The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—Massachusetts, Rhode Island, and Maine

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Historical review and summary of areal, stratigraphic, structural, and economic geology of Mississippian and Pennsylvanian rocks in Massachusetts, Rhode Island, and Maine

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CONTENTS

ILLUSTRATIONS

[Plate follows references cited]

TABLE

THE MISSISSIPPIAN AND PENNSYLVANIAN (CARBONIFEROUS) SYSTEMS IN THE UNITED STATES — MASSACHUSETTS, RHODE ISLAND, AND MAINE

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ABSTRACT

In New England, deposits known or inferred to be of Carboniferous age are present in five basins in Massachusetts and Rhode Island and in several additional isolated localities in Massachusetts and eastern Maine. Rocks near Worcester, Mass., and in the Narragansett and Norfolk Basins are dated as Pennsylvanian on the basis of plant megafossils. Deposits of the Boston, Woonsocket, and North Scituate Basins and the Harvard Conglomerate at Pin Hill, Harvard, Mass., are of uncertain age but may be Carboniferous. Rocks within a series of graben blocks in eastern Maine are inferred to be Carboniferous.

The Narragansett Basin, Massachusetts and Rhode Island, is a structural depression and topographic lowland occupying 2,460 km^2. Rocks dated by plant megafossils as Early to Late Pennsylvanian unconformably overlie a Cambrian or Precambrian basement; the Precambrian basement consists primarily of 600-million- to 650-million-year-old granitic rocks cutting older volcanic, volcaniclastic, and plutonic rocks. The Middle to Upper Pensylvanian rocks are coal, sandstone, conglomerate, siltstone, and shale. Distribution of lithologies and sedimentary structures in the approximately 3,700-m-thick section indicate that most of the sedimentary rocks of the five formations that compose the section were deposited in a fluvial environment.

Anthracite and semianthracite are found widely, in seams as much as 8 m thick, in the 1,700-km^2 part of the basin that has undergone lower greenschist-facies metamorphism. These coals have very low sulfur contents; have moderate to high contents of ash, which is dominantly secondary quartz; and yield 13,000 to 14,700 BTU's per ton.

The Narragansett Basin is characterized by a rich megaflora consisting of 300 nominal species from approximately 140 floral localities. Nearly all are confined to the Rhode Island Formation and range from Alleghenian to Conemaughian (Westphalian C to Stephanian A) or younger.

Most rocks in the Narragansett Basin are in the lower greenschist facies; however, in southern Rhode Island, the regional metamorphic grade increases in a short distance to upper amphibolite facies and, in at least an indirect way, is associated with the late syntectonic to posttectonic Narragansett Pier Granite of Permian age. The larger, Massachusetts, part of the basin is faulted and mildly folded. In contrast, the southern, Rhode Island, section of the basin is moderately to intensely deformed and is characterized by several generations of folds and faults.

The Norfolk Basin contains two formations of Pennsylvanian age, the Wamsutta Formation and the Pondville Conglomerate; these formations are also present in the adjacent Narragansett Basin. In the Norfolk Basin, these rocks are present in a syncline overturned to the southeast and are in part bounded by thrust faults. Plant fossils from the Pondville suggest a Pottsvillian age, probably equivalent to the Westphalian B of Maritime Canada and Europe.

The Woonsocket and North Scituate Basins contain clastic sedimentary rocks long correlated with those of the Narragansett Basin; however, they may be much older. The beds dip generally to the east, are polydeformed, and are in the upper greenschist facies of metamorphism.

Two small patches of nonmarine phyllite are present near Worcester, Mass. Phyllite encloses a 2-m-thick lens of meta-anthracite at the "Worcester Coal Mine." To the south, at the second outcrop area, a similar phyllite is interbedded with coarse stretched-pebble conglomerate, granule conglomerate, and arkose. The metamorphic grade is just below the almandine isograd. On the basis of plant fossils, the rocks are assigned an Early to Middle Pennsylvanian age. The Harvard Conglomerate, an isolated deposit northeast of Worcester, has been considered Pennsylvanian. However, the unit is unfossiliferous, and the field relationships have been debated.

The bedrock in and near the Boston Basin may be assigned to five map units: (1) "basement," Precambrian, possibly including some Paleozoic; (2) Blue Hills-Quincy and Nahant areas, Lower and Middle Cambrian sedimentary rocks and Ordovician(?) igneous rocks; (3) Mattapan and Lynn Volcanic Complexes, possibly as old as Precambrian or as young as Pennsylvanian; (4) Boston Bay Group, having a maximum thickness of 5,700 m and consisting of the Cambridge Argillite and the Roxbury Conglomerate, which is a southerly lithofacies of the lower part of the Cambridge

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Argillite; and (5) Triassic(?) diabases. A diamictite (tillite) is present at the top of the Roxbury Conglomerate.

Because supposed fossils collected from the Boston Bay Group may be inorganic, the age of the group is still in doubt. On lithologic and tectonic grounds, the group is considered to be Pennsylvanian, but other ages have been proposed.

The strata of the Boston Bay Group are thrown into a series of folds, most of which plunge eastward. Five longitudinal faults, some of which dip steeply, are present. One transverse fault strikes north. The deformation was late Paleozoic.

Similarities in ages, lithologies, stratigraphy, and structure of the Narragansett and Norfolk Basins and of the deposits at Worcester suggest that their origins are related and that all these deposits may have been part of a single fluviatile, nonmarine basin. The ages of the Boston, Woonsocket, and North Scituate Basins are uncertain. These three basins are dissimilar enough from the other basins and have lithologies and stratigraphy, in part at least, similar enough to fossiliferous Cambrian rocks to suggest that they may be much older than Carboniferous. All five basins and the deposits at Worcester were deformed by folding and faulting in the Alleghanian orogeny.

Sedimentary rocks inferred to be of Carboniferous age have been mapped in eastern Maine within a series of graben blocks related to segments of the 320-km-long Norumbega fault system. The rocks have been tentatively separated into two members, arkosic and nonarkosic. The unit consists of multicolored bedded and nonbedded siltstone, sandstone, arkose, and polymictic conglomerate. No fossils or economic minerals have been reported.

INTRODUCTION

Deposits of the Narragansett Basin, Massachusetts and Rhode Island, deposits of the Norfolk Basin, Massachusetts, and deposits near Worcester, Mass., are dated as Pennsylvanian on the basis of plant megafossils. Deposits of the Boston, Woonsocket, and North Scituate Basins and the Harvard Conglomerate at Pin Hill, Harvard, Mass., are of uncertain age but may be Carboniferous. Sedimentary rocks within a series of graben blocks in eastern Maine are inferred to be Carboniferous. The area in southeastern New England occupied by deposits known or inferred to be Carboniferous is shown in figure 1.

The stratigraphic nomenclature used in this paper has not been reviewed by the Geologic Names Committee of the U.S. Geological Survey. The nomenclature used here conforms with the current usage of the Massachusetts Department of Public Works; the Massachusetts Department of Environmental Quality Engineering Office, of the State Geologist; and the Maine Geological Survey, Department of Conservation.

ACKNOWLEDGMENTS

Research in the Narragansett Basin was supported largely by NSF (National Science Foundation) Grant No. AER7602147 and U.S. Bureau of Mines Contract No. J0188022; that in the Norfolk Basin was supported by NSF Grant No. AER 7602147.

We wish to acknowledge the excellent spirit of cooperation among the authors of the several parts of this chapter. We are also grateful to members of the Narragansett Basin Project who have assisted in various phases of the field and laboratory studies, particularly Frederick Adinolfi, Robert Bouchard, Gregory Gintoff, Jay Jones, Daniel Logue, Anne O'Connell, Jonathan Raben, James W. Ring, S.J., Peter Rushworth, and Tarin Smith and to Joanne Tucker, Sally Sargent, and Bruce Withey who assisted in the preparation of the manuscript and illustrations.

P. C. Lyons wishes to acknowledge Clifford G. Grant, who collected the plant specimens illustrated on plate 1, and Paul Jappe, who photographed them. The identification of *Neuropteris rarinervis* (pl. 1, fig. Q) was made by W. C. Darrah.

No review of the Carboniferous geology of New England would be complete without mentioning the late Alonzo W. Quinn, who was the driving force behind the systematic mapping and related studies in the Narragansett Basin and other parts of New England during the last several decades. We wish to dedicate these papers to this geologist, one of the dedicated pioneers of regional geologic studies in New England and one who gave substantial moral support to the Narragansett Basin Project from the beginning and who followed its progress with interest and encouragement.

We thank William R. Barton, Joseph Pecoraro, and Joseph Sinnott for their encouragement to the senior author to undertake the Narragansett Basin Project and for their assistance, as well as that of very many people, especially the Hon Margaret M. Heckler who supported the project from the beginning, Thomas P. O'Neill III, Lt. Governor of Massachusetts, and the entire New England Congressional delegation. Additionally, we acknowledge Russell Dutcher, Lincoln R. Page, Nicholas Rast, and especially Irving Sacks for valuable assistance at many stages of the project and all the many others too numerous to mention who have contributed in important ways.

NARRAGANSETT BASIN OF MASSACHUSETTS AND RHODE ISLAND

By JAMES W. SKEHAN, S.J., and DANIEL P. MURRAY

The Narragansett Basin is a structural depression and topographic lowland occupying 2,460 km². Rocks

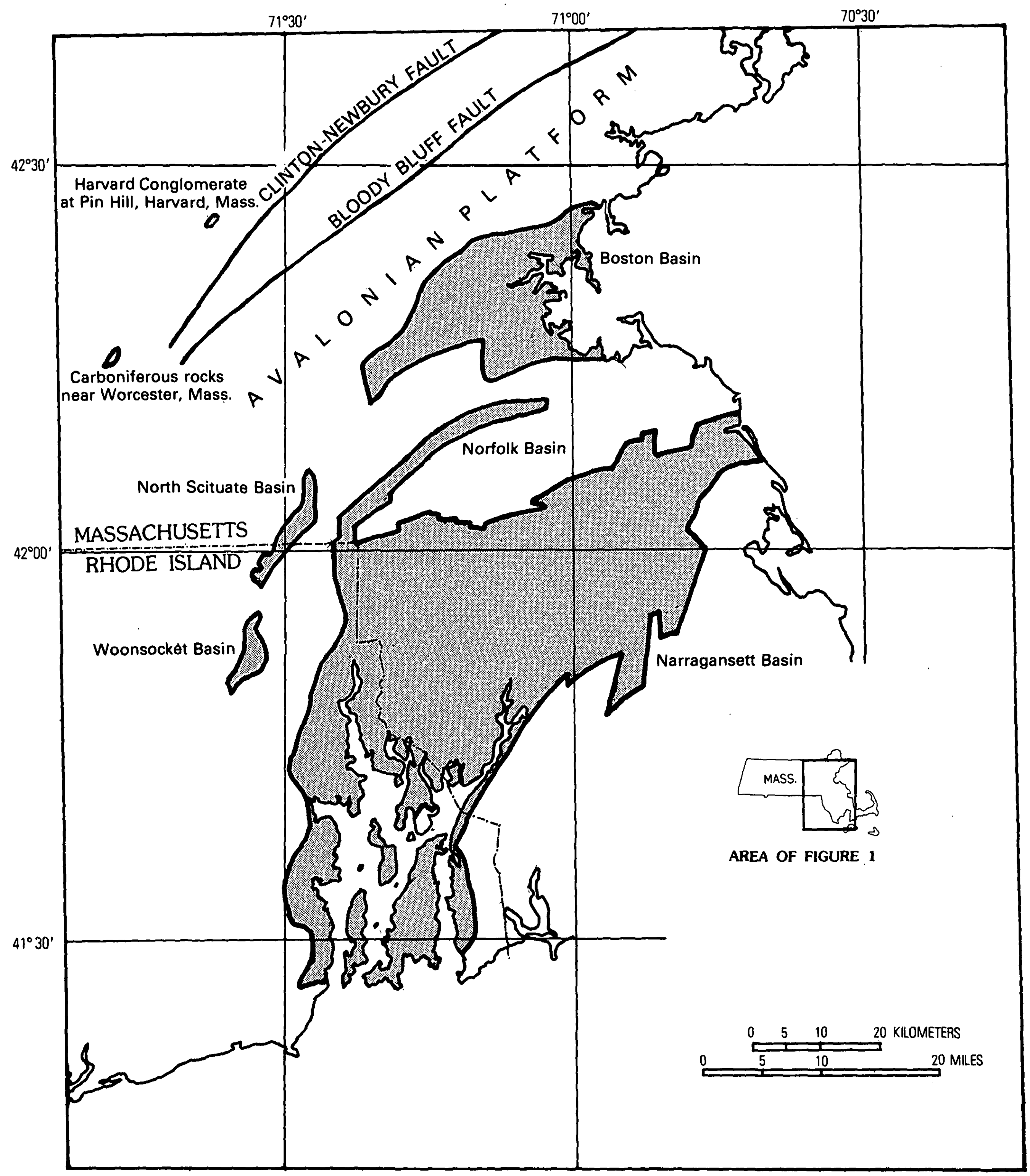


FIGURE 1.—Area of southeastern New England occupied by deposits known or inferred to be Carboniferous.

dated by plant megafossils as Early to Late Pennsylvanian unconformably overlie a Cambrian or Precambrian basement; the Precambrian basement consists primarily of 600-million- to 650-million-year-old granitic rocks (Naylor, 1975) cutting older volcanic, volcaniclastic, and plutonic rocks. The Middle to Upper Pennsylvanian rocks (fig. 2) are coal, sandstone, conglomerate, siltstone, and shale. Distribution of lithologies and sedimentary structures indicate that most of the sedimentary rocks were deposited in a fluviatile environment. Most of these rocks are in the lower greenschist facies; however, in southern Rhode Island, the regional metamorphic grade increases in a short distance to upper amphibolite facies and, in at least an indirect way, is associated with the late syntectonic to posttectonic Narragansett Pier Granite of Permian age. The larger, Massachusetts, part of the basin is faulted and mildly folded. In contrast, the southern, Rhode Island, section of the basin is moderately to intensely deformed and is characterized by several generations of folds and faults.

