in the associated pegmatites to the north; increase in the yellowish-green muscovite (up to 10 percent), and in garnet (up to 3 percent); and the decrease in oligoclase (15-26 percent), and in biotite (in many outcrops entirely absent).

Origin. -- The granite is of magmatic origin. Schist inclusions are sharply rotated, and at the few granite-schist contacts observed, there is evidence of forceful emplacement (fig. 6). The fact that associated pegmatites displace and buckle the country rock lends support to the theory of magmatic origin for the granite. Plagioclase is zoned more sodic outward, as expected in a granite crystallized from a liquid.

The granite intruded Pennsylvanian sedimentary rocks during a late stage of their folding. Schist inclusions are identical with the country rock and were metamorphosed before intrusion. In a single outcrop at the south end of Tower Hill, extremely elongate pebbles in the sedimentary rocks are within inches of massive granite sills which show only slight crushing. The granite

Figure 5. Sills of granite (G) intrusive into Pennsylvanian schists. Note cross-cutting granite dike, and matching walls. Granite here is massive whereas pebbles in schist are elongate. Location, south end of Tower Hill.

Figure 6. Converging granite tongues (G) have forced Pennsylvanian schists apart, causing local folding in the schistosity. Location, south end of Tower Hill.

has been somewhat deformed in most localities. Twin lamellae of plagioclase are commonly bent, and much of the quartz shows undulatory extinction. Foliation and lineation are feeble.

In speaking of the red granite exposed at Westerly, Rhode Island, Martin (1925, p. 39) states, "The rock exposed at Narragansett Pier is indistinguishable from the Redstone both megascopically and microscopically, except that in places it is more pegmatitic and carries more muscovite." The writer wholeheartedly agrees after comparing specimens from Narragansett Pier and the Redstone quarry northeast of Westerly. This correlation permits the dating of the Westerly "Redstone" as late or post-Pennsylvanian. A porphyritic olivine diabase dike which cuts the granite of the Westerly Redstone quarry is regarded as Triassic by Dale (1908, p. 201).

Pegmatite (p)

Distribution. -- Granite pegmatites related to the granite of Narragansett Pier cut Pennsylvanian sedimentary rocks on the west side of Narragansett Bay. The pegmatites are well exposed at intervals along the shore from the northern edge of the quadrangle to Boston Neck, becoming larger and more abundant as the granite is approached. The exposures are particularly good south of Wesquage Beach where 2 large pegmatites, each over 1400 feet long, and numerous smaller pegmatites comprise the low, rugged cliffs and stacks along the shore of the bay.

Separate exposures on Tower Hill have been mapped by Loughlin (1912, p. 453) as individual pegmatite dikes. However, from the random distribution of outcrops, it is not possible to assign certain outcrops to one dike rather than to another. If they are individual pegmatite dikes, neither their trends nor sizes can be determined. On the shore where individual pegmatites can be recognized, they show a crude zoning about one or more coarse, quartz-rich cores, whereas all pegmatite outcrops on Tower Hill are quite uniform in mineralogy and in texture. Therefore this area is mapped as undifferentiated pegmatite (pl. 2), allowing for the possibility of several pegmatite bodies separated by rather broad areas of Pennsylvanian rocks, or for the possibility of a few or even a single large pegmatite body. A few scattered outcrops pierce the till cover north of Boston Neck between the shore of the bay and Pettaquamscutt River. Shoreline occurrences suggest that the inland distribution of pegmatites is considerably more extensive than mapped. Quartz veins associated with the pegmatites are abundant north of Bonnet Point.

Size and shape. -- The pegmatites vary in size from thin veins less than an inch wide up to massive bodies 75 to 100 feet wide and 1600 feet long. The widths of most dikes are not constant; pinching and swelling is common along both strike and dip. The majority of the dikes are roughly concordant with the surrounding schists but locally are sharply discordant. Many small discordant dikes lie along joints.

Petrography. -- The grain size is variable, ranging from coarse cores within the pegmatite with crystals up to 2 feet in diameter, to medium-grained granite of the same composition. However the average grain size is about 2 inches with usually a somewhat finer-grained border zone.

