Bedrock Geology of the Wickford Quadrangle Rhode Island

By ROGER B. WILLIAMS

GEOLOGY OF SELECTED QUADRANGLES IN RHODE ISLAND

GEOLOGICAL SURVEY BULLETIN 1158-C

Prepared in cooperation with the State of Rhode Island Development Council

NITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1964

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

GEOLOGY OF SELECTED QUADRANGLES IN RHODE ISLAND

BEDROCK GEOLOGY OF THE WICKFORD QUADRANGLE, RHODE ISLAND

By Roger B. Williams

ABSTRACT

The Wickford quadrangle, in the southwestern part of the Narragansett basin, Rhode Island, is underlain by (1) metasedimentary biotite gneiss of the Blackstone Series of Precambrian(?) age, (2) the intrusive Hope Valley Alaskite and Ten Rod Granite Gneiss and the Cowesett Granite of pre-Pennsylvanian age, (3) the Pondville Conglomerate and Rhode Island Formation of Pennsylvanian age, and (4) quartz veins and pegmatites of Late Pennsylvanian or post-Pennsylvanian age.

Two periods of thermal and dynamic metamorphism have been recognized. The most intense episode was in pre-Pennsylvanian time; another occurred in Late Pennsylvanian or post-Pennsylvanian time, caused by the Appalachian revolution and the intrusion of the Narragansett Pier Granite, which formed metamorphic rocks of staurolite grade.

The dominant structural feature is the Narragansett basin, in which the Pennsylvanian rocks show tight or even overturned folds in the more argillaceous units and more open folds in the coarser grained clastic rocks. The fold axes in general trend north. The older rocks are structurally similar to one another and have east-trending foliations northeast-plunging lineations.

INTRODUCTION

This report is one of a series of studies of the bedrock and surficial geology of the State of Rhode Island, a program of geologic mapping supported jointly by the State of Rhode Island Development Council and the U.S. Geological Survey. Fieldwork was done during 1956. The report on the surficial geology of this quadrangle (Schafer, 1961) has been published.

The Wickford quadrangle is along the southwest shore of Narragansett Bay. Wickford, the principal town, is about 18 miles south of Providence, R.I.

Most of the quadrangle is underlain by metamorphosed nonmarine Pennsylvanian sedimentary rock of the Narragansett basin, the major structural feature of the area. Pre-Pennsylvanian gneisses underlie a small area in the northwest corner and a larger area in the southwest corner. The pre-Pennsylvanian rocks, which are more resistant to erosion, form an upland standing above the basin. A prominent escarpment marks the margin of the basin. This escarpment extends from the south edge of the quadrangle along the west bank of the Pettaquamscutt River and the west side of Pausacaco Pond, then bends west-northwest to a point north of the town of Slocum (in Slocum quadrangle), and thence runs to Briggs Corners and northeast to the edge of the Wickford quadrangle.

Pennsylvanian sedimentary rocks underlie the lowlands east of the escarpment and for the most part are covered by a veneer of glacial debris and water. Narragansett Bay covers nearly a third of these low areas; swamps, marshes, streams, and ponds occupy much of the remainder. Most outcrops are on north-trending ridges or along the shore. Elsewhere, glacial debris covers the area to considerable depth, and outcrops are sparse.

Gratitude is extended to Professor Alonzo W. Quinn, of the Department of Geology at Brown University, who provided advice and assistance in the field and in the laboratory. Mr. J. P. Schafer of the U.S. Geological Survey supplied the author with the locations of all bedrock exposures.

LITHOLOGIC UNITS

The lithologic units recognized in the Wickford quadrangle include (1) the metasedimentary biotite gneiss of the Blackstone Series of Precambrian(?) age, (2) the intrusive Hope Valley Alaskite and Ten Rod Granite Gneiss and Cowesett Granite of pre-Pennsylvanian age, (3) the Pondville Conglomerate and the Rhode Island Formation of Pennsylvanian age, and (4) quartz veins and pegmatites of Late Pennsylvanian or post-Pennsylvanian age.

The sedimentary rocks of Pennsylvanian age lie unconformably above the older units, although the Cowesett Granite is not exposed in this quadrangle.