The first detailed survey of the Narragansett Basin was by Shaler, Woodworth, and Foerste (1899). More recently, Quinn and Oliver (1962), Mutch (1968), and Skehan and Murray (1978) provided comprehensive reviews of the geology of this basin and of the many previous reports on it. All Rhode Island has been mapped at the scale of 1:24,000, and these data are available as published or open-file reports. This work is summarized on the geologic map of Rhode Island (Quinn, 1971). Lyons (1977) has mapped the Massachusetts part of the basin in reconnaissance at this scale; his maps are available at the scale of 1:31,250 (Lyons, 1977).

BASIN CONFIGURATION

Recent mapping has resulted in several significant changes in our ideas of the shape of the Narragansett Basin (fig. 2): (1) Discovery of a trilobite fauna having Acado-Baltic affinities indicates that phyllites on Conanicut Island that were previously mapped as Carboniferous are Middle Cambrian marine metasediments (Skehan, Murray, Palmer, and Smith, 1977). (2) The Narragansett Basin may extend to the northeast at least as far as the present coastline (Lyons, 1977, p. 17); moreover, the basin may continue some distance beneath the sea north of Cape Cod Bay. (3) New floral ages (Brown and others, 1978) confirm the previously assumed Pennsylvanian age for the clastic metasedimentary rocks along the southwest margin of Narragansett Bay. (4) Observations on distribution of glacial erratics relative to bedrock indicate that Pennsylvanian deposits of the Narragansett and Norfolk Basins are separated by no more than 1 km near the northeastern corner of Rhode Island, suggesting that the two basins were formerly connected. Recent geophysical studies off southern New England (McMaster and Collins, 1978, p. 15) suggest that the basin extends 16–22 km south-southwest of Narragansett Bay.

Contacts between Pennsylvanian sedimentary rocks and basement rocks along the basin margin and within the basin are exposed in only a few localities. In some exposures, the contact is an unfaulted unconformity; in others, the Pennsylvanian rocks are in contact with basement rocks as a result of faulting (Quinn, 1971; Skehan and others, 1976; Lyons, 1977).

A relatively simple geometry has been assumed for the basement-cover configuration (Shaler and others, 1899, fig. 8). High-angle normal and low-angle thrust faults are thought to define the irregular contact in places. A schematic structural profile of the southern Narragansett Basin is shown in figure 3.

STRATIGRAPHIC RELATIONSHIPS

Five formations, now referred to collectively as the Narragansett Bay Group (new name), are recognized in the Narragansett Basin, the Pondville Conglomerate, the Wamsutta Formation, the Rhode Island Formation, the Dighton Conglomerate, and the Purgatory Conglomerate. All these consist of clastic terrigenous sedimentary rocks. Lack of outcrop coupled with rapid facies changes and structural complexities has prevented the construction of a detailed stratigraphy for the Narragansett Basin. The stratigraphic sequence of these units is the same as that presented by Mutch (1968, fig. 2), except for the age assignment of the Purgatory Conglomerate, which may be correlative with the Dighton Conglomerate. A previously estimated total thickness (Shaler and others, 1899) of 3,700 m for these formations was highly speculative; however, it is consistent with stratigraphic sections determined recently from depth to basement under the Narragansett Basin computed from gravity observations (Peter Sherman, written commun., 1978). The lithologic characteristics and ages of these formations are summarized in table 1.

Pondville Conglomerate.—The type locality for the Pondville Conglomerate is in the Norfolk Basin at Pondville Station, Mass. (Shaler and others, 1899, p. 134–139), where it consists of coarse conglom-

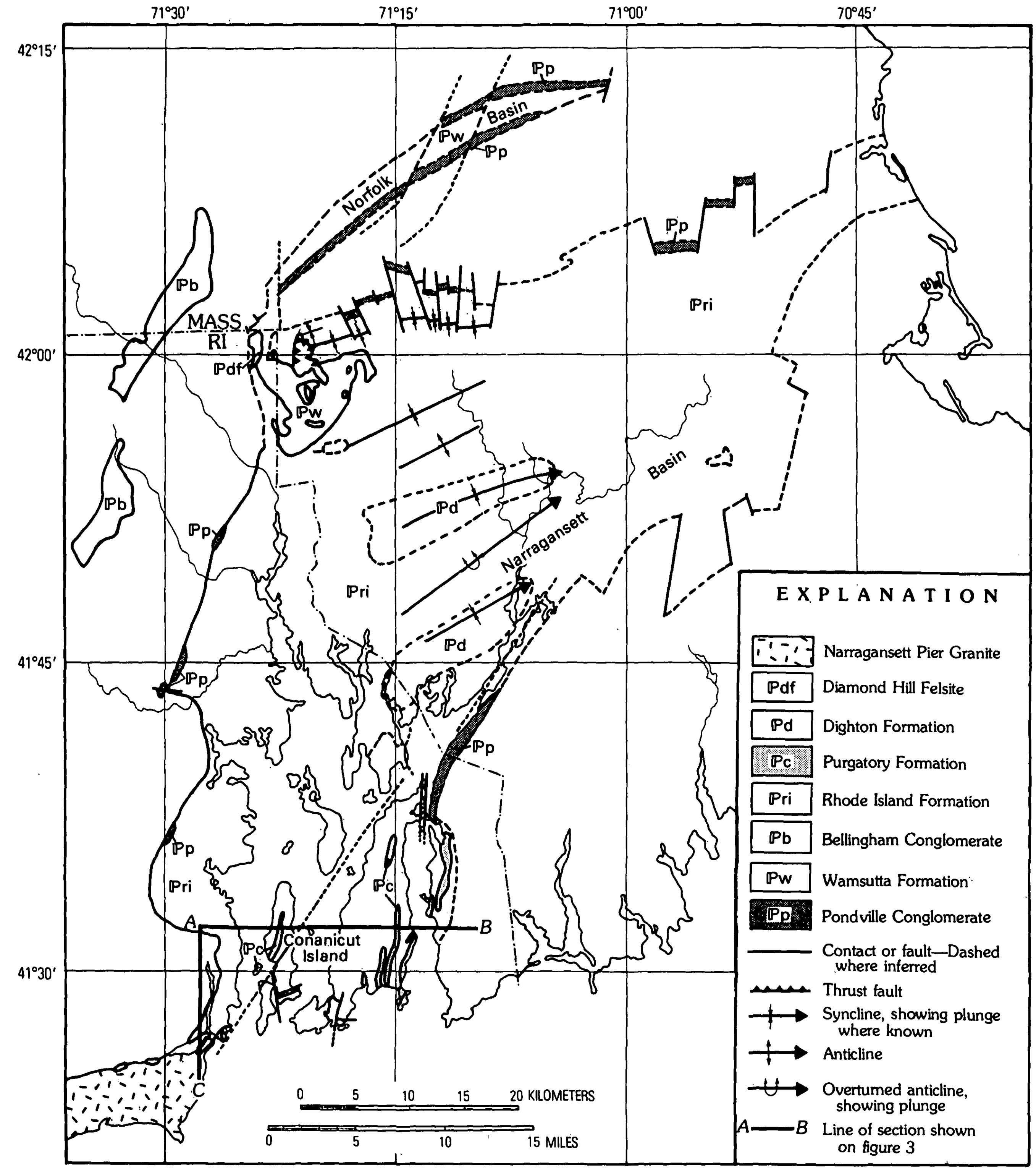


Figure 2.—Geologic map of the Narragansett, Norfolk, North Scituate, and Woonsocket Basins, Massachusetts and Rhode Island. Locations of structural profiles (figs. 3, 5) are shown. The complex fold patterns of the southern part of the Narragansett Basin are not shown.

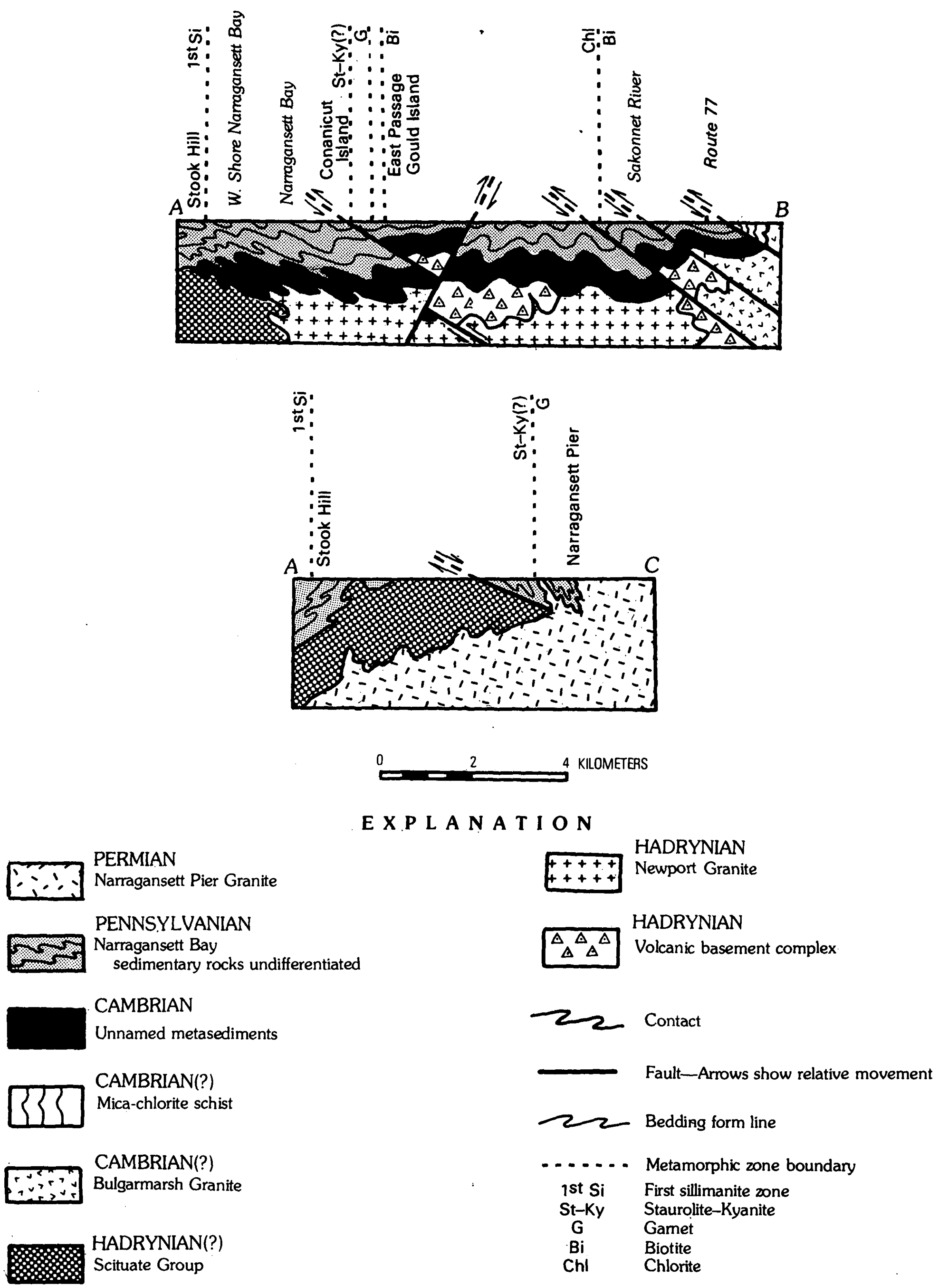


Figure 3.—Schematic structural profile across the southern Narragansett Basin.