The chief constituents are microcline, microperthite, quartz, muscovite, and small amounts of oligoclase and orthoclase. Minor constituents include spessartite, apatite, pyrite, beryl, and occasional biotite. It should be noted that with the exception of beryl, the mineral assemblage is identical with that of the granite of Narragansett Pier. Potash feldspar comprises the major part of the pegmatite, and its creamy-white color is distinctive. Oligoclase is early and has been replaced to a large extent by potash feldspars and quartz. Roughly parallel oligoclase lamellae of the microperthite may be remnants of former single grains since the lamellae and connecting stringers are in optical continuity. Quartz is smoky to milky and is interstitial around the euhedral crystals of feldspar, although it is commonly graphically intergrown with other feldspar. Muscovite occurs in small books, rarely over an inch in diameter, and in small radiating sprays. Spessartite is particularly abundant in the finer-grained wall zones of the pegmatite. Dodecahedral crystals rarely exceed one-quarter of an inch in diameter although crystals up to three-fourths of an inch were observed. Pale green beryl apparently reaches its greatest concentration about one-half mile south of Wesquage beach, but no systematic distribution of beryl is evident.

In the large pegmatites along the shore, coarse quartz-rich cores are elongate parallel to the strike of the dikes (fig. 7a). Some are sharply defined although most grade insensibly into the normal 2 inch grained pegmatite of the wall zone. Their distribution is somewhat sporadic with a rough concentration near the centers of the dikes. In crossing a 50 foot-wide pegmatite from one side to the other, 3 or 4 staggered cores may be encountered, some up to 4 feet wide and 35 feet long. These cores may connect at depth. The mineralogy of the cores is rather simple, ranging from almost all quartz with minor amounts of feldspar, to cores composed of large euhedral crystals of potash feldspar up to 2 feet in diameter with interstitial quartz. Garnet crystals are embedded in some of the core feldspar. Zoning may be observed in many of the smaller pegmatites (less than 10 feet wide), although it is lacking in most. Where zoned, the normal development is a central core of massive quartz and a little muscovite. Feldspar and minor amounts of quartz and muscovite are limited to the wall and border zones.

Figure 7a. Pegmatite core consisting of euhedral feldspar crystals 2 feet in diameter with interstitial quartz. Core trends parallel to pegmatite contacts and pinches out on both ends. It is surrounded by normal 2 inch-grained pegmatite. Location, south of Wesquage beach.

Figure 7b. Small (18-inch) pegmatite concordant with schistosity. Central portion mostly euhedral crystals of potash feldspar of finer-grained feldspar, quartz, muscovite. Three-fourths inch chilled border zone. Location, 1000 feet north of Bonnet Point.

Every gradation exists between the small pegmatites and pure quartz veins. The quartz veins are most abundant as joint and fracture fillings in the country schist north of Bonnet Point. Milky quartz veins cut the small pegmatites and apparently represent the extreme silicic phase of the post-Pennsylvanian intrusive series. Quartz veins on the islands may be related to the intrusive granite or may be products of metamorphic differentiation.

Origin. -- The pegmatites are of magmatic origin as indicated by the following observations: The larger pegmatites were forcefully emplaced. The country schist has been bodily displaced with steepened and even overturned dips to make room for the intrusive pegmatites. Much of the schist is badly shattered and buckled at and near the contacts. Schist inclusions in the pegmatite, up to 15 feet long, usually retain the northerly trend of the country rock, but there are exceptions where the inclusions, particularly the smaller ones, have been sharply rotated.

Quartz veins associated with the intrusive series appear to have 2 origins. The quartz forming the cores of pegmatites apparently represents the latest consolidation phase of the pegmatite. Quartz veins, with minor amounts of feldspar or in most cases with none at all, are also late but are hydrothermal.

Age. -- The pegmatites were emplaced during and after the crystallization of the granite, since the granite is gradational into pegmatite on Boston Neck, yet elsewhere is intersected by many pegmatite dikes occupying joints that could not have formed until the granite was at least partly cooled. The pegmatites are contemporaneous with the granite aplites since they mutually intersect. The pegmatites were intruded near the close of the deformation that affected the enclosing Pennsylvanian sedimentary rocks. Crushing is slight and few slickensided surfaces have developed. Schist inclusions are identical with the country rock and often have the same orientation; they were metamorphosed into schist before being caught up in the invading melt.