PRECAMBRIAN(?) ROCKS

BLACKSTONE SERIES, BIOTITE GNEISS

The only exposure of the Blackstone Series is a biotite gneiss that crops out on the bank of a small creek in the extreme northwest corner of the area and extends into the adjacent Slocum quadrangle (Power, 1959). This medium-grained, well-jointed, and foliated rock is generally light gray and contains bands of darker biotite schist. The foliation strikes N. 12° W. and dips 44° E. Porphyroblastic quartz and feldspar stand out in slight relief on weathered surfaces. The predominant minerals are quartz, microcline, microperthite, biotite, and plagioclase. The common accessory minerals are fluorite, magnetite, and muscovite. Zircon and garnet are present in very small amounts. Structural relations with other rocks were not observed. The lithologic, structural, and metamorphic similarities of this metasedimentary biotite gneiss to other exposures of the Blackstone Series of northern Rhode Island (Power, 1959) suggest Precambrian (?) age.

PRE-PENNSYLVANIAN PLUTONIC ROCKS

HOPE VALLEY ALASKITE GNEISS

The Hope Valley Alaskite Gneiss of Mississippian (?) or older age is exposed in the area surrounding Hammond Hill and along Boston Post Road to the south. It is correlated with nearly identical rock exposed in the Hope Valley quadrangle. The rock was named by Moore in 1958, and Nichols (1956) mapped a similar rock in the Narragansett Pier quadrangle. The alaskite gneiss is bordered on the north and east by the Pennsylvanian rocks of the Narragansett basin; on the west, glacial debris conceals the contact with the nonporphyritic facies of the Ten Rod Granite Gneiss.

The Hope Valley Alaskite Gneiss is a flesh-colored to orange coarse-grained rock. In places it is cut by thin aplite dikes. The pronounced lineation of rodshaped aggregates of clear to smoky quartz in the gneiss plunges 25°–45° in a N. 45°–55° E. direction. Locally, foliation planes are marked by small amounts of muscovite and biotite. The amounts of mineral constituents vary, but typically the rock contains about 29 percent microcline, 29 percent albite-oligoclase, and 40 percent quartz. The plagioclase is strongly sericitized. Sericite, muscovite, biotite, and hematite amount to less than 3 percent. In a darker facies of the alaskite, magnetite and sphene crystals as much as 4 mm across are visible; sphene comprises 2 to 3 percent, amphibole more than 5 percent, and biotite more than 6 percent.

Structural relations, especially well displayed along the escarpment west of Pettaquamscutt River where the Pennsylvanian sedimentary rocks appear to be "plastered" onto the alaskite gneiss with considerable nonconformity, indicate that the Hope Valley Alaskite Gneiss unconformably underlies, and therefore is older than, the Rhode Island Formation. Nichols (1956) indicated that the Hope Valley Alaskite Gneiss and the Ten Rod Granite Gneiss are nearly of the same age, Devonian (?) or older, but that the alaskite is possibly slightly older. Moore (1959) indicated that lead-alpha age determinations on zircon from the Ten Rod Granite Gneiss gave it an age of 303 million years, which is Mississippian or late Carboniferous according to Faul (1960).

TEN ROD GRANITE GNEISS

The Ten Rod Granite Gneiss exposed in the southwest corner of the area is part of a large mass which extends into the Narragansett Pier, Kingston, and Slocum quadrangles. The Ten Rod Granite Gneiss was named by Moore (1958); its type locality is a roadcut on Ten Rod Road 0.85 mile west of Millville, which is about 15 miles west of Wickford, in the Hope Valley quadrangle. Three facies have been mapped: porphyritic, nonporphyritic, and fine grained.

The gray foliated porphyritic facies contains abundant biotite and augen-shaped grains of microcline. Nichols (1956) reported the composition as follows: Quartz (40–50 percent), microcline-microperthite, (28 percent), oligoclase (22 percent), biotite (7 percent), and minor constituents including magnetite, garnet, muscovite, chlorite, zircon, apatite, pyrite, and keilhauite. Moore (Written communication, 1961) reports that the average quartz content is about 30 percent. No modal analysis of the porphyritic Ten Rod Granite Gneiss from the Wickford quadrangle was made. In the Wickford quadrangle, the gneiss is characterized by abundant biotite and augen-shaped microcline that become less common to the north and east until the nonporphyritic facies appears.

The contacts between the porphyritic facies and the nonporphyritic facies of the Ten Rod Granite Gneiss are poorly exposed in the map area but these facies appear to be gradational southwest of Congdon Hill. Here, alternating exposures range from biotite-rich to biotite-lean; some exposures show augen-shaped feldspar, others do not. Foliation is present in every exposure. Smoky quartz may be mistaken for zones of biotite on the planes of foliation.