TABLE 1.—*Description of stratigraphic units in the Narragansett and Norfolk Basins*

Stratigraphic unit	Lithology	Sedimentary and other distinguishing features	Approximate thickness	Age	References [1]
Purgatory Conglomerate.	Coarse-grained to very coarse grained conglomerate, interbedded with thin sandstone and magnetite-rich sandstone lenses; clasts in conglomerate are almost entirely quartzite, but several varieties of quartzite are present.		>30 m (>100 ft)	No Pennsylvanian floro yet known, but coal pebble is present; several distintive lower Paleozoic faunas are present in quartzite clasts.	Mosher and Wood, 1976.
Dighton Conglomerate.	Gray conglomerate consisting primarily of rounded quartzite cobbles to boulders and containing subordinate rounded granite cobbles and slate pebbles; very little sand matrix; lenses of medium sandstone form less than 20 percent of the unit.	The sandstone lenses are faintly cross-bedded and coarser both upward and downward into adjacent conglomerate.	<300–450 m (<1,000–1,500 ft)	Small isolated amounts of allochthonous? nondiagnostic plant debris.	Skehan and others, 1976.
Rhode Island Conglomerate.	Gray sandstone and siltstone and lesser amounts of gray to black shale, gray conglomerate, and coal 10 m (30 ft) thick. Quartz forms the major components of the sandstone (Mutch, 1968, fig. 5) and conglomerate.	Both fining- and coarsening-upward sequences are present; paleocurrents have been defined only locally; conglomerate is relatively less abundant than in Dighton.	<3,000 m (<10,000 ft)	Westphalian C and D and Stephanian.	Skehan and Murray, 1978; Lyons and Chase, 1976.

TABLE 1.—*Description of stratigraphic units in the Narragansett and Norfolk Basins*—Con.

Stratigraphic unit	Lithology	Sedimentary and other distinguishing features	Approximate thickness	Age	References[1]
Wamsutta Formation.	Interbedded red coarse-grained conglomerate, lithic graywacke, sandstone, and shale; conglomerate layers contain felsite clasts <1.2 m (4 ft); a few lenses of limestone, one rhyolite flow, and several sheets of basalt are present.	Crossbedding and interfingering of layers is characteristic.	300 m (1,000 ft)	Partly equivalent to the Rhode Island Formation as the red layers interfinger with gray and black; contains a few plant fossils.	Lidback, 1977.
Pondville Conglomerate.	At type locality (Pondville Station, Mass.): interbedded red and green slate, siltstone, arkose, and quartzite-pebble conglomerate; elsewhere may also include gray to greenish coarse conglomerate, most pebbles being quartzite, but some being granite or schist; abundant sandy matrix; and dark-gray granule conglomerate containing pebbles of smoky quartz 5 mm (0.2 in.) in diameter irregularly bedded with sandstone and lithic graywacke.	Generally, a basal conglomerate is absent, and the first-deposited beds are siltstone or arkosic sandstone; however, sandstone and shale of the Wamsutta Formation or Rhode Island Formation may lie directly on older rocks; clasts 15–60 cm (6–25 in.) in diameter.	0–150 m (0–500 ft)	Westphalian A or B.	

[1] These references are in addition to Quinn and Oliver (1962), Mutch (1968), and Quinn (1971), which contain information on all these stratigraphic units.

erate resting unconformably upon pre-Devonian rocks. The conglomerate grades vertically into gray sandstone that grades into Wamsutta redbeds.

However, in the Narragansett Basin, the Pondville consists of discontinuous arkosic beds and, to a lesser extent, conglomerate (Mutch, 1968) resting unconformably upon basement rocks that are at least locally deeply weathered. Its absence along most parts of the basin margin may be due to faulting or nondeposition. Moreover, where present, it grades upward into either the Wamsutta Formation, as in the northwest part of the basin, or directly into the Rhode Island Formation, as in southern Narragansett Bay. Finally, we agree with Mutch (1968, p. 180–181) that in the Narragansett and Norfolk Basins, this unit contains many lithologies (see table 1), but we are continuing the traditional use of the name Pondville Conglomerate rather than using the name Pondville Formation.

Wamsutta Formation.—The type locality of the Wamsutta Formation is at Wamsutta Mills, North Attleboro, Mass. (Shaler and others, 1899, p. 144). This unit consists of conglomeratic to arkosic redbeds (table 1). Unlike the Wamsutta in the Norfolk Basin, the Wamsutta in the Narragansett Basin contains a significant amount of volcanic deposits. The Wamsutta Formation interfingers with gray and black sandstones and shales of the Rhode Island Formation. Mutch (1968, p. 187–188) has described the Wamsutta in detail.

Rhode Island Formation.—The Rhode Island Formation was originally called the Rhode Island Coal Measures (Shaler and others, 1899, p. 134, 159). The evolution of the name and a description of the rocks that compose the formation were given by Mutch (1968, p. 183) and Quinn (1971, p. 39–41). The lithologic characteristics are summarized in table 1.

The Rhode Island Formation consists largely of gray sandstone and siltstone and contains lesser amounts of gray to black shale, gray conglomerate, and coal (table 1). Calcareous rocks are confined to the southwestern metamorphosed part of the basin where they are now represented as amphibolite.

This formation constitutes most of the basin; however, because of stratigraphic complexity and lack of outcrops, it is not well understood. Ongoing work in the basin by the staff of Weston Observatory, Department of Geology and Geophysics, Boston College, is concentrated on the Rhode Island Formation (Weston Observatory Staff, 1977). These studies involve mapping of outcrops and a geophysical and drilling program whose purpose is to delineate the coal resources of the basin. Early results of these studies, including detailed logs of 3,100 m of drill core, have provided preliminary information on sedimentary cycles and the paleoenvironment of the Rhode Island Formation (Skehan and others, 1976. p. 449–458; Skehan and Murray, 1978).

Dighton Conglomerate.—The type locality of the Dighton Conglomerate is in Dighton, Mass. (Shaler and others, 1899, p. 184–187). The Dighton consists, for the most part, of cobble conglomerate in the cores of three poorly defined synclines (fig. 2 and table 1).

Purgatory Conglomerate.—The type locality for the Purgatory Conglomerate is Purgatory Chasm in southern Narragansett Bay. Clasts in the Purgatory are cobble- to boulder-sized quartzite. This formation is confined to the southeastern part of the basin where it is everywhere deformed into a stretched-pebble conglomerate (table 1). In the past it has been correlated either with the Dighton (Emerson, 1917, p. 55) or with the lower part of the Rhode Island Formation (Quinn and Oliver, 1962, p. 67). The recent discovery by John Peck (oral commun., 1978) of a well-rounded coal pebble in the Purgatory, although not diagnostic, favors a higher stratigraphic position rather than a lower one. We believe that now no compelling structural or stratigraphic evidence exists for correlating the Purgatory with the lower part of the Rhode Island Formation; results of ongoing studies show that the Purgatory Conglomerate may be near the top of the stratigraphic column (Sharon Mosher, written commun., 1977; Skehan and Murray, 1978). Thus, on the basis of recent structural data and lithologic similarities, we believe that the Purgatory is probably correlative with the Dighton Conglomerate.

COAL DEPOSITS

The Narragansett Basin supported the limited intermittent mining of anthracite from 1808 until 1959. Studies of this coal were reviewed by Toenges and others (1948) and Quinn and Glass (1958). Because of energy shortages in New England and renewed interest in coal, these coal deposits are being reevaluated in a study that relies heavily upon moderately deep continuously cored boreholes (Skehan and Murray, 1978). This section summarizes the results to date of studies of the coal drilled during this program.

As outcrops of coal-bearing rocks are very scarce in the virtually unmetamorphosed part of the Narragansett Basin, only approximately 25 coal occurrences have been recorded (fig. 4); most of these are prospects or small abandoned mines, and more than half of these places were mined. The largest mine was at Portsmouth, R.I., and yielded more than 1 million short tons (Harry Chase, written commun., 1978).

The locations of completed drill holes, chosen primarily to sample these coal occurrences, are shown in figure 4. The coal is anthracite and semianthracite, not meta-anthracite as previously reported. A complete description of the chemical and physical properties of the coal is contained in Skehan and Murray (1978).

Coal seams sampled during drilling are as much as 10 m thick and commonly are internally folded and brecciated. The coal has an very low sulfur content and is moderate- to high-ash anthracite yielding 13,000–14,700 BTU's per ton (as determined from dry samples free of mineral matter). Megascopically, the coal has a dull graphitic appearance and is friable.

Vitrinites are textured and untextured and show mosaic structures in some samples and have reflectance values in the range of normal anthracite; organic inert components have unusually low reflectances. Mineral matter includes quartz, sericitized feldspar, chlorite, illite or muscovite, calcite, pyrite, marcasite, chalcopyrite, sphalerite, and rutile. Petrographically, three types of coal are seen: (1) normal anthracite similar to Pennsylvania anthracite; (2) brecciated anthracite having graphitic carbon coating on surfaces of voids and cracks and common annealing textures; (3) natural coke having graphitic coating similar to type 2. In both types 2 and 3, the secondary carbon acts as a cementing agent.

These coals are interpreted to have undergone coalification to low-volatile bituminous and semianthracite rank. These two ranks were then deformed to produce natural coke and brecciated anthracite, respectively; voids may have formed where coal migrated to low-pressure areas. The deformation also released methane that was subsequently thermally cracked to produce a carbon-rich gas phase. Upon cooling, carbon precipitated out to give the graphitic coating now seen, (Ralph Gray, written and oral communs., 1978). This model for the evolution of the coals correlates well with the known tectonic and metamorphic history of the Narragansett Basin and can also explain many of the previously confusing physical and chemical analyses of the coals.

STRUCTURAL GEOLOGY

The Narragansett Basin is characterized by two structural domains separated approximately along the State boundary between Massachusetts and Rhode Island. In Massachusetts, the deformation was relatively mild, being characterized by northeast- to east-northeast-trending folds (fig. 2) having axial planes dipping moderately to steeply to the northwest. In Rhone Island, the deformation was more intense and is characterized by mainly north-trending folds. It is not yet clear whether this change in trend is accomplished abruptly near the head of the Narragansett Bay, approximately along the Rhode Island-Massachusetts border, or gradually along an arcuate path whose axial region is the area noted above. The southern part of the basin is characterized by folds overturned to the west and associated east-dipping cleavage. The northern part of the basin, like the northern part of the Norfolk Basin (fig. 2), appears to be characterized by less intensely deformed folds that are overturned to the southeast and by associated northwest-dipping cleavage. The rocks of the southern part of the basin are lightly overprinted by structures that are dominant in the northern part of the basin. The Carboniferous rocks of the Narragansett Basin show fewer magnetic lineaments than the rest of southern New England west of the basin (Barosh and others, 1977). Those present are extensions of magnetic lineaments in older basement rocks.

Pennsylvanian rocks at several widely separated localities, such as the Hanover, Mass., and Middletown, R.I., areas, rest unconformably on older rocks of Late Precambrian and Cambrian age. At several other widely separated localities, Precambrian and Cambrian rocks are in fault contact with Pennsylvanian rocks. Whether the Pennsylvanian rocks were for the most part deposited on an extensively eroded land surface or in separate faulted basins is not yet known.

Southern Narragansett Basin.—Mapping by Mosher and Wood (1976) and Skehan and Murray (1978) has shown that the dominant structural features of the southern part of the Narragansett Basin are asymmetric westward-verging folds having east-dipping axial-plane cleavage. Closely associated east-dipping, west-directed thrust faults displace Pennsylvanian rocks. Superimposed on these earlier formed structures is a less conspicuous cleavage commonly associated with westward-dipping, high-angle reverse faults (Skehan, Belt, and Rast, 1977; Mosher and Wood, written commun., 1977; Skehan and Murray, 1978). Late normal faults cut earlier structures (Quinn, 1971, pl. 1).