Since the pegmatites and the minette dikes of Conanicut Island intruded Pennsylvanian strata during the period of deformation, there is strong reason to suspect that they are members of the same intrusive series. Although the minette shows stronger metamorphism, no definite age relations between the two rocks has been established.

Minette Dikes (md)

Location. -- Four minette dikes, from 2 to 13 feet wide, intersect the phyllites of Pennsylvanian age on Beaver Neck (pl. 2). A fifth cuts the granite of Conanicut Island in the Newport quadrangle (Collie, 1894, p. 228; Lahee, 1912, p. 448). The proposed connections of various segments are based on like trends and on the similarities in width and approximate dip of separated exposures. Large boulders on the north side of Austin Hollow suggest the extension of the Hull Cove dike across the island.

Description. -- All the dikes have a general mineralogical and structural resemblance and are of the same approximate age. The dikes are olive gray to light gray where fresh, but usually are weathered light brown. The dikes include fragments of wall-rock and are veined by quartz and calcite (fig. 8a). Prominent phenocrysts of brown biotite up to 1 cm in length are set in a medium- to fine-grained groundmass (fig. 8b). A second stage of biotite formation is represented by grains averaging 0.5 mm in length. All the plates are arranged more or less parallel to the dike contacts. The grains are moderately to extensively replaced by chlorite which, with opaque iron oxide, reaches maximum development near grain boundaries. In places alteration is so complete that biotite is no longer recognizable as the original ferromagnesium mineral. Orthoclase feldspar forms an important part of the groundmass. Secondary calcite has replaced a large part of the orthoclase. Sericite has developed in varying amounts at the expense of the feldspar, and locally imparts a bleached appearance to the rock. Small remnants of plagioclase

Figure 8a. Gently dipping minette dike cutting gnarled phyllites along cleavage. Note blocky jointing in dike and extensive milky quartz veining. Location, Lion Head on southeastern shore of Beaver Neck.

Figure 8b. Porphyritic texture in minette dike. Biotite phenocrysts in groundmass of altered orthoclase. Plane light, x 15. Location, west shore of Beaver Neck 1 mile south of Fox Hill.

and finely twinned microcline are scattered through the groundmass. Euhedral crystals of apatite, reaching 1.5 mm in length, are aligned parallel to the dike contacts and account for the 0.22 percent P_2O_5 content in the analysis of Hawkins (1918, p. 451). Minute rutile crystals form characteristic "A" and herringbone structure in chlorite and were produced during the alteration of biotite to chlorite. Cubes of pyrite, mostly less than .06 mm across, are especially common in the fine-grained portions of the dike.

Structural relations. -- Most of the dikes intruded along axial plane cleavage of the phyllite during deformation. The dikes are commonly fractured into irregular blocks with slickensided surfaces (fig. 8a). The dike at Lion Head is transversed by four normal faults, each with a vertical displacement of less than 5 feet, and a fifth with a throw of about 30 feet. Segments of the northernmost minette, underlying the highest hill on Beaver Neck, are en echelon.

Wallrock alteration. -- Wallrock alteration is confined to a narrow zone not more than a few inches wide. The phyllites are bleached and are somewhat rusty in appearance due to the weathering of thin impregnations of minette along cleavage planes.

Age. -- The dikes were probably emplaced during the Appalachian disturbance and may represent the closing stage of an igneous cycle that included the intrusion of the granite of Narragansett Pier and its associated pegmatites.

STRUCTURAL GEOLOGY

Regional Structure

The principal structural feature of the Narragansett Pier quadrangle is the synclinal Narragansett Basin (pl. 2), developed during the Appalachian deformation. A general concordance of basin structures and those of older rocks on the border masks the unconformity between the two. The older rocks were deformed before the beds of the Narragansett Basin were deposited as indicated by the sharp disconformity of Pennsylvanian strata with older folds of pre-Pennsylvanian rocks in the Pawtucket, North Scituate, and East Greenwich quadrangles (Quinn, Ray, and Seymour, 1949; Quinn, 1951, 1952).