Nichols (1956) stated that the rock appears to be the result of the feldspathization of schists correlated with the Blackstone Series and that there is a gradational zone between the Ten Rod Granite Gneiss and the quartz-biotite schist. Within this zone, potassium feldspar content and grain size increase, and biotite decreases, toward the Ten Rod Granite Gneiss. Moore (1958), however, cited stronger evidence for the intrusive character of the Ten Rod Granite Gneiss, and the author believes the rock to be of magmatic origin.

Lead-alpha age determinations by Howard W. Jaffe of the U.S. Geological Survey on a sample of the Ten Rod Granite Gneiss from the Hope Valley quadrangle gave 303 million years. Quinn and others (1957, p. 556) first reported the age to be 285 million years, but the estimate was later changed to 303 million years because of a new determination of the half life of thorium. This new estimate supports the conclusion that the rock is of Mississippian (?) age according to the time scale of Faul (1960).

NONPORPHYRITIC FACIES

The nonporphyritic facies of the Ten Rod Granite Gneiss, and the fine-grained facies within it, are exposed in the southwest corner of the quadrangle to the south and east of Congdon Hill.

The rock is flesh colored on freshly exposed surfaces. The foliation, accented by thin bands of smoky quartz, in most places strikes east and dips 30°–50° N. The nonporphyritic rock is composed of quartz (34 percent), albite-oligoclase (34 percent), microcline, (28 percent), accessory minerals (4 percent) including biotite, and muscovite, and lesser amounts of magnetite, sphene, zircon, apatite, and sericite. Magnetite locally forms crystals 17 mm or more across. Porphyritic texture is present only locally.

The contact between the porphyritic facies and the nonporphyritic facies of the Ten Rod Granite Gneiss is gradational. An interfingering relationship can be seen on the hill west of Congdon Hill, where adjacent outcrops display the characteristics of these rocks. This interfingering is believed to be typical of the entire contact between the two facies, but the contact is largely concealed by glacial debris.

The discordance of the Ten Rod gneisses with the margin of the Narragansett basin and with the bedding of the Pennsylvanian rocks of the basin indicates a pre-Pennsylvanian age for these contemporary units.

FINE-GRAINED FACIES

A few small masses of fine-grained gneiss are surrrounded by nonporphyritic facies of the Ten Rod Granite Gneiss; the only one large enough to map on a scale of 1:24,000 is south of Congdom Hill along the road. A smaller mass crops out 0.5 mile west of the road intersection south of Congdon Hill.

The rock is light tan or buff and locally is discolored or streaked with reddish iron oxide stain. Two modal analyses of the fine-grained gneiss indicate that it is composed of quartz (31–34 percent), microcline (25–30 percent), oligoclase (36–39 percent), biotite (1–2 percent), and accessory minerals (1 percent) which include magnetite, muscovite, chlorite (altered from biotite), sericite (altered from plagioclase), zircon, and apatite.

The lens-shaped units of fine-grained gneiss parallel the foliation of the nonporphyritic facies of the Ten Rod Granite Gneiss. The contacts appear to be gradational, and the rocks probably are of the

716-689—64——2

same age. Nichols (1956) and Power (1959) suggest that the Ten Rod Granite Gneiss originated by the feldspathization of schist and other metamorphic rocks. If so, the fine-grained gneiss represents beds of the metamorphic rocks that were originally different from those that formed the nonporphyritic facies, or a part of the metamorphic formation that was not affected in the same way by feldspathization.

Moore (1958) cites evidence of the intrusive character of part of the Ten Rod Granite Gneiss, but states that other bodies of the Ten Rod Granite Gneiss may "be a result of magmatic intrusion or granitization." Thus, the origin of this part of the Ten Rod Granite Gneiss and of its nonporphyroblastic and fine-grained facies is still very much open to question.

COWESETT GRANITE

The Cowesett Granite is not exposed in the Wickford quadrangle, but exposures in the East Greenwich quadrangle (Quinn, 1952) and in the Slocum quadrangle (Power, 1959) indicate that this granite probably underlies a small area in the northwest corner. It was named by Quinn (1952); the type locality is along Cowesett Road 0.5 mile west of Hardig Road in the East Greenwich quadrangle, about 5.5 miles north of Briggs Corner. Emerson and Perry (1907) indicated the presence of the Northbridge Granite Gneiss and a body of micrographic granite in the northwest corner. These two lithologic units are now included in the Cowesett Granite (Quinn, 1952).