A stretched-pebble conglomerate containing extraordinarily elongated pebbles is present in many different localities in the southern Narragansett

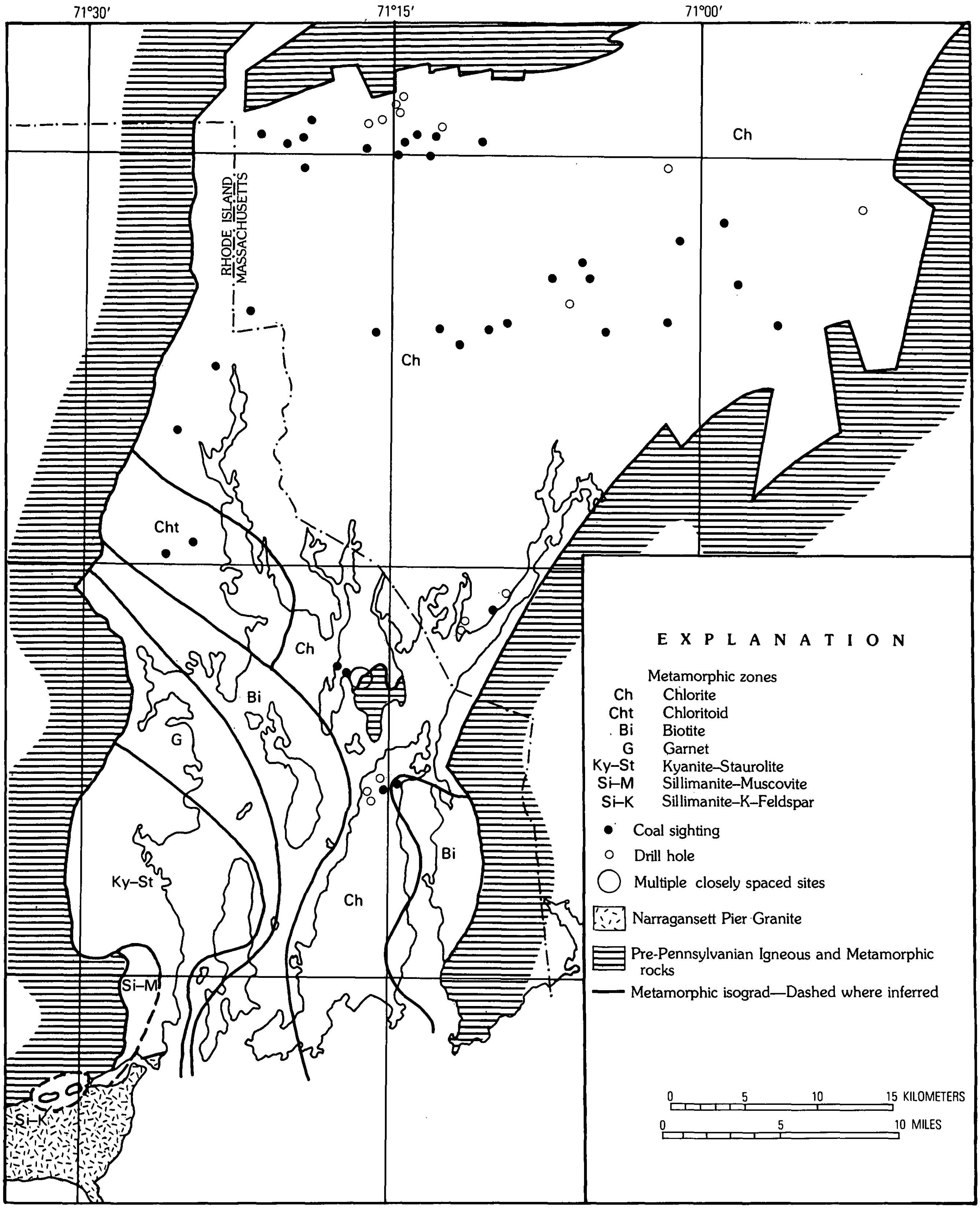


FIGURE 4.—Metamorphic zones and locations of drill holes and coal sightings in the Narragansett Basin.

Basin. A classic location is at Purgatory Chasm, Aquidneck Island, Rhode Island, the type locality of the Purgatory Conglomerate. The longest axis is typically parallel to the primary fold axis.

Northern Narragansett Basin.—The regional folding pattern in the northern part of the Narragansett Basin is defined chiefly by reconnaissance mapping of the Dighton Conglomerate in the east-northeast-trending Great Meadow and Dighton synclines (Shaler and others, 1899; Lyons, 1977). The intensity of metamorphism and deformation effects in the north are far less than in the south.

Faults.—Faults of several orientations and relative ages have been recognized and mapped in a preliminary and reconnaissance fashion (Shaler and others, 1899; Quinn, 1971; Skehan and others, 1976; and Lyons, 1977). Figure 2 shows a number of such faults.

West-directed, east-dipping thrusts, interpreted as early, are succeeded by west-dipping high-angle reverse faults. These compressional faults are considered to be of Alleghanian age. Preliminary mapping by ourselves and by Lyons (1977) suggests that the southeastern margin of the basin may be controlled by such a fault, although its angle of dip is not yet known. The northeasern part of the basin may be a thrust cut by later normal faults (fig. 2).

At the Masslite Quarry, Plainville, Mass., southeast-dipping thrust faults, cut by later north-striking normal faults, are recognized. This sequence of faults suggests that the Pennsylvanian rocks of the Narragansett Basin may have been thrust northwestward over the basement and later displaced by normal faults. An 865-foot NX-cored hole near the quarry shows that the Pennsylvanian sedimentary rocks are unconformable on the basement; therefore, the above-mentioned thrust faults are in the cover rocks.

The northern margin of the basin (fig. 2) and the eastern third of the southern margin are assumed to be offset by normal faults that strike generally within 20° of north. Quinn (1971) mapped a horst block near the southeastern margin of the basin as being bound by north-striking faults and as exposing basement rocks of the Metacom Granite. The granite is cut by a series of closely spaced east-dipping older thrusts. The western margin of the basin at Diamond Hill is marked by a generally north-striking silicified fault zone (Quinn, 1971), similar in orientation to that in Bristol, R. I. (fig. 2).

Faults striking generally northwest or northeast may be more numerous than previously recognized; offset on the northeast-striking faults may be more important than offset on the northwest-striking faults. Evidence for the existence and orientation of the northwest-striking faults in the southern part of the basin consists of (1) various combinations of topographic and drainage alinements that in some places are associated with subparallel orientation of structural elements in the bedrock, (2) offsets of basin margins, and (3) steplike offsets of shorelines. Because these faults have limited demonstrated continuity, they have not been shown in figure 2.

METAMORPHISM

The Narragansett Basin has undergone a Barrovian regional metamorphism that increases in intensity to the southwest as shown in figure 4. The metamorphic gradient is neither uniform nor simple. All the Massachusetts part of the basin and part of the Rhode Island part of the basin are in the chlorite zone, on the basis of mineral assemblages and coal rank. The thermal maximum of this regional metamorphism is roughly centered about the contact between the Narragansett Pier Granite and Pennsylvanian metasediments. However, in detail, it appears that (1) the isograds are oblique to structural trends but are truncated by the granite, and (2) the thermal maximum is actually displaced somewhat to the north of the granite. Our ongoing studies of the southwestern part of the basin suggest that the peraluminous Narragansett Pier Granite is anatectic in origin and thus may be one of the results of the metamorphism and not the cause.

Radiometric dates on muscovite and biotite from the kyanite-staurolite zone indicate a Permian age for the metamorphism (Hurley and others, 1960). Moreover, sillimanite-bearing mineral assemblages in eastern Connecticut may represent the western extension of the Alleghanian metamorphism recorded in Rhode Island (Murray and others, 1978).

Our studies also suggest that sedimentary rocks in the southwestern part of the basin record three episodes of metamorphism: (1) an early greenschist facies of dynamothermal metamorphism; (2) a later period of static prograde Barrovian facies series that peaked at the second sillimanite isograd; and (3) a youngest, localized greenschist facies of dynamothermal retrograde metamorphism.

Because of the availability of thousands of meters of drill core from Massachusetts and northern Rhode Island and abundant sea cliff exposures, roadcuts, and drill core from construction sites in the southwestern part of the basin, we have begun a study of the effects of progressive metamorphism and deformation on coal and associated rock under a wide range of conditions (D. Murray, J. Rehmer, and J. C. Hepburn, unpub. data, 1978). Because of the sensitivity of coal to changes in temperature, pressure, and other factors, study of this area promises to yield valuable insights into regional metamorphic processes.

IGNEOUS ACTIVITY

Both extrusive and intrusive igneous rocks are present within or adjacent to the Narragansett Basin. The former are limited to felsic and mafic flows within the Wamsutta Formation in the Attleboro area. Moreover, the Wamsutta contains a relatively high percentage of volcanic detritus, implying the presence of abundant volcanoes during its formation (Mutch, 1968).

The subsolvus Narragansett Pier Granite intrudes the southwest margin of the Narragansett Basin. Away from the contact with the sedimentary rocks, this pink granite contains abundant biotite and subordinate muscovite. Near the Pennsylvanian sedimentary rocks, the granite is white, and muscovite plus garnet are common (Kocis and others, 1977, 1978). Recently obtained paleontologic dates from xenoliths within the granite (Brown and others, 1978) and radiometric dates from monazites (Kocis and others, 1978) confirm the previously assumed Permian age for the granite.

Other Permian plutonic events are probably represented by pegmatites found throughout southern New England (Zartman and others, 1970) and by the granite in southern New Hampshire (J. B. Lyons, oral commun., 1978).

AGE RELATIONSHIPS

Radiometric dates coupled with the abundant floral dates allow a precise definition of the Alleghanian orogeny as recorded in the Narragansett Basin. Floral dates indicate that deposition of sediments began in early Pottsvillian (Westphalian B) time and persisted at least through Conemaughian (Stephanian A) time. Moreover, at least several hundred meters of Rhode Island Formation plus the Dighton Conglomerate lie stratigraphically above the Stephanian A (or younger) dated rocks. This stratigraphic succession suggests that deposition probably continued well into Conemaughian (Stephanian A) time and possibly into early Monongahelan (Stephanian B) time (280 million years ago).

Mutch (1968, p. 198) summarized radiometric data collected through the mid-1960's. Most of these ages should be used with caution because they are either (1) anomalously old (because of older inherited ages in detrital material) or (2) anomalously young (because of migration of radiogenic material). Of the ages listed in Mutch's review, the Rb/Sr biotite and K/Ar whole-rock ages of Hurley and others (1960) are probably the most useful. These, as well as other ages, were obtained by them from biotite-staurolite-garnet schist on Conanicut Island, southern Narragansett Bay, and indicate that the major progressive metamorphism took place 260± 13 m.y. (million years) ago. The somewhat younger (≈230 m.y.–250 m.y.) K/Ar biotite ages also given may represent ages of cooling or uplift.

Recently, the Narragansett Pier Granite was dated at 276 m.y. on the basis of U-Pb ages on monazites (Kocis and others, 1978). Dikes of the Westerly Granite, a homogeneous peraluminous granite, cut the western part of the Narragansett Pier Granite and have been dated at 240 m.y. (Hurley and others, 1960). This also may represent a cooling age, rather than the age of a much younger intrusion.

Taken together, the age relationships suggest that deposition of sediments began in Upper Pottsvillian (Westphalian B) and continued at least through Conemaughian time (Stephanian A). The deposits were buried, deformed, and metamorphosed by 260 m.y. ago.. The intrusions of the granites were virtually contemporaneous at 276 m.y. ago. K/Ar ages in the range of 230 my. to 250 m.y. may record uplift or cooling.

NORFOLK BASIN OF MASSACHUSETTS

By DANIEL P. MURRAY and JAMES W. SKEHAN, S.J.

The Norfolk Basin is a northeast-trending basin that extends from the northwest margin of the Narragansett Basin toward the Boston Basin (fig. 2). The Norfolk and Narragansett Basins are now separated by about 1 km but were probably connected prior to the formation of the present erosion surface and therefore are shown as one basin in figure 2. Most of the Norfolk Basin is within the Norwood and Blue Hills quadrangles, which were mapped by Chute (1964, 1966, 1969). The sedimentology of one of the major outcrops in this basin was the subject of a detailed study by Stanley (1968).

Stratigraphic relationships.—The Pennsylvanian rocks of the Norfolk Basin consist of two units, the Pondville Conglomerate and the Wamsutta Formation. The Pondville is subdivided into a lower boulder conglomerate member and an upper member of gray coarse sandstone to pebble conglomerate. On the basis of plant megafossils, the upper member has been dated as late Pottsvillian (Lyons and others, 1976). The upper member grades upward into the Wamsutta which, except for the absence of volcanic deposits, is similar to the formation as exposed in the Narragansett Basin. A subaerial paleoenvironment had been previously assumed for the Wamsutta on the basis of the red color and presence of mud cracks (Stanley, 1968). However, the redness of deposits is no longer considered sufficient to indicate a subaerial origin (Van Houten, 1973), and the cracks are reinterpreted by the authors to be dewatering structures. The Wamsutta is thought to represent outwash or sheet deposits on flood plains that formed adjacent to alluvial fans (now seen as the coarser grained Pondville Conglomerate).

Structure and metamorphism.—The dominant structural feature of the Norfolk Basin is a northeast-trending syncline overturned to the southeast; this mainly defines the shape of the basin. Several high-angle north-striking faults also cut the basin (Lyons, 1977, Map B-24). However, the displacement on them is not great. The Pennsylvanian rocks are in part bounded by thrust faults. A schematic structural profile across the Norfolk Basin is shown in figure 5. The entire basin is in the lower greenschist facies.