Blackstone Series

The Blackstone series was deformed early in the Paleozoic era before the intrusion of the Devonian(?) or earlier Esmond granite (Quinn, 1952). The bedding and schistosity of the quartz-biotite schist are parallel. They trend generally northeast and dip steeply southeast. The lineation of elongate minerals plunges northeast in the plane of foliation. Boudinage in hornblende-epidote layers indicate stretching of the beds along the strike. No other direction of stretching was observed in the glacially polished exposures. The presence of similar beds across the strike may be a feature of sedimentation or may result from isoclinal folding.

Scituate Granite Gneiss

The foliation of the Scituate granite gneiss near Peace Dale trends northeastward, at McSparran Hill is generally northward, and near Mooresfield swings around to the northwest. The foliation dips from southeast to northeast. The structure appears to be inherited from older rocks of the Blackstone series. Near the contact with sedimentary rocks of the Narragansett Basin the foliation varies by as much as 90 degrees in ten feet. These local deviations are caused by the same deformation that folded the adjacent Pennsylvanian strata. In the North Scituate quadrangle, foliation of the gneisses bears no relation to the folds in the Pennsylvanian rocks, and in the Narragansett Pier quadrangle the general conformity of pre-Pennsylvanian and Pennsylvanian rocks is fortuitous. Although the late Paleozoic Appalachian deformation