According to Quinn (1952), the Cowesett Granite is gray to pink, medium grained, subporphyritic, and mostly massive, but it is foliated near the contacts owing to partial replacement of schist. Main constituents include microcline and microperthite (39–52 percent), oligoclase (1–24 percent), quartz (22–42 percent), and biotite (3–6 percent). Minor constituents and accessory minerals include muscovite, apatite, chlorite, zircon, magnetite, rutile, garnet, epidote, sphene, fluorite, and pyrite.

Quinn (1952) assigned the Cowesett Granite a tentative age of Mississippian(?).

PENNSYLVANIAN ROCKS

The rocks of Pennsylvanian age in the Wickford quadrangle include the Pondville Conglomerate and the Rhode Island Formation which has been mapped as two units. One unit of the Rhode Island Formation includes several undifferentiated clastic facies and the other is an argillaceous facies.

PONDVILLE CONGLOMERATE

The Pondville Conglomerate underlies a small area near the northwest corner of the quadrangle. It is poorly exposed and is assumed to be a lenticular mass below the Rhode Island Formation; it trends about N. 15° E. Where exposed, bedding(?) and foliation are parallel and strike N. 25° W. and dip 55°–65° NE.

Originally made up of coarse-grained sandstone and conglomerate, the Pondville Conglomerate is now interbedded light- to dark-green schistose quartzite, schistose conglomeratic quartzite, and quartz schist; it is rich in biotite, muscovite, garnet, and microcline. Garnet stands out in relief on weathered surfaces.

Stretched pebbles in the conglomeratic facies are as much as 3 inches long; the long axis is down the dip of the foliation. Most of the biotite is oriented parallel to schistosity, but some grains are discordant to the schistosity; all the biotite is displaced by poikiloblastic garnet and microcline that enclose relict quartz grains.

The Pondville Conglomerate is stratigraphically between the pre-Pennsylvanian rocks and the Rhode Island Formation, although the contact is covered by glacial drift. Only the conglomerate at the base of the Narragansett basin sequence is assigned to the Pondville Conglomerate (Nichols, 1956, Quinn, 1952, 1959). The field relations at Pondville Station, Mass., as described by Shaler (*in* Shaler, Woodworth, and Foerste, 1899, p. 136) are similar.

RHODE ISLAND FORMATION

The Rhode Island Formation is the thickest and most extensive of the Pennsylvanian formations in the area. It underlies most of the quadrangle. Emerson (1917) indicated on his bedrock map of Massachusetts and Rhode Island that the Wickford quadrangle area is underlain by the Wamsutta Formation and the Pondville Conglomerate. The two units were combined by Emerson on his map and described as "basal arkose, quartz conglomerate, and red rocks." In the present report the Pondville Conglomerate is mapped separately where exposed. The other Pennsylvanian rocks do not have the characteristic red color of the Wamsutta Formation, but are typically dark colored; they are therefore considered as Rhode Island Formation.

Nichols (1956) divided the Rhode Island Formation of the Narragansett Pier quadrangle to the south into two units: (1) sandstone and conglomerate and (2) phyllite. The phyllite extends into the Wickford quadrangle without any significant change, but most of the rest of the Rhode Island Formation in the Wickford quadrangle is quartzite and schist, rather than sandstone and conglomerate. The formation in the Wickford quadrangle is therefore divided into (1)

Rhode Island Formation, undifferentiated, equivalent to Nichols' sandstone and conglomerate unit, and (2) the Rhode Island Formation, argillaceous facies, equivalent to Nichols' argillaceous phyllite facies.

Exposures are widespread on north-trending ridges, along shorelines, and in railroad and highway cuts. The two best are (1) along the railroad 0.5 mile south-southwest of Davisville and (2) in a former railroad cut 300 feet southwest of the intersection of Davisville Road and Boston Post Road. The second locality is referred to locally as "Devils Foot Ledge" or "Devils Footprint," from a small erosional feature there. Another exposure is along the highway west of Jamestown Bridge. These three exposures afford an opportunity to study the lithologic character and the structure of the Rhode Island Formation. Shoreline exposures are near Plum Beach and on Conanicut Island.