WOONSOCKET AND NORTH SCITUATE BASINS OF MASSACHUSETTS AND RHODE ISLAND

By JAMES W. SKEHAN, S.J., and DANIEL P. MURRAY

The rocks of the Woonsocket and North Scituate Basins (fig. 1) have long been correlated with rocks at Bellingham, Mass. (Mansfield, 1906, p. 99), referred to as Bellingham Conglomerate (Hall, 1963, p. 53). The rocks of these basins consist of gray to green conglomerate, sandstone, lithic graywacke, and phyllite, all irregularly interbedded (Quinn, 1971, p. 42). In the Woonsocket Basin, the dominant quartzite pebbles are elongate, but in the North Scituate Basin, pebbles are less elongate, conglomerate is less abundant, and sand-size grains are predominant (Quinn, 1971, p. 42).

Structure and metamorphism.—Two alternate interpretations of the structure of these basins are presently permissible: (1) On the basis of a general easterly dip and discordance of the basin rocks with the structure of the older rocks, the eastern borders may be a fault (Richmond, 1952); or (2) the basins may be large infolded synclines, overturned to the northwest. These garnetiferous rocks are in the upper greenschist facies.

On the basis of preliminary structural studies by Hall (1963, p. 53), two and probably three phases of deformation are recognized. The first phase of folding warped bedding around northeast-plunging axes (B1) and caused the formation of an east-dipping axial-plane schistosity; a mica lineation, quartz rods, and stretched pebbles are all parallel to the fold axes. The second phase warped the axial-plane schistosity of B1 folds in an east-northeast direction and caused the formation of a new schistosity and a "crinkle" lineation due to intersection of the two schistosities. A third phase apparently folded the first schistosity as well as the pebbles and warped the crinkle lineation.

Age.—The rocks of the Woonsocket and North Scituate basins may be correlative with those of the Narragansett Basin. We suggest the alternative pos-

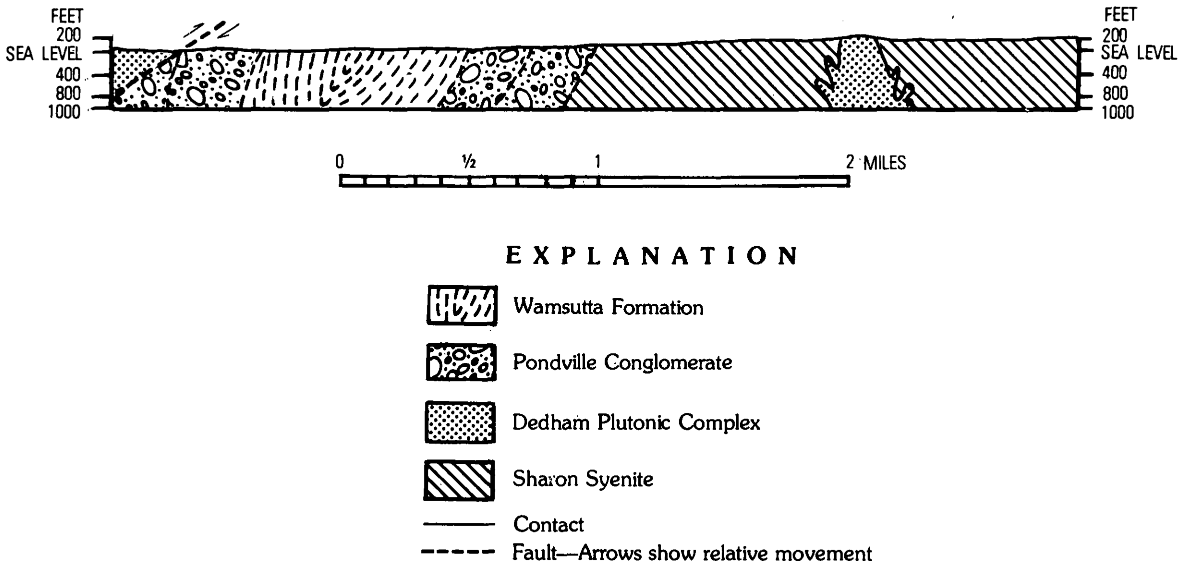


FIGURE 5.—Schematic structural profile across the Norfolk Basin.

sibility that they may be much older. Because these two basins may be virtually in the same structural position as the Boston Basin with respect to the authenticated Carboniferous basins, an understanding of the age of any of these basins' sedimentary rocks may apply to the others.

DEPOSITS NEAR WORCESTER, MASS.

By J. CHRISTOPHER HEPBURN

Two small patches of nonmarine Carboniferous rocks near the city of Worcester in east-central Massachusetts are shown by one symbol in figure 1. Pennsylvanian-age plant fossils have been identified from the northern outcrop area.

Lithology.—Gray to dark-gray, very carbonaceous slate or phyllite is the predominant rock in the northern outcrop area (fig. 6). One 2-m-thick lens of very impure, shiny, black meta-anthracite is present within the phyllite at the site of the long-abandoned "Worcester Coal Mine." A similar phyllite is also present in the poorly exposed southern outcrop area (fig. 6) where it is interbedded with coarse stretched-pebble, polymict conglomerate, feldspathic granule conglomerate, and arkose. The clasts in the conglomerate are in a shaly matrix.

Structure and metamorphism.—The Carboniferous rocks of the Worcester area are moderately to steeply dipping, and the finer grained rocks show a secondary slip cleavage. Electron-microprobe analysis of small garnet porphyroblasts in the phyllite show them to have appreciable MnO (as much as 9.1 weight percent). Thus, the grade of metamorphism is somewhat below that for the normal almandine isograd.

Age.—The "Worcester Coal Mine" has long been of geological interest and has been visited by such luminaries as E. Hitchock, Lyell, and Agassiz. Fossils were first found in 1883 supposedly in response to a remark by Agassiz of "Where are the fossils?" (Perry and Emerson, 1903, p. 18). Grew, Mamay, and Barghoorn, in the most recent summary of the plant fossils, indicate that they "are clearly of Carboniferous age and most likely of the Pennsylvanian Period" (1970, p. 122) and that they most likely can be assigned a Pottsville age. However, P. C. Lyons (in Grew, 1976, p. 395) suggested that the flora is Alleghenian (Westphalian C) in age, that is, younger than Pottsville (fig. 10).

The granite-pebble conglomerate in the southern outcrop area contains clasts of the adjacent blue-quartz-bearing Millstone Hill Granite which has been dated at 345±15 m.y. (Zartman and others, 1965). Therefore, the conglomerate containing this granite must be of Carboniferous age.

Correlation.—Because no readily observable structural or metamorphic breaks exist between these poorly exposed Pennsylvanian rocks and the surrounding rocks, Emerson (1917), in his summary of Massachusetts geology, assigned a Carboniferous age to many of the rocks in central Massachusetts. Recent detailed mapping in the Worcester area (Grew, 1973; Hepburn, 1976; J. C. Hepburn and E. S. Grew, unpub. data, 1977) has shown that the Pennsylvanian deposits are restricted to two small, largely fault-bounded basins. The nomenclature of the Pennsylvanian rocks of the Worcester area is in a state of flux at present. The Worcester Phyllite in the original formational designations (Emerson, 1917; Perry and Emerson, 1903) included both Pennsylvanian and what are now believed to be pre-Pennsylvanian rocks. Probably, the name Worcester Phyllite will be restricted to the pre-Pennsylvanian rocks (Hepburn, 1976) and a new designation will be given to the Pennsylvanian rocks. Whether the conglomeratic units in the Pennsylvanian of the Worcester area are similar in age to, and can be correlated with, the Harvard Conglomerate to the northeast is still not clear.

The Pennsylvanian rocks of the Worcester area probably once were continuous with rocks of similar age in the Narragansett and Norfolk Basins and likely were deposited under similar conditions.

Harvard Conglomerate at Pin Hill.—An isolated deposit of the Harvard Conglomerate at Pin Hill in Harvard, Mass. (fig. 1), has been considered Pennsylvanian in age (Emerson, 1917; Thompson and Robinson, 1976). However, the unit is unfossiliferous, and the field relationships have been debated.

BOSTON BASIN, MASSACHUSETTS

By MARLAND P. BILLINGS

The Boston Basin is a lithologic-tectonic unit that trends east-northeast, is 50 km long, and is 25 km wide (fig. 7). The basin is also a topographic lowland, bounded on the north by the Fells Upland and on the south by the Blue Hills and Sharon Upland (LaForge, 1932, p. 8). On the east, the Boston Basin is submerged by Boston Harbor and Boston Bay, but on the southwest, it merges imperceptibly with the Needham Upland.

The most recent summaries of the bedrock geology by Billings (1976a, b) and other pertinent articles are in Lyons and Brownlow (1976) and New England Intercollegiate Geological Conference (1976).

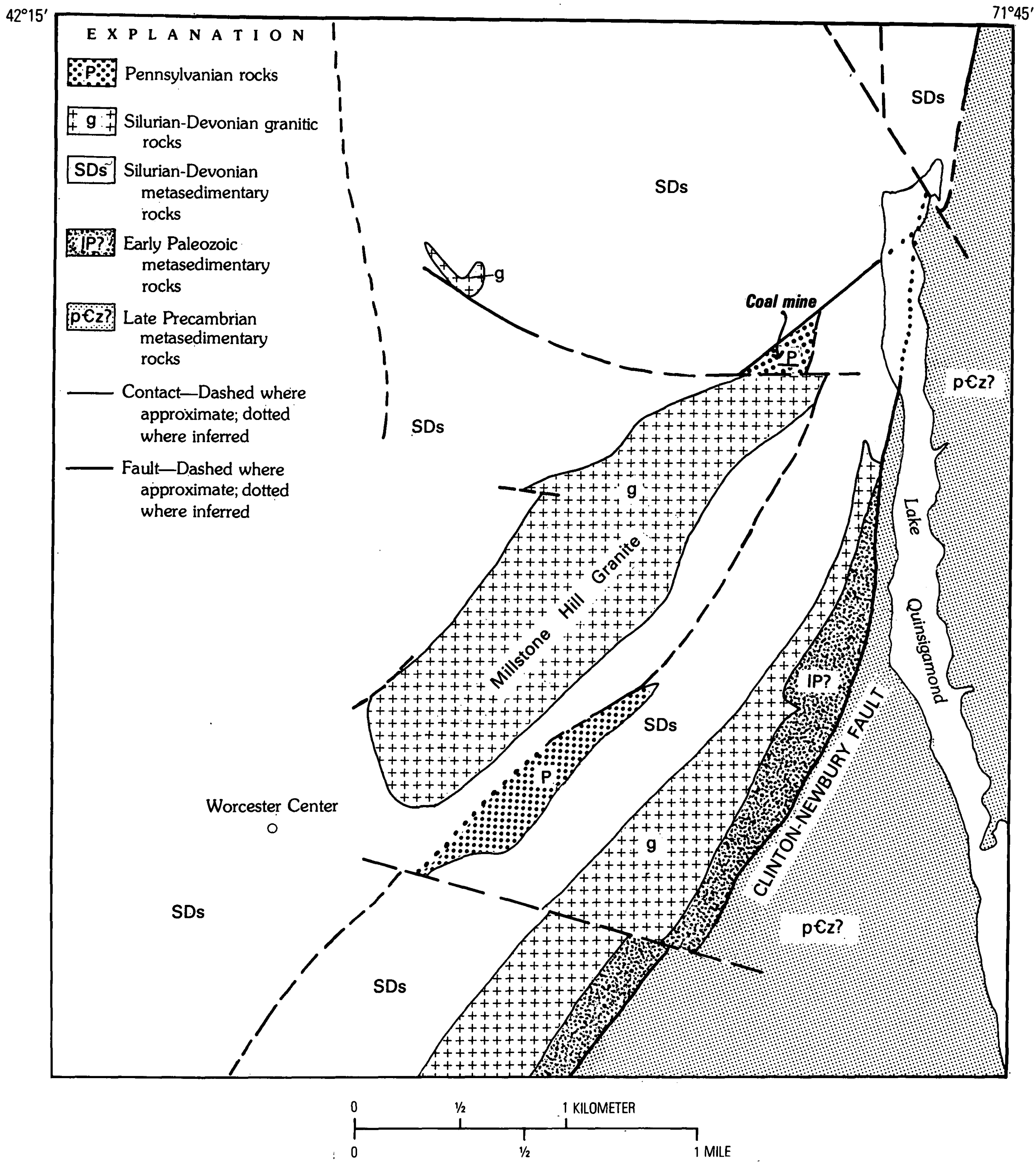


FIGURE 6.—Geologic map of the Worcester area, Massachusetts.