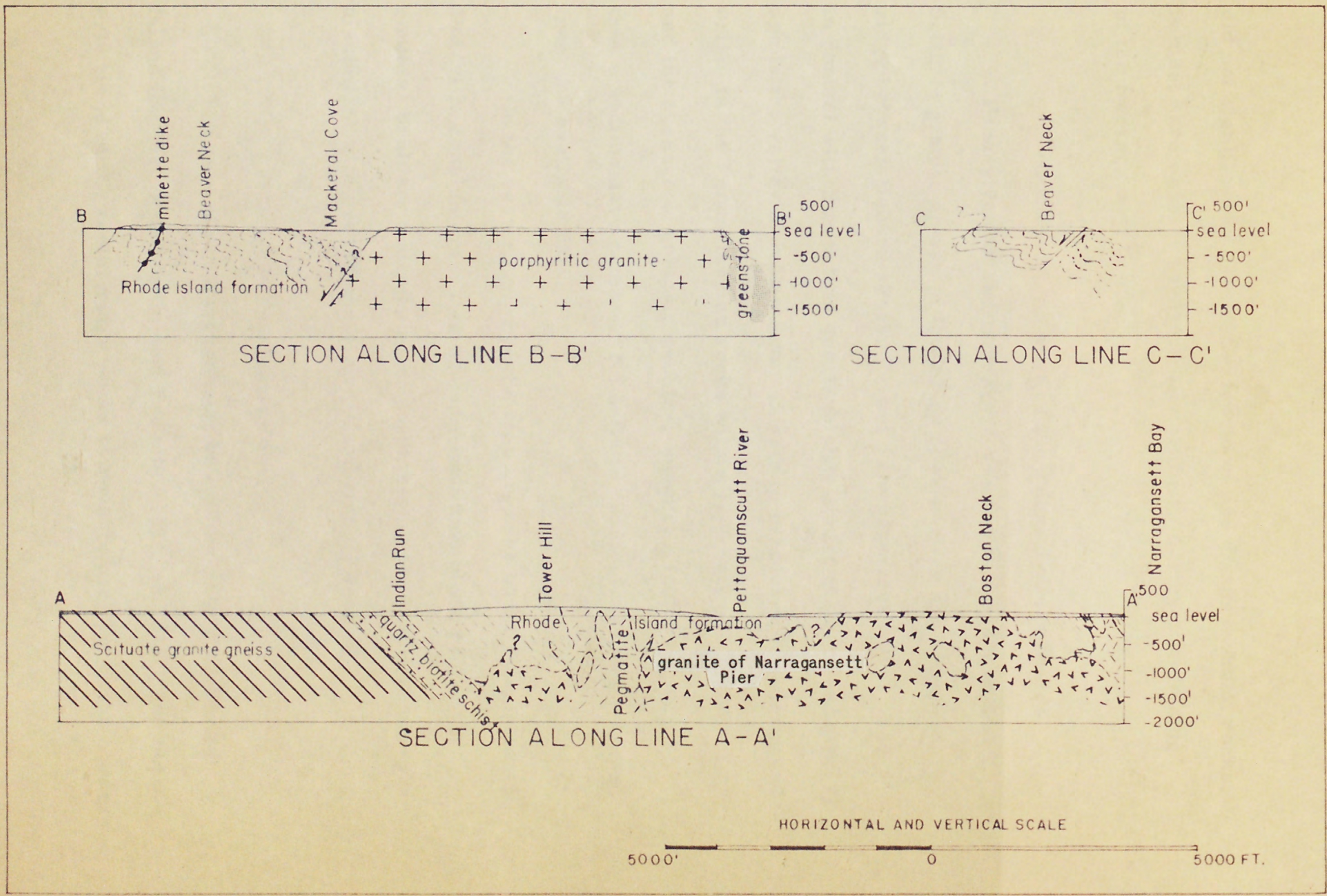

Figure 9

Structure sections

did not significantly change the fabric of pre-Pennsylvanian rocks, it must have at least changed their attitudes during downfolding of the Narragansett Basin.

Contact at the base of the Pennsylvanian Series

Pennsylvanian sedimentary rocks are in contact with the Scituate granite gneiss of Devonian(?) or earlier age along the ridge between Hazard reservoir and Pettaquamscutt River, and in contact with Blackstone quartz-biotite schist of pre-Cambrian(?) age in the valley of Indian Run. Quartzite pebbles of undetermined origin in the Pennsylvanian rocks within 1200 feet of the contact, and the absence of gneissic pebbles, suggest a faulted rather than a sedimentary contact. No definite conclusions can be drawn from the available data.

On the eastern edge of the map area the basal Pennsylvanian Pondville conglomerate lies unconformably on older rocks. It contains boulders and pebbles of porphyritic granite and is sharply discordant with greenstone of pre-Cambrian(?) age.

Pennsylvanian Series

The axis of the Narragansett Basin lies east of Conanicut Island (Shaler, Woodworth, and Foerste, 1899, pl. 31). The northerly trend of the sedimentary rocks is roughly parallel to the borders of the basin. Very little is known of the structure owing to the widespread covering by glacial deposits and water. Structural interpretations are also limited by the absence of key beds suitable for mapping.

Over 5 1/2 square miles on the west side of Narragansett Bay are underlain by Pennsylvanian rocks. Yet no exposures were observed in the inland area between the shore of the bay and Pettaquamscutt River, and less than 20 exposures of Pennsylvanian rocks were observed west of the river. In most of the outcrops schistosity trends slightly east of north; bedding is too rare to be of significance. Along the shore of the bay, schistosity and bedding are parallel or nearly so and everywhere dip eastward. Lineation of elongate minerals and pebbles plunges northeast in the plane of foliation. Tops of beds are determined by cross bedding and graded bedding.

Folds

A complex structure for the covered area is suggested by variable dips of the few inland exposures, the presence of large boulders of brecciated material on the west side of Pettaquamscutt River, and folding observed in a deep road cut at the west end of Jamestown bridge 2 miles north of the Narragansett Pier quadrangle.

Excellent shoreline exposures on Dutch Island and Conanicut Island (Figs. 4a, 10) provide important structural data for the southwestern part of the Narragansett Basin. The structure is too complex in many places on Conanicut Island to be mapped satisfactorily on the scale of 1:31,680. Where bedding can be seen, it is usually only as thin bands on the cleavage surfaces (fig. 4a), and in many places not enough is seen along the dip to make accurate observations. Although highly contorted, the beds have a general easterly dip (fig. 9, secs. B-B', C-C'). In places, the bedding is steeper than cleavage and overturning is indicated (fig. 4a). This is especially common on the west side of Beavertail Point (fig. 9, sec. C-C'). Axial plane cleavage is well developed and commonly obliterates the bedding. On most parts of the island axial plane cleavage dips westward. On the west side of Mackeral Cove the axial plane cleavage is itself folded, with no apparent system. This may be a further indication of a major fault parallel to the axis of Mackeral Cove (see below). Minor fold axes are horizontal and have a northerly trend. From the dips on Conanicut and Dutch Islands, and those in the Newport quadrangle (Shaler, Woodworth, and Foerste, 1899, pl. 31) it is concluded that the islands are located on the west limb of a major syncline. No such conclusions can be drawn for the area west of Narragansett Bay.