The margin of the Pennsylvanian rocks of the Narragansett basin is not exposed, but south of Hammond Hill, Pennsylvanian rocks are separated from pre-Pennsylvanian rocks by a distance of only a few hundred feet. The contact, as mapped, extends into a drift-covered area in the Slocum quadrangle at a point 3,000 feet south of the contact as mapped by Power (1959). Because of the lack of exposures, Power located the contact on the basis of topography. Since that time, however, test drillings have intersected graphitic rocks of the Rhode Island Formation south of Power's contact in the Slocum quadrangle. This test-drilling program was carried out by the U.S. Geological Survey; the rocks were identified by A.W. Quinn.

RHODE ISLAND FORMATION, UNDIFFERENTIATED

The Rhode Island Formation, undifferentiated, consists of a thick sequence of light-gray to black rocks—originally a great variety of sedimentary rocks including quartzose, carbonaceous, calcareous, and feldspathic sandstone, arkose, subgraywacke, graywacke, coarse to fine conglomerate, and shale. These rocks are characterized by sharp variations and great irregularity in grain size, mineralogy, and extent. Because beds are discontinuous, the sedimentary sequence in any one place is generally different from nearby rocks. The thicknesses of beds range from a few inches to 4 feet.

Because the rocks of the Narragansett basin have undergone progressive metamorphism, the grade of metamorphism increasing toward the south, a variety of metamorphic equivalents are found in a short distance. North of Pawtucket, which is approximately 22 miles north of Wickford, the rocks are virtually unmetamorphosed. In the Providence quadrangle, chloritoid and biotite schists are present, and farther south in the East Greenwich quadrangle, which is north of the Wickford quadrangle, garnet schist occurs (Quinn and others, 1949; Quinn, 1952, 1959; Quinn and Oliver, 1962). In the Wickford quadrangle, garnet-staurolite schist is known on the Conanicut Island.

The Rhode Island Formation at the northern margin of the Wickford quadrangle is fine-grained micaceous quartzite having a poorly developed schistosity. In the vicinity of Black Swamp, it has a few relict detrital rock fragments and feldspar grains, and contains garnet in places. Some of the garnet is in dodecahedral crystalline shells that enclose coarse grains of muscovite, biotite, and quartz. To the south, garnet is locally more abundant, particularly in the more argillaceous beds. Amphibole, together with chlorite, carbonates, and zoisite, is present in some of the most resistant darker, more graphitic beds. These beds are lenticular and as much as 5 inches thick.

In the vicinity of Plum Beach, especially in the roadcut on the west approach to Jamestown Bridge and in the quarries along the shore, most of the rock is thick-bedded light-gray granitelike quartzite containing garnet. Darker beds range from phyllite to fine-grained or conglomeratic micaceous schist. The feldspar content of these rocks is generally less than 35 percent. Bedding and crossbedding are conspicuous in these outcrops. Elongate pebbles are present in the conglomerate at this locality.

On the west shore of Conanicut Island, from a point 3,800 feet south of Jamestown Bridge to a point 500 feet north of Sand Point, euhedral staurolite as much as 6 inches long, mostly altered to chlorite, is present in black graphitic garnet-mica schist. This rock was originally iron-bearing shale. Adjacent, lighter colored, more quartzose beds contain garnet locally. In conglomeratic beds, the pebbles are elongated and flattened. Amphibole is present in a coarse-grained elongate-pebble conglomerate exposed in a quarry on North Main Road. The sedimentary rocks and their metamorphic equivalents on Conanicut Island are estimated to be 3,000 feet thick.

Fossil ferns are found 1,500 feet south of the east end of Jamestown Bridge within the area of the most intense metamorphism. The enclosing black graphitic rock is cut by many thin veins of fibrous quartz. Similar veins of fibrous quartz at Cranston, R.I., were reported by Richards (1925) to be replacements of aphrosiderite. The fossil-bearing beds are slickensided parallel to the foliation and adjacent beds contain staurolite and garnet. Dale (1885) referred to fossil plants found somewhere on the west shore of Conanicut Island, but one cannot be sure he referred to this area.