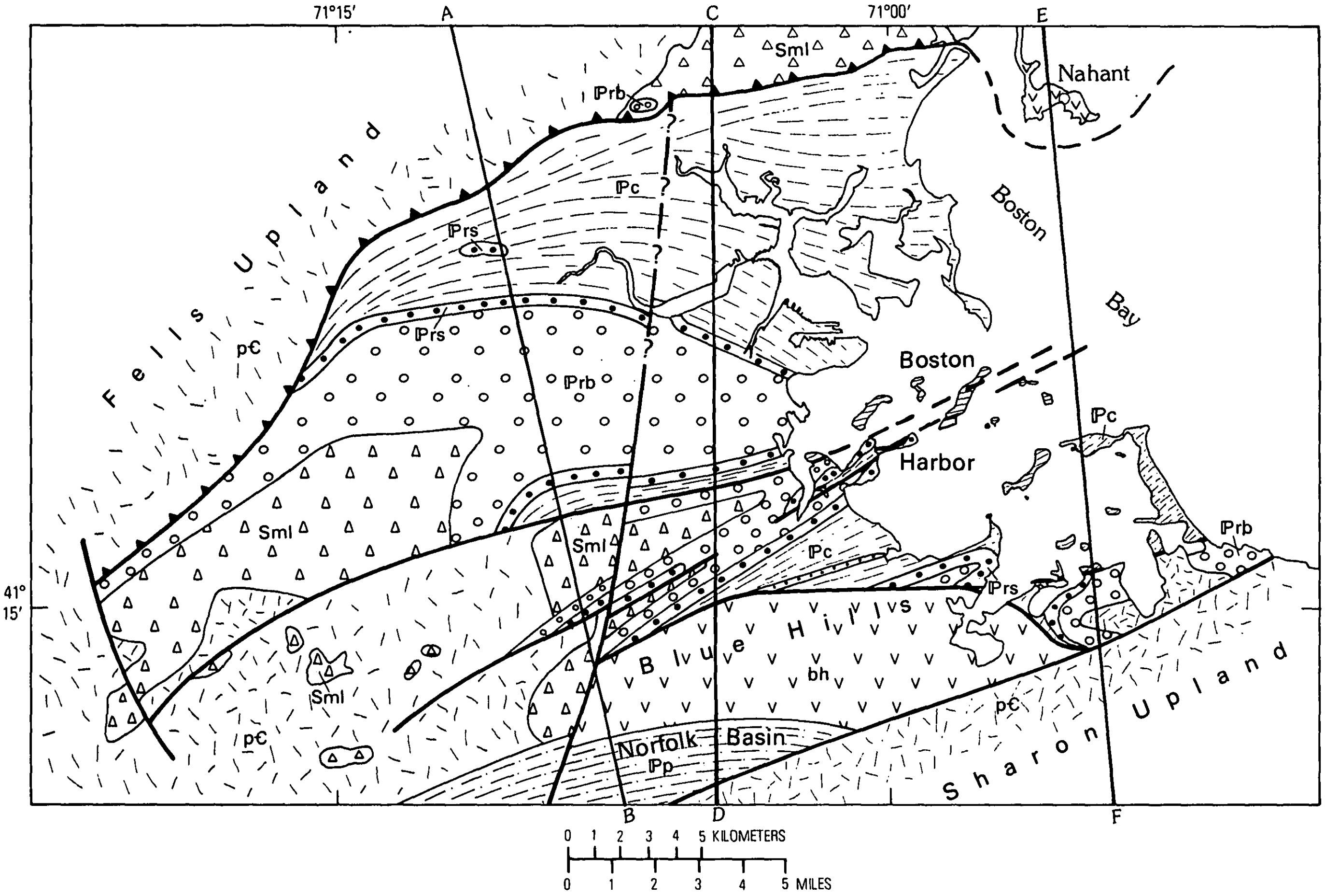


FIGURE 7.—Geologic map of the Boston Basin, Massachusetts. Structural profiles along lines AB, CD, and EF are shown in figure 8. Symbols are shown on p. A18.

LITHOLOGY

In this paper, the rocks will be described as belonging to the following units: (1) "basement," (2) Mattapan and Lynn Volcanic Complexes, (3) Boston Bay Group, and (4) rocks of the Blue Hills-Quincy and Nahant areas. The Triassic(?) diabase is not shown and is not discussed in figure 7.

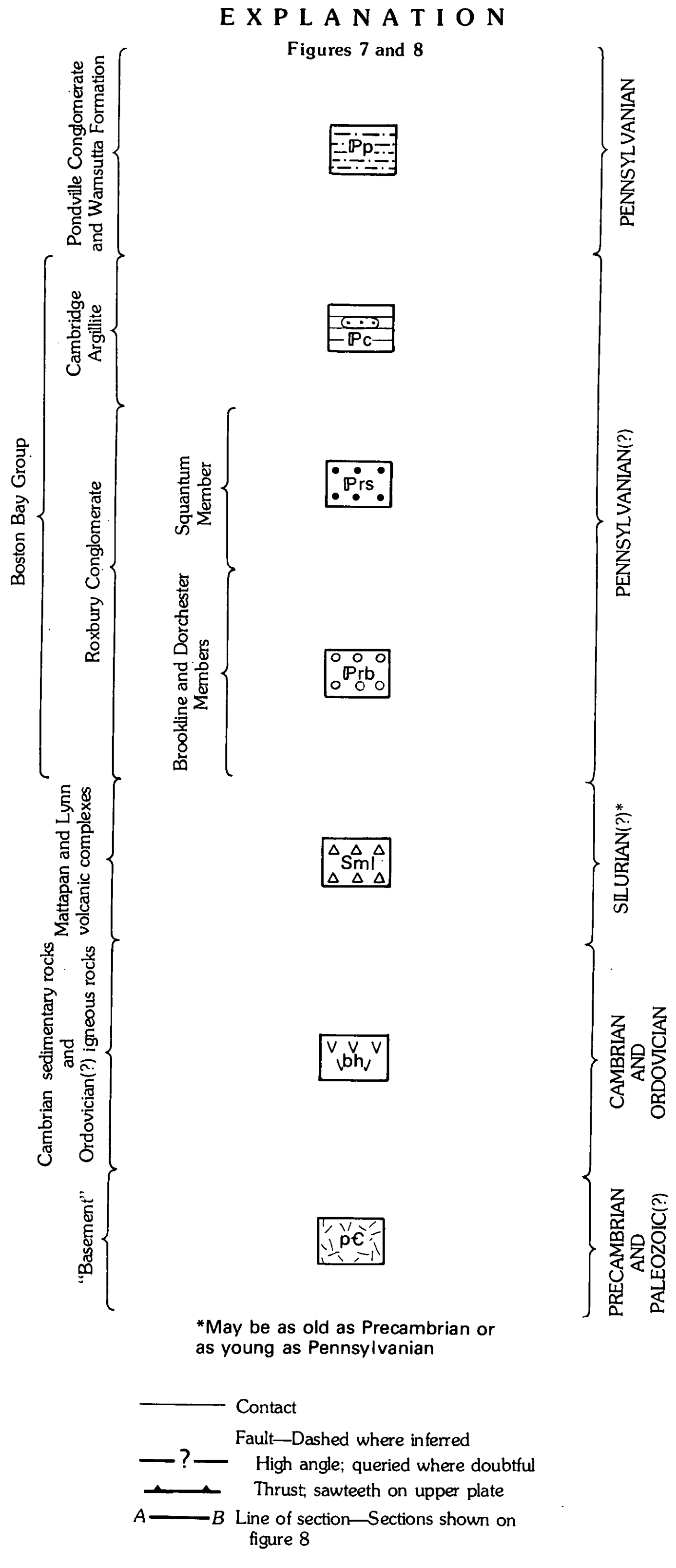
"BASEMENT"

A description of "basement" rocks is beyond the scope of the present paper. The reader is referred to Emerson (1917), LaForge (1932), Bell and Alvord (1976), Castle and others (1976), and Nelson (1975). Within the limits of figure 7, many or all rocks in the "basement" are Precambrian; some may be Paleozoic.

MATTAPAN AND LYNN VOLCANIC COMPLEXES

The Mattapan and Lynn Volcanic Complexes are chiefly hard dense white, pink, and red rhyolites, often called felsite locally. The less abundant melaphyres are dark green to light green and are composed largely of such secondary minerals as albite, hornblende, and epidote. Some trachytes and andesites are present (Emerson, 1917, p. 204). Pyroclastic rocks include crystal tuff, lapilli tuff, breccia, and lahars (Nelson, 1975). Although much of the material in the Lynn and Mattapan Volcanic Complexes appears to have been erupted on the surface as flows, ashfalls, and ashflows, it has long been known that many bodies occupy vents and dikes in the older rocks, such as the Dedham Granodiorite.

The Mattapan is 600 m thick in Hyde Park (Billings, 1929, p. 104); data given by Nelson (1975) indicate that it is at least 760 m thick in Dover and Natick. But in places, as in Hingham and Nantasket, the formation is absent. In 1929, I (Billings, 1929, p. 104) thought that an angular unconformity separated the Mattapan from the overlying Roxbury.



These volcanic complexes are younger than the Dedham Granodiorite, which is 608±17 m.y. or latest Precambrian (Dowse, 1950; Kovach and others, 1977). Moreover, the pronounced unconformity between the volcanic complexes and the Dedham (LaForge, 1932, p. 31) indicates deep erosion after the emplacement of the Dedham and the eruption of the volcanic complexes. R. E. Zartman has recently obtained a zircon age of 580 m.y. from a rhyolite in the Mattapan Volcanic Complex (E-an Zen, written commun., 1977). Such ages are questionable (Higgins and others, 1977), especially for a rock that is present in vents. LaForge (1932, p. 33) said that the Lynn "is cut by the Quincy granite type." Zartman and Marvin (1971) dated the Quincy as 437±32 m.y. (latest Ordovician).

If the Mattapan can be correlated with the volcanic rocks in the Blue Hills, as Chute (1969) assumed, then it is latest Ordovician. The radiometric dates are consistent with assigning the Mattapan and Lynn Volcanic Complexes to the Cambrian or Ordovician.

The Newbury Volcanic Complex is dated by fossils as latest Silurian and possibly earliest Devonian (Shride, 1976, p. 147). This complex can be traced to within 13 km of the Lynn Volcanic Complex. The Newbury and Lynn are lithologically similar. On the basis of dubious paleontological evidence, Pollard (1965) suggested that the Mattapan is Mississippian. Rhyolite and melaphyre similar to those in the Mattapan and Lynn Volcanic Complexes are present in the Alleghenian (Pennsylvanian) Wamsutta Formation of the Narragansett Basin (Emerson, 1917). The possibility that the Mattapan and Lynn may be as old as Precambrian or as young as Pennsylvanian is adopted in figure 7.

BOSTON BAY GROUP

Perhaps the most striking new interpretation of rocks in the Boston Basin is that the Roxbury Conglomerate is a southerly facies of the lower part of the Cambridge Argillite. The rocks of the Boston Bay Group are relatively unmetamorphosed, although some chlorite is present. The maximum thickness of 5,700 m is found in the northern half of the basin, but toward the south, the known thickness is only 1,600 m. The group is probably Pennsylvanian, although many geologists would accept a much older age. An excellent concise tabular summary of the lithology is given in Rehmer and Roy (1976, p. 72).

ROXBURY CONGLOMERATE

The Roxbury Conglomerate is a complex assemblage of nonmarine conglomerate, shale, sandstone, quartzite, arkose, melaphyre, and diamictite. Most of the rocks, except the diamictite, are present throughout the formation. The division into members is based on the relative abundance of the various lithologic types. From bottom to top the three members are: Brookline, Dorchester, and Squantum. The compositions and distinctive features of these members were described by Billings (1976a) and by Bailey, Newman, and Genes (1976). The Brookline Member ranges from 300 to 1,310 m in thickness. The Dorchester Member ranges from 84 to 485 m in thickness. Its top is usually defined by the distinctive diamictite of the Squantum Member which many geologists consider to be a tillite (Rehmer and Roy, 1976; Bailey and others, 1976; Wolfe, 1976). The Squantum ranges from 19 to 122 m in thickness.

CAMBRIDGE ARGILLITE

In the southern part of the Boston Basin, where the Cambridge Argillite is above the Squantum Member of the Roxbury Conglomerate, the Cambridge is 2,500 m thick. In the northern part of the basin, where the lower part of the formation is interpreted as a facies equivalent of the Roxbury Conglomerate, the Cambridge is 5,700 m thick. The "Milton Quartzite" (Billings, 1929, 1976a) is a white sericitic quartzite that is 150 m thick and that lies 850 m above the Squantum Member.