Figure 10. Crumpled schists on the southern tip of Dutch Island. Bedding and schistosity dip eastward. Axial planes of minor folds dip west. Steeply dipping sediments across Narragansett Bay form sea cliffs north of Bonnet Point.

Figure 11a. Contorted Pennsylvanian strata. Alternating layers of quartzite and black phyllite. Location, Fox Hill.

Figure 11b. Axial plane cleavage in minor folds of Pennsylvanian strata. Location, west side of Beaver Neck, south of Austin Hollow.

Stretched Pebbles

Quartzite pebbles in the Narragansett Basin strata have been elongated by metamorphism. The shape of these pebbles before stretching is unknown but presumably was more or less equidimensional. Only a few measurements were recorded. At Fox Hill the pebbles are disc-shaped and their length is approximately 4 times their width (fig. 12a). Pebbles on Dutch Island and on the west side of Narragansett Bay are spindle-shaped (fig. 12b). On Dutch Island and in boulders along the west shore of the bay, the long dimension is about 6 times the short dimension. In an outcrop on Tower Hill, the elongation is as much as 13 times the width. This comparative elongation suggests that directive pressures were higher near the border of the basin (see Metamorphism).

The pebbles are elongate in the plane of bedding and are either parallel to the strike of the beds or plunge gently northeast. The elongation indicates that besides shortening perpendicular to the axial plane of folds, the deforming stresses were relieved by extension of the rocks along bedding planes and parallel to fold axes.

Faults

At Lion Head. -- A northeasterly trending, high angle normal fault may be traced for over 0.6 mile along the shore from

Figure 12a. Stretched quartzite pebbles in argillaceous matrix. Pebbles are disc-shaped in contrast with spindle-shaped pebbles below. Location, Fox Hill.

Figure 12b. Stretched quartzite pebbles. Poorly developed joints cut across pebbles. Location, Dutch Island.

Lion Head to Beavertail Point. At Lion Head the fault branches into 2 major parts, although the main displacement is on the eastern branch. Vertically slickensided offsets of a minette dike indicate a throw of approximately 30 feet with the east side upthrown. Minor normal faults within the fork have displacements of less than 5 feet. Near Beavertail Point an offset quartz vein indicates a vertical displacement of about 5 feet. Fine gouge is developed at many places along the fault plane.

Faulting occurred after the consolidation of the minette dikes which in most cases intruded along axial plane cleavage.

<u>At Mackeral Cove</u>. -- On the east side of Mackeral Cove, boulders of the basal Pennsylvanian Pondville conglomerate continue northward from the porphyritic granite to a small stream entering the bay. Here they give way abruptly to Pennsylvanian phyllites. The absence of a transition zone and the discordance of the phyllite and conglomerate indicate a probable fault between them. On the eastern shore of Conanicut Island, Crosby (1897, p. 236) notes, "....between the arkose and shale a magnificent development of fault breccia. For a breadth of about fifty feet the green and black shales (phyllites) are completely brecciated..." This area is now cemented behind a concrete sea wall, but breccia fragments are numerous along

the narrow beach. The sedimentary rocks on Beaver Neck dip toward the older granite of Conanicut Island. Therefore the fault probably continues down the axis of Mackeral Cove. The Lion Head fault may be part of the same fault system.

Small normal faults are mapped on the west side of Beavertail point and on the east side of Mackeral Cove.

Joints

One hundred and fifteen joint readings were made with the hope of finding some relation between the joint pattern in the Pennsylvanian sedimentary rocks of the Narragansett Basin, and the gneissic rocks to the west whose age was uncertain. Such an investigation might have revealed two distinct patterns, indicating deformation of the gneissic rocks prior to the Appalachian disturbance that produced the joints in the Pennsylvanian rocks. Too few readings were made in the scattered exposures of Scituate granite gneiss to establish a definite trend.