Hurley and others (1960) give a potassium-argon age determination on biotite from rock that they identified as "granite" from a sill in the roadcut leading to the west entrance of Jamestown Bridge. The age of this rock was given as 230±11 million years, which is Permian by the time scale of Faul (1960). However, detailed investigations of the rocks in this roadcut made by the author and A. W. Quinn, supported by the opinions of other geologists who have seen this roadcut, did not reveal any sill of granite. Instead, the rocks in this roadcut consist of metamorphosed interbedded massive sandstone and shale of the Rhode Island Formation. The sandstone in many places in this area now has a slightly granitic appearance, but clastic textures shown in thin section and sedimentary structures shown in the field, such as crossbedding, make its sedimentary origin unquestionable.

RHODE ISLAND FORMATION, ARGILLACEOUS FACIES

Pennsylvanian sedimentary rocks which were originally deposited as an argillaceous facies of the Rhode Island Formation are present south of Jamestown Brook on Conanicut Island.

In the Narragansett Pier quadrangle, most of the Pennsylvanian rocks on Conanicut Island are phyllite (Nichols, 1956). The northward extension of these rocks is exposed in the extreme southeast corner of the Wickford quadrangle. Eastward into Prudence Island quadrangle, the rocks decrease in metamorphic grade to soft slate.

The argillaceous facies of the Rhode Island Formation consists mostly of fine-grained greenish-gray to black phyllite or schist containing round metacrysts of chlorite pseudomorphous after garnet. Staurolite was not observed. The rock is shiny and crenulated in many places.

The contact between the argillaceous facies of the Rhode Island Formation and the undifferentiated facies is concealed. Differences in the attitude of beds suggest that it may be a fault contact.

The argillaceous facies of the Rhode Island Formation is the light greenish-gray micaceous schist of Collie (1895, p. 210) and the Aquidneck shales of Foerste (*in* Shaler, Woodworth, and Foerste, 1899, pl. 31). Fossils are not present, but the graphitic beds and their field relations suggest that these beds are Pennsylvanian.

UPPER PENNSYLVANIAN OR POST-PENNSYLVANIAN ROCKS

PEGMATITE

Concordant and discordant pegmatites are exposed as dikes and veins as far north as Stook Hill, but are more abundant to the south. Only one dike, on the east bank of Pettaquamscutt River at the south-central margin of the quadrangle, is mappable on a scale of 1:24,000. This pegmatite consists of microline, quartz, and a little muscovite. Concentrations of quartz and feldspar occur, but no zoning was observed; Nichols (1956) stated that pegmatites to the south are zoned.

In the vicinity of Packard Rocks and Plum Beach along the shore of Narragansett Bay, thin muscovite-rich pegmatite veins locally contain small euhedral white to green beryl.

The pegmatites are intrusive and are therefore post-Rhode Island Formation or late or post-Pennsylvanian in age. South of Saunderstown along the shore, the pegmatite contains many schistose inclusions. Nichols (1956) stated that the pegmatite was intruded during the later stages of crystallization of the Narragansett Pier granite that is exposed to the south, and near the close of, or after, the deformation of the Pennsylvanian sedimentary rocks.

QUARTZ VEINS

Quartz veins are present throughout the Wickford quadrangle. The only vein mappable on the scale of 1:24,000 is on the west shore of Conanicut Island, south of Jamestown Bridge. The vein of milky quartz includes fragments of folded schistose rock of the Rhode Island Formation, undifferentiated. Some or all of the local deformation of these beds therefore must have preceded the intrusion of the quartz. Nearly all the quartz veins are along planes of foliation or bedding. Quartz veins in the argillaceous facies of the Rhode Island Formation include aggregates of chlorite. They are believed to be Late Pennsylvanian or post-Pennsylvanian in age.

METAMORPHISM

Most of the rocks of the Wickford quadrangle have been subjected to thermal and dynamic metamorphism. The pre-Pennsylvanian rocks probably were metamorphosed prior to deposition of the Pondville Conglomerate, as indicated by regional studies.