LITHOFACIES IN THE BOSTON BAY GROUP

The facies relationship shown in figure 8 is based largely on observations in the City Tunnel Extension (Billings and Tierney, 1964). The axis of the Charles River syncline coincides in this diagram with the northern limit of the Squantum Member. In the south limb of the syncline, the Squantum and Dorchester Members, as well as the upper part of the Brookline Member, are exposed. But where these units should appear on the north limb, they are replaced by the Cambridge Argillite. Moreover, on the south limb, many beds of gray argillite, similar to those in the Cambridge Argillite, are present in the Dorchester Member. Details are given in Billings and Tierney (1964, fig. 9).

AGE OF THE BOSTON BAY GROUP

For 77 years, the age of the Boston Bay Group has been based on supposed fossils found by Burr and Burke (1900) in the Roxbury Conglomerate.

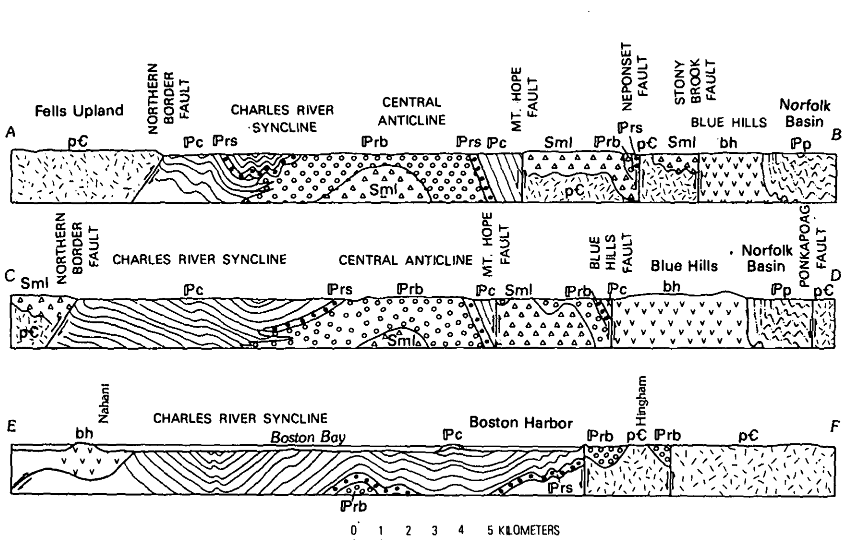


FIGURE 8.—Structural profiles across the Boston Basin along lines AB, CD, and EF shown in figure 7. Symbols are the same as those used in figure 7.

LaForge (1932, p. 38) said: "Except for a few short pieces of tree trunks, of which not even the genus can be certainly determined and which may be either Devonian or Carboniferous, no fossils have been found in these rocks." These specimens were lost for many decades, but one of them was found about 20 years ago in the Harvard paleobotanical collections. Rahm (1962, p. 329) said: "According to Professor Elso Barghoorn (personal communication) the specimens are either *Callixylon* or *Cordaites*, genera which together span a period from the Upper Devonian to the Permian." Professor Barghoorn (oral commun., 1977) has recently concluded that the specimen is inorganic. Bailey and Newman (1978) also consider the specimen to be inorganic, but their proposed mechanism for such an origin is not satisfactory. Under the circumstances, reliable paleobotanical evidence for dating the Boston Bay Group is lacking.

The Roxbury Conglomerate is younger than the Dedham Granodiorite and the Mattapan Volcanic Complex, as many of the clasts in the Roxbury were derived from the Dedham and Mattapan. If, as I believed earlier (Billings, 1929), the Mattapan and Lynn Volcanic Complexes are unconformable beneath the Boston Bay Group, their age tells us only that the Boston Bay Group is younger. However, I agree that the evidence for an unconformity should be restudied.

The most compelling argument on the age of the Boston Bay Group is based on the extensive conglomerate in the Boston Bay Group. In the Narragansett and Norfolk Basins, the only paleontologically dated conglomerate of the kind found in the Roxbury Formation are Pennsylvanian, thus, it seems that tectonic conditions favorable for deposition of "molasse" existed in eastern New England only in the Pennsylvanian.

BLUE HILLS-QUINCY AND NAHANT AREAS

The Blue Hills-Quincy area (fig. 6) contains Lower and Middle Cambrian sedimentary rocks and four mappable igneous units: (1) a volcanic complex (Mattapan Volcanic Complex?), (2) "rhombenporphyry," (3) Blue Hills granite porphyry, and (4) Quincy Granite (Billings, 1976a). The Nahant area contains Lower Cambrian sedimentary rocks and the Nahant Gabbro (Billings, 1976a).

STRUCTURE

A more complete discussion of the geological structure of the Boston Basin has been presented previously (Billings, 1976a, b). Many of the structural features are apparent from the geological map (fig. 7) and structural sections (fig. 8). In order to be more objective, in figure 7 the longitudinal faults in the southern part of the basin are shown as steep (essentially vertical) faults without any indication of their genesis. But I still believe that they are thrusts, originally dipping south, that have been rotated to their present attitude.

Age of Deformation.—The deformation in the Boston Basin is presumed to be the same age as that in the Norfolk and Narragansett Basins, that is, post-Pennsylvanian and older than the Triassic Medford Dike.

BIOSTRATIGRAPHY OF THE PENNSYLVANIAN OF MASSACHUSETTS AND RHODE ISLAND

By PAUL C. LYONS

The Narragansett Basin has a rich megaflora consisting of about 300 nominal species, nearly all of which are from the Rhode Island Formation; 31 of these were considered new species or genera by previous workers. The uppermost formation, the Dighton Conglomerate, does not have a known florule. Animal fossils, principally insects and amphibian tracks, have been found, but these are of little stratigraphic importance because of the scarcity of discoveries. Microfloral remains have not been found in the coal or adjacent strata of the Rhode Island Formation. Because structural complexities and facies changes in many parts of the Narragansett Basin interrupt the continuity of the beds, a floral zonation scheme is essential for clarification of the physical stratigraphy.

HISTORY OF BIOSTRATIGRAPHY OF THE NARRAGANSETT BASIN

Some of the earliest contributions to American paleobotany were based on specimens collected during coal mining operations in the Narragansett Basin (Brongniart, 1828–1838; Jackson, 1840; E. Hitchcock, 1841; Teschemacher, 1847). No attempt, however, was made to relate the megaflora to the physical stratigraphy until C. H. Hitchcock (1861) correlated the floral assemblages identified by Lesquereux with the stratigraphic section exposed in the vicinity of Newport, R.I. This first correlation of biologic and rock data was documented by Lyons and Darrah (1977) who concluded that the assemblage in the upper part of the Newport section was of Stephanian age and referable to the Aquidneck shales of Foerste (in Shaler and others, 1899).

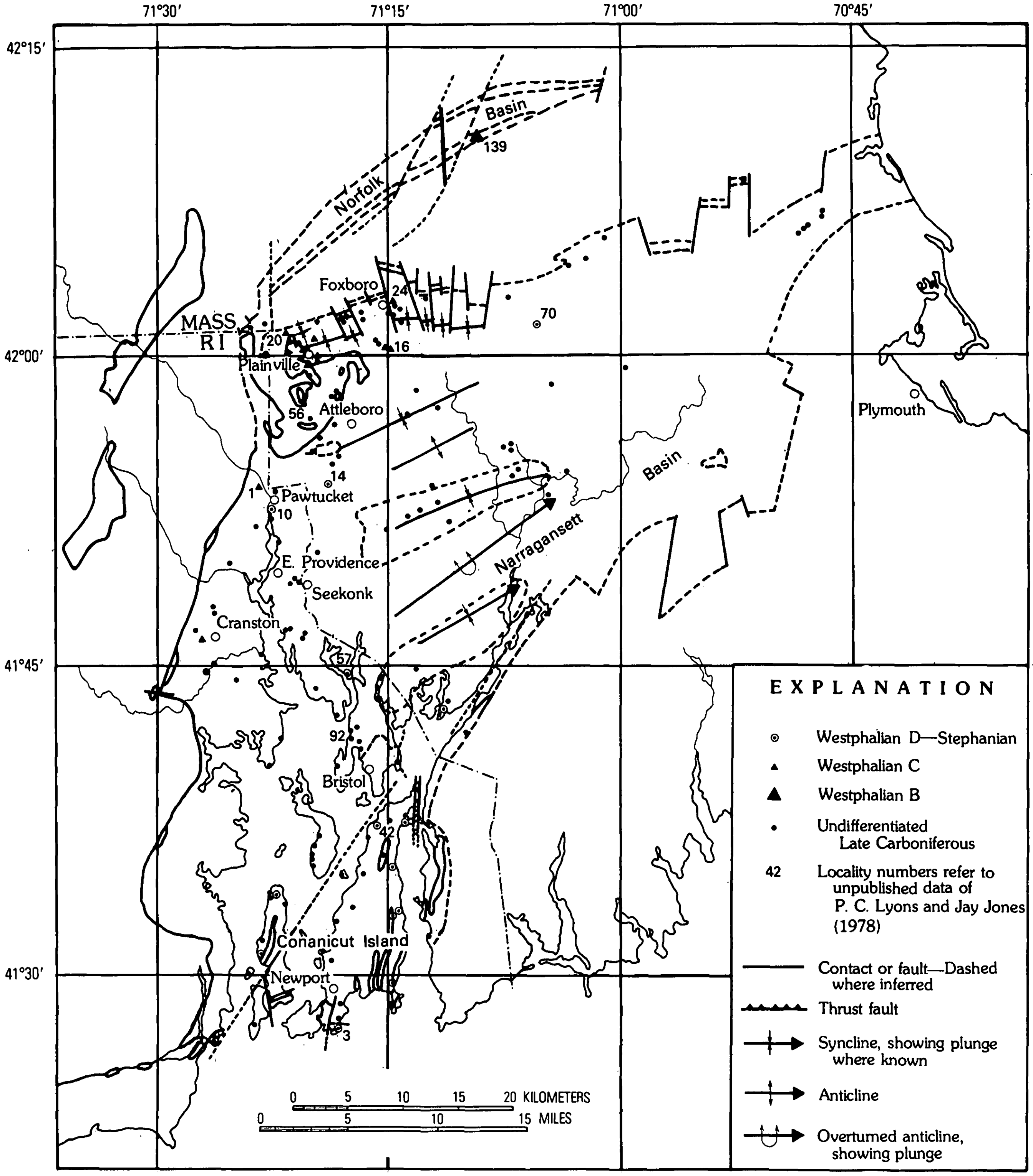


FIGURE 9.—Floral localities in the Narragansett and Norfolk Basins.

The Aquidneck shales are here referred to the upper part of the Rhode Island Formation.

Brongniart's (1828–1838, p. 303) specimens of *Pecopteris arguta* Brong. (=*P. feminaeformis* Schloth.) apparently came from the roof shales of the coal beds mined at Portsmouth, R.I. (fig. 9, loc. 42). The Portsmouth coals were assigned to the Aquidneck shales (Shaler and others, 1899). Coal mining began here in 1809, and these coal beds yielded approximately 2 million tons of coal by the end of the century. A similar amount of coal is still unmined (H. B. Chase, oral commun., 1977).

Further contributions to the flora of the coal-bearing Rhode Island Formation were made later in the 19th century (Jackson, 1851; Lesquereux, 1880–84, 1884, 1889; Clark, 1884; Fuller, 1897; Providence Franklin Society, 1887; Shaler and others, 1899). These authors provided lists of species but little analysis of the stratigraphic positions of these floras.

Weston (1917) and Round (1920) presented many photographs and sketches of the flora of the Narragansett Basin. Weston's thesis (1917) contained little stratigraphic or locality data. Round's thesis (1920) provided generalized locality information indicating that her work was based mainly on specimens derived from the lower part of the Rhode Island Formation, including the Pawtucket (fig. 9, loc. 10) and Valley Falls coal beds (fig. 9, loc. 1). She concluded that the flora examined was similar to that in the Lower Allegheny. Later, Round (1921, 1922a, b) reported taxonomic data on selected species or genera in the basin and correlated (1924, 1927) the flora with those in New Brunswick, Canada, and Henry County, Mo.

During the 1930's, Darrah and his students collected specimens from Perrin's Crossing in Seekonk, Mass., (fig. 9, loc. 14). The variety of pecopterid species reported by Darrah (1969) and the presence of *Sphenophyllum oblongifolium* in these collections are evidence of a Late Pennsylvanian (roughly Stephanian) age for the beds exposed near Perrin's Crossing. A stratigraphic section of these beds assigned to the upper part of the Rhode Island Formation is given in Lyons and Chase (1976). Darrah (1969) noted the absence of the *Neuropteris scheuchzeri-Neuropteris ovata* association from this florule and from the Mount Hope coal beds, that is, the coals mined at Portsmouth, R.I. (fig. 9, loc. 42). Knox (1944) reported an important florule from the Wamsutta Formation (fig. 9, loc. 56) in the same area in Attleboro where amphibian tracks were discovered by Woodworth (1894). Knox (1944) did not provide photographs or taxonomic notes, but he listed species or genera from the Wamsutta that are also found in the lower part of the Rhode Island Formation. These taxa include *Neuropteris* cf. *rarinervis*, *Asterophyllites (Calamocladus) equisetiformis*, and *Sphenopteris* species; only one *Pecopteris* sp. was found in the Wamsutta. He concluded that the Wamsutta assemblage was similar to that in the Lower Allegheny and equivalent to that in the lower part of the Rhode Island Formation.