Eighty of the joint readings were taken in the Narragansett Basin. The joint directions in the Pennsylvanian rocks are systematic but gradually change direction from one part of the basin to another (pl. 2). They formed after the deformation of these rocks, as indicated by joints cutting across stretched pebbles, and joints in the Pennsylvanian strata passing into the late Pennsylvanian or post-Pennsylvanian granite.

METAMORPHISM

All the rocks in the Narragansett Pier quadrangle have been deformed to some extent, but metamorphic effects are greatest in the rocks of sedimentary origin.

Blackstone Series

The presence of almandite, andesine, and hornblende in the pre-Cambrian(?) rocks exposed in the valley of Indian Run indicates a medium or high grade of metamorphism under high temperature and stress. The partial replacement of almandite-andesine-hornblende of the staurolite-kyanite subfacies, amphibolite facies (Turner, 1948, p. 89) by chlorite-calcite-epidote-sericite of the chloritoid almandite subfacies, albite-epidote amphibolite facies (Turner, 1948, p. 89) is clear evidence of a second stage of equilibrium in the rock. The new minerals, according to the classical viewpoint (Eskola, 1915, p. 114-117; Turner, 1948, p. 54), are products of retrograde metamorphism, but more recently it has been proposed (Yoder, 1952, p. 615-616) that the new assemblage need not mean a change in pressure or temperature conditions, but may mean addition of water vapor. Fractures in the garnet porphyroblasts are perpendicular to schistosity. (See fig. 1.) They were developed either late in metamorphism that permitted crystallization of the garnet when, with declining temperature, the garnet crystals had lost their power of recrystallization (Harker, 1952, p. 220), or during a later metamorphism.

The observed metamorphism probably results from at least two different episodes of metamorphism. In the North Scituate quadrangle, the Blackstone series was metamorphosed before the intrusion of several types of pre-Pennsylvanian plutonic rocks (Quinn, 1951). In the Narragansett Pier quadrangle the widespread foliation of the Scituate granite gneiss of pre-Pennsylvanian age was inherited from schists of the Blackstone series before the Pennsylvanian sediments were deposited. The granitization may be a late phase of the metamorphism that converted the Blackstone sediments into the present metamorphic rocks, or a phase of a much later pre-Pennsylvanian metamorphism that affected conglomeratic beds containing pebbles of the Esmond granite of Devonian(?) or earlier age in the East Greenwich quadrangle (Quinn, 1952). An even later metamorphism, presumably during the Appalachian revolution, produced the metamorphism shown in the Rhode Island formation, and may have produced the retrograde effects in the Blackstone series.

Pennsylvanian Series

Regional relationships

The metamorphic grade of the Pennsylvanian rocks increases toward the southern part of the Narragansett Basin. Rocks in the northern part of the basin are essentially unmetamorphosed. In the Pawtucket quadrangle (about 4 miles north of Providence), carbonaceous beds have been changed to meta-anthracite (Quinn, Ray, and Seymour, 1949), and just south of Providence the shale beds have a slaty cleavage and contain chloritoid (Quinn, 1953, p. 268). Garnet-staurolite schist is exposed in the Wickford quadrangle at the east end of the Jamestown bridge (about 2.5 miles north of Beaver Neck). In the Narragansett Pier quadrangle, in the southern part of the basin, metamorphic effects include elongate pebbles, prominent slaty cleavage, and development of such minerals as muscovite, biotite, chloritoid, epidote, and garnet. Shaler (Shaler, Woodworth, and Foerste, 1899, p. 28) believed that the increased metamorphism in the southern part of the basin was caused by an extensive concealed intrusion.

Local relationships

Metamorphic trends within the Narragansett Pier quadrangle are difficult to establish. Metamorphic response is dependent not only on temperature and pressure, but also on the texture and bulk composition of the rocks involved. Metamorphism of the predominantly siliceous rocks on the west side of the bay is difficult to compare with that of pelitic rocks of the islands.

At the north end of Beaver Neck and on Dutch Island, the assemblage albite-quartz-muscovite-almandite-chloritoid-epidote-chlorite of the chloritoid-almandite subfacies, albite-epidote amphibolite facies (Turner, 1948, p. 89) indicates a lower grade of metamorphism than is represented in the Wickford locality described above. The phyllites south and east of Fox Hill also contain chlorite, sericite, and almandite and may be classed in the same metamorphic facies.