The mineralogy and internal structure of these older rocks, except the metasedimentary rocks of the Blackstone Series, contrast with that of the Pennsylvanian rocks because of their plutonic origin. The biotite gneiss of the Blackstone Series, like the Hope Valley Alaskite Gneiss, the Ten Rod Granite Gneiss, and the Cowesett Granite, has a mineral assemblage including biotite, microcline, and oligoclase in proportions expectable in granitic rather than sedimentary rocks; however, if the biotite gneiss or other rocks are metamorphosed sediments, the mineral assemblage indicates a much higher grade of metamorphism than do the assemblages in the adjacent Pennsylvanian rocks. The predominant foliation and lineation approximately parallel those in the Pennsylvanian rocks across formational boundaries, and suggest a close genetic relationship. The only structural evidence in this quadrangle of the possible earlier metamorphism is a nondistinctive second foliation (see pl. 1) at an angle to the dominant trend in a few places in the Ten Rod Gneiss. This foliation could also be a relict primary structure of the plutonic masses. Minor amounts of garnet, chlorite, and sericite, and possibly miscovite, sphene, and magnetite may indicate alteration of this rock to garnet-staurolite grade during the regional metamorphism of Pennsylvanian age.

The metamorphism of Pennsylvanian age appears to have been in part dynamic, a result of folding during Appalachian time, and in part a result of the intrusion of the Narragansett Pier Granite which was probably also the source of the pegmatites and late quartz veins found in the Wickford quadrangle. Progressive metamorphism affected the southern part of the Narragansett basin and diminished in intensity northward to the Pawtucket area where the Pennsylvanian sedimentary rocks are unmetamorphosed. The Wickford area was subjected to temperatures and pressures of intermediate intensity that formed garnet, staurolite, and amphibole in the Rhode Island Formation. Later retrogressive metamorphism converted garnet and staurolite to chlorite in parts of the area. The foliation and linear structures in the metasedimentary rocks and in the earlier plutonic rocks indicate that the latter were affected by the same metamorphic conditions but reacted in a quite different manner. The igneous minerals were reoriented in response to the new temperatures and pressures with little change in mineral assemblage.

The fact that the argillaceous facies of the Rhode Island Formation on Conanicut Island is much finer grained and phyllitic suggests that it is much lower grade than the rocks in the undifferentiated unit; however, garnets were formed and later reconverted to chlorite, and the phyllitic character of the rock may be the result of the same process.

Lesser retrograde effects are present, however, in other areas. East of Black Swamp, some rock contains small dodecahedral crystals of garnet, some of which are chloritized. Two forms of garnet are present: a solid zoned variety, and a shell of garnet enclosing grains of muscovite, biotite, chlorite, and quartz. Some of the biotite which comprises part of the matrix is locally altered to chlorite. All combinations of these effects are found from unaltered garnet containing chloritized biotite to chloritized garnet and unaltered biotite.

STRUCTURAL GEOLOGY

The Narragansett synclinal basin is the dominant structural feature in the quadrangle. Part of the western margin of the basin lies in the Wickford quadrangle. The basin deepens to the east; its eastern margin is on the east side of Narragansett Bay near Tiverton, R.I. The metamorphosed sedimentary rocks that now fill the basin were deposited in Pennsylvanian time and lie uncomformably upon pre-Pennsylvanian rocks, which were folded and probably metamorphosed prior to the formation of the basin. The folding of the basin was associated with the Appalachian revolution.

The Mississippian(?) or older rocks, including the Ten Rod Granite Gneiss and its nonporphyritic and fine-grained facies, and the Hope Valley Alaskite Gneiss are structurally similar to one another. The planes of foliation have a very general easterly trend, and the linear features of the alaskite gneiss and the nonporphyritic facies of the Ten Rod Granite Gneiss plunge northeast. The Mississippian(?) or older rocks are overlain by the sedimentary rocks of the Narragansett basin that have similar plunge of linear features. There is a sharp discordance in structure less than a mile south of Hammond Hill, where the northeasterly strike of the Pennsylvanian strata contrasts with the northwest-trending foliation of the adjacent alaskite gneiss, but the discordance in foliation in the two units is no more than would be expected if these older rocks acted as a locus for the later folding that formed this schistosity. The discordant strikes and dips to this general trend may be relics from earlier features.

The arching of the northward-dipping foliation and the uniformity of the related linear features are among the most notable of the area; they were formed during the Appalachian revolution together with a series of tight to open folds whose axes trend northward. In most places the schistosity of the metasediments follows the bedding, but in some localities, notably near the west end of Jamestown Bridge and to the south, the foliation appears to be axial-plane cleavage. Contrasts in dip between foliation and bedding suggest a recumbent anticline thrust from the southeast near the Jamestown Bridge; south of Saunderstown, drag folds indicate the beds are also overturned to the west. This complex structure is in contrast to the simpler structure of the rest of the basin, though similar complexities are locally exposed in the adjoining Narragansett Pier quadrangle (Nichols, 1956).