Other florules assignable to the lower part of the Rhode Island Formation were reported by Lyons (1969, 1971) from Foxboro (fig. 9, loc. 24), by Oleksyshyn (1976) from Plainville (fig. 9, loc. 20), and by Lyons and Chase (1976) from these two localities and from Mansfield (fig. 9, loc. 16). Lyons and Darrah (1978) have documented a younger floral zone within the Rhode Island Formation at Easton, Mass. (fig. 9, loc. 70). This assemblage consists of 40 species and is dominated by pecopterids: *Pecopteris arborescens* (pl. 1, figs. A, E), very common; *P. lamuriana* (pl. 1, fig. F) and *P.* cf. *lamuriana* (pl. 1, fig. H), common; *P.* aff. *hemitelioides* (pl. 1, figs. D, G); *P. unita* (pl. 1, fig. C); and other pecopterids (pl. 1, figs. B, I). *Odontopteris* cf. *reichiana* (pl. 1, fig. L), *Neuropteris rarinervis* (pl. 1, fig. Q), and *Sphenophyllum oblongifolium* are sparingly represented. Other species in this assemblage are shown on plate 1, figures J, K, M, N, O, and P. Lyons and Darrah (1978) concluded that the assemblage was transitional between the Middle and Late Pennsylvanian epochs and is similar to that in rocks of the Upper Allegheny and Lower Conemaugh. A comparable flora (Lyons, unpub. data) is found at Barrington, R.I. (fig. 9, loc. 57).

Important new collections made in connection with the Narragansett Basin Project are from Bristol, R.I. (fig. 9, loc. 92), and the northern part of Conanicut Island, Rhode Island. These florules have not yet been documented but are probably younger than the Easton florule as evidenced by the abundance of *Odontopteris* specimens. *Sphenophyllum oblongifolium* and several *Odontopteris* and *Pecopteris* species reported by Lesquereux (1889) to be present at Pawtucket, R.I. (fig. 9, loc. 10), probably are the youngest reported florule from the Narragansett Basin. The flora from these three localities and the floras from Newport (fig. 9, loc. 3) and Portsmouth, R.I. (fig. 9, loc. 42), and from Seekonk, Mass. (fig. 9), are all considered to be of Late Pennsylvanian age.

A florule from Canton, Mass. (fig. 9, loc. 139), dominated by *Neuropteris obliqua*, *Calamites cisti*, *Cordaites pricipalis*, and a few seeds in the upper member of the Pondville Conglomerate in the Norfolk Basin was reported by Lyons Tiffney, and Cameron (1976). An important discovery in this assemblage was a species probably belonging to *Lonchopteris*, a genus not known in North America west of New England. The authors concluded that the assemblage was similar in other respects, however, to that in the Upper Pottsville rocks of the Southern Anthracite field, Pennsylvania (White, 1900; Wood and others, 1969).

FLORAL ZONATION

A summary of the floral zones here recognized in the Pennsylvanian rocks of New England is given in figure 10. The florule from the Pondville Conglomerate does not readily compare with any floral zones of Read and Mamay (1964). However, this florule is in the zone of *Lonchopteris* assigned by Jongmans (1952) to Westphalian B and, therefore, is presumably equivalent to floral zone 5 or 6 of Read and Mamay (1964). On the basis of work by Grew, Mamay, and Barghoorn (1970), the florule from the "coal mine" at Worcester, Mass. (fig. 6), is presumably referable to floral zone 4. However, I have identified a probable *Neuropteris scheuchzeri* in this assemblage and, therefore, refer it to floral zone 9.

The lower part of the Wamsutta Formation and the lower member of the Pondville Conglomerate do not have known florules; however, the lower part of the Wamsutta is believed to be in floral zones 5 or 6, and the lower member of the Pondville is believed to be in floral zone 5. A florule has not been identified in the Dighton Conglomerate, but, if one is identified, it probably will be assignable to floral zone 11 or 12 of Read and Mamay (1964).

FAUNA OF THE NARRAGANSETT BASIN

Summaries of the fauna found in the Narragansett Basin are in Shaler, Woodworth, and Foerste (1899), Quinn and Oliver (1962), and Willard and Cleaves (1930).

Scudder (1893) described an entirely new insect fauna from Rhode Island. Although consisting almost entirely of wings, it included a spider, 11 (nine new) species of cockroaches, and two other species of insects. In 1895, he designated one of the two cockroaches that were not specifically identified in 1893 as a new species and added a new species of cockroach from East Providence. The fauna was collected principally at localities near Pawtucket, Silver Spring (East Providence), Cranston, Bristol, and East Providence, R.I.; it was apparently derived from the lower part of the Rhode Island

TIME-STRATIGRAPHIC UNITS		FLORAL ZONES OF READ AND MAMAY (1964)	ROCK-STRATIGRAPHIC UNITS				NEW ENGLAND		
			CENTRAL APPALACHIANS			NEW ENGLAND			
NORTH AMERICA	EUROPE		CENTRAL AND WESTERN PENNSYLVANIA	EASTERN PENNSYLVANIA	WEST VIRGINIA	MASSACHUSETTS RHODE ISLAND	FLORAL LOCALITY	FIGURE 9 LOCALITY NUMBER	REFERENCE
LATE PENNSYLVANIAN	Stephanian B(?) or C(?)	11 or 12	Waynesburg Formation			Dighton Conglomerate			This report
			Monongahela Formation			Rhode Island Formation (upper part)	Pawtucket, RI	10	Lesquereux (1889)
	Stephanian A and B	11	Conemaugh Formation (upper part)	LLEWELLYN FORMATION			Portsmouth, RI Seekonk, MA	42 14	Darrah (1969)
	Cantabrian Westphalian D	10	Conemaugh Formation (lower part)			Rhode Island Formation (middle part)	Easton, MA	70	Lyons and Darrah (1978)
MIDDLE PENNSYLVANIAN	late Westphalian C	9	Allegheny Formation (upper part)			Rhode Island Formation (lower part)	Foxboro, MA	24	Lyons (1969)
							Mansfield, MA	16	Lyons and Chase (1976)
	middle Westphalian C	8					Worcester "coal mine", MA	(see figure 6)	Grew and others (1970)
	early Westphalian C	7	Allegheny Formation (lower part)				Plainville, MA	20	Oleksyshyn (1976)
							Valley Falls, RI	1	Round (1920)
	late Westphalian B (?)	6 or 7	– – – – – –	Sharp Mountain Member (POTTSVILLE FORMATION)	Kanawha Formation	Wamsutta Formation (upper part)	Attleboro, MA	56	Knox (1944)
EARLY PENNSYLVANIAN	Westphalian A or B	5 or 6		Schuylkill Member (POTTSVILLE FORMATION)	New River Formation	Wamsutta Formation (lower part)	Canton, MA	1	This report
	Westphalian A-Namurian C(?)	5(?)				Pondville Conglomerate (upper member)			Lyons and others (1976)
	Namurian B	4		Tumbling Run Member (POTTSVILLE FORMATION)	Pocahontas Formation	Pondville Conglomerate (lower member)		139	This report

FIGURE 10.—Pennsylvanian stratigraphic correlation chart.

Formation (Shaler and others, 1899, p. 203). Packard (1889) reported that the lower part of the Rhode Island Formation in Pawtucket yielded several other species of cockroaches of two genera; a spider; *Spirorbis*, a tube of an annelid worm; and a presumed track of a gastropod.

Willard and Cleaves (1930) summarized discoveries of seven species of amphibian footprints: four from Plainville, Mass., and one each from Seekonk (Perrin's Crossing) and South Attleboro, Mass., and East Providence, R.I. Six were new species. Six were from the Rhode Island Formation, and one was from the Wamsutta Formation in South Attleboro. Lyons and Chase (1976) noted possible amphibian skin from Plainville, Mass., and a burrow from Foxboro, Mass.

PALEOGEOGRAPHIC IMPLICATIONS OF PALEONTOLOGIC DATA

Scudder (1895) noted that none of the 193 species of North American (including Nova Scotia and Cape Breton) cockroach was known from Europe and that five of the 14 genera found in America are absent from Europe. These faunal data may indicate that North America and western Europe were somewhat isolated during Early and Middle Pennsylvanian times. However, the presence of *Lonchopteris* in New England, Maritime Canada, and western Europe indicates that North America and Europe were connected during these times. The absence of *Lonchopteris* from areas west of New England probably indicates a Pennsylvanian barrier between New England and the central Appalachians.

Willard and Cleaves (1930) observed that the amphibian footprints of the Narragansett Basin have a closer affinity to the genera identified in Nova Scotia than to the genera described for the central Appalachians. This affinity to Nova Scotian amphibian genera, together with floral data presented by Round (1924) and Lyons (1971), strongly supports a paleogeographic connection between New England and Maritime Canada (Lyons, 1976) during Middle Pennsylvanian time.

ROCKS OF MAINE INFERRED TO BE CARBONIFEROUS

By Robert G. Doyle

Some sedimentary rocks in parts of Hancock and Washington Counties, Maine, are inferred to be of Carboniferous age. These rocks are not fossiliferous; the assignment of this age is based upon (1) proximity to similar rocks that are known to be Carboniferous and that crop out approximately 56 km to the east in the Province of New Brunswick (Larrabee, 1963); (2) lithologic character and the lack of any metamorphic imprint, the latter requiring a post-Acadian age; and (3) identification of a syntectonic granitic source for the conglomeratic granite pebbles within the unit.

LOCATION AND GEOLOGIC SETTING

The rocks inferred to be of Carboniferous age are present in a graben bounded by subparallel segments (fig. 11) of the Norumbega fault system. The

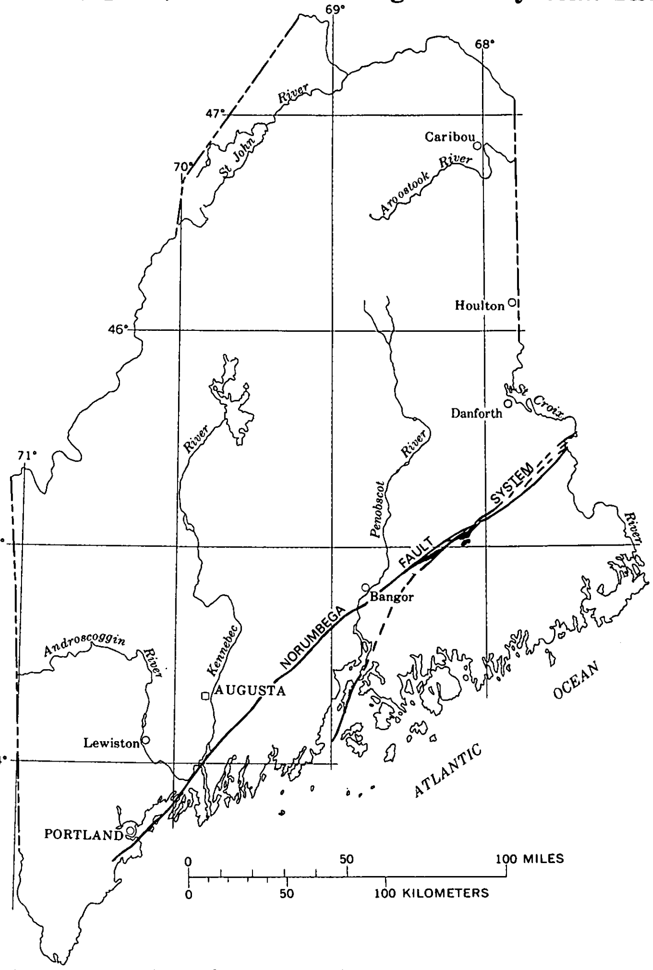


FIGURE 11.—Locations of Maine rocks inferred to be Carboniferous.

Norumbega fault system is a major structure extending 320 km north-northeast from Portland, Maine, on the south-central Atlantic coast to the Maine-New Brunswick line 16 km south of Danforth, Maine. Exposures of the unit are present on the northwest shore of Great Pond and in Alligator Stream which flows into Great Pond (Great Pond, Maine, U.S. Geological Survey 15-minute quadrangle). The unit is bounded on the southeast by silicic metavolcanic and metavolcaniclastic rocks of presumed Ordovician age (Larrabee and others, 1965), and on the north by the quartzite member of the Kellyland Formation of Silurian age (Larrabee and others, 1965; Ludman, 1975). Metasedimentary