The rocks on the west side of the bay are mainly siliceous, but the presence of muscovite, biotite, chlorite, and almandite is sufficient to classify these rocks in the albite-epidote amphibolite facies. The garnet-muscovite schists west of Pettaquamscutt River are much coarser grained than any of the pelitic rocks on the islands of the bay. Since mineral assemblages seem to indicate equal temperature-pressure conditions, the difference in grain size may represent some other factor in metamorphism, such as amount of water or directed pressure.

A comparison of quartzite pebble elongation (see Structural Geology) suggests that directive pressures were higher near the border of the basin where the Pennsylvanian rocks were closest to the point of application of the deforming forces, assuming that the forces were mostly transmitted tangentially through the rigid border rocks.

Contortion of the Pennsylvanian strata is greatest in the phyllites of the islands, probably because of their finer grain size.

Influence of the granite of Narragansett Pier. -- The granite of Narragansett Pier is exposed on Boston Neck. Northward the granite grades into pegmatites, which in turn grade into quartz veins, the youngest and most silicic members of the intrusive series. The abundance of quartz veins and the absence of pegmatites on the islands of the bay, suggests that these areas are somewhat remote from the granite batholith. It should be noted that the quartz veins on the islands, may not be a reflection of the zoning in the intrusive series, but may, like the quartz veins in many other regions, be products of metamorphic differentiation. Metamorphic minerals indicate no temperature differences in the Pennsylvanian rocks in any part of the Narragansett Pier quadrangle. Lack of chill contacts of the granite suggests that the Pennsylvanian rocks were warm at the time of the granite intrusion. Gneissic structure is poorly developed in the granite. All of these lines of evidence indicate that the major deformation and accompanying metamorphism of Pennsylvanian rocks was accomplished before the granite was emplaced.

Conclusions. -- Metamorphic differences within the Narragansett Pier quadrangle may be due to variations in directed pressure. Elongate pebbles suggest that pressures were greatest near the border of the basin. The increased grade of metamorphism in the southern part of the Narragansett Basin probably is due to the greater depth of burial with subsequent higher temperature and pressure, rather than to intrusion of the granite.

ECONOMIC GEOLOGY

Economic deposits of interest in the past, present, or for the future consist of granites and gneisses, graphite, pegmatites, and sand and gravel.

The Scituate granite gneiss has been quarried near Mooresfield for use in ocean piers and breakwaters. Dimension stone for local use has also been quarried at Mooresfield and from several small pits 0.35 mile northwest of Indian Run reservoir. Most of the rock is strong and sound for foundations except where it grades into earlier schists. In such zones the rock is usually weathered and is weak due to increased amounts of biotite. The schistosity is the direction of greatest weakness.

The reddish granite south of Narragansett Pier is more massive than the Scituate granite gneiss. This granite has been quarried at a few small pits. Similar redstone granite at Westerly, Rhode Island has been worked extensively for construction stone. The texture of the granite along the shore is extremely variable with irregular patches of pegmatitic and aplitic material dispersed throughout the rock. Sharply defined pegmatite and aplite dikes, numerous schist inclusions, and irregularly spaced joints also render large portions of the rock unsuitable for quarrying.

The Pennsylvanian strata are probably the weakest rocks in the area and have no economic use. Although Shaler in 1899 (Shaler, Woodworth, and Foerste, p. 79) considered the coal beds the most important resource of the Narragansett Basin, the material is graphitic from metamorphism and its fuel value is far inferior to that of other coals shipped into the area. In the Narragansett Pier quadrangle 2 small mines on the hillside southwest of Bridgetown were worked for graphite many years ago. The best grade of graphite apparently has been worked out.

Post-Pennsylvanian pegmatites along the west side of Pettaquamscutt River are a potential source of feldspar, but the pegmatites in the sea cliffs south of Wesquage beach are too exposed for quarrying operations. Beryl occurs sparingly in the shore pegmatites and would be profitable only as a by-product.

Sand and gravel deposits were being mined in 1953 northwest of Peace Dale.

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