Slickensided surfaces in rocks on the west shore of Conanicut Island indicate shearing and faulting between units of the Rhode Island Formation along the graphitic beds.

ECONOMIC GEOLOGY

Of the 11 lithologic units present in the Wickford quadrangle, only the Rhode Island Formation, undifferentiated, has been of economic significance. Evidence of earlier small quarrying operations is present in many localities. These quarries probably supplied small amounts of building stone, mainly metasandstone, to local areas. The quarries at Plum Beach, known locally as Hazard's quarry, produced metasandstone and were worked as a source of rock for piers and jetties along the seacoast. Graphite is reported to have been mined at the northern end of Conanicut Island, but no evidence of this was seen.

Ground water, an important resource in this area, is present along joints and other fractures in the pre-Pennsylvanian gneisses and in the more massive sandy Pennsylvanian rocks, and is also present in great quantity in valleys now filled by glacial debris. Water also occurs along fractures in the shaly beds of the Rhode Island Formation but, because of the presence of iron minerals, is locally unsuitable for drinking.

LITERATURE CITED

Collie, G. L., 1895, The geology of Conanicut Island, Rhode Island: Wisconsin Acad. Sci. Trans., v. 10, p. 199–230.

Dale, T. N., 1885, The geology of the mouth of Narragansett Bay: Newport Natl. Hist. Soc. Proc., v. 3, p. 8–11.

Emerson, B. K., 1917, Geology of Massachusetts and Rhode Island: U.S. Geol. Survey Bull. 597, 289 p.

Emerson, B. K., and Perry, J. H., 1907, The green schists and associated granites and porphyries of Rhode Island: U.S. Geol. Survey Bull. 311, 74 p.

Faul, Henry, 1960, Geologic time scale: Geol. Soc. America Bull., v. 71, p. 637–644.

Hurley, P. M., Fairbairn, H. W., Pinson, W. H., and Faure, G., 1960, K–A and Rb-Sr minimum ages for the Pennsylvanian section in the Narragansett basin: Geochim. et Cosmochim. Acta, v. 18, p. 247–258.

Moore, G. E., Jr., 1958, Bedrock geology of the Hope Valley quadrangle, R.I.: U.S. Geol. Survey Geol. Quad. Map GQ–105.

——— 1959. Bedrock geology of the Carolina and Quonochontaug quadrangles, R.I.: U.S. Geol. Survey Geol. Quad Map GQ–117.

Nichols, D. R., 1956, Bedrock geology of the Narragansett Pier quadrangle, R.I.: U.S. Geol. Survey Geol. Quad. Map GQ–91.

Power, W. R., Jr., 1959, Bedrock geology of the Slocum quadrangle, R.I.: U.S. Geol. Survey Geol. Quad. Map GQ–114.

Quinn, A. W., 1952, Bedrock geology of the East Greenwich quadrangle, R.I.: U.S. Geol. Survey Geol. Quad. Map GQ–17.

——— 1959, Bedrock geology of the Providence quadrangle, R.I.: U.S. Geol. Survey Geol. Quad. Map GQ–118.

Quinn, A. W., Jaffe, H. W., Smith, W. L., and Waring, C. L., 1957, Lead-alpha ages of Rhode Island granitic rocks compared to their geologic ages: Am. Jour. Sci., v. 225, p. 547–560.

Quinn, A. W., and Oliver, W. A., Jr., 1962, Pennsylvanian rocks of New England *in* Pennsylvanian System in the United States: Am. Assoc. Petroleum Geologists Symposium, p. 60–73.

Quinn, A. W., Ray, R. G., and Seymour, W. L., 1949, Bedrock geology of the Pawtucket quadrangle, R.I.-Mass.: U.S. Geol. Survey Geol. Quad. Map GQ–1.

Richards, Gragg, 1925, Veins with fibrous quartz and chlorite in the vicinity of Providence, Rhode Island: Am. Mineralogist, v. 10, p. 429–433.

Schafer, J. P., 1961, Surficial geology of the Wickford quadrangle, Rhode Island: U.S. Geol. Survey Geol. Quad. Map GQ–136.

Shaler, N. S., Woodworth, J. B., and Foerste, A. F., 1899, Geology of the Narragansett basin: U.S. Geol. Survey Mon. 33, 402 p.

U.S. GOVERNMENT PRINTING OFFICE: 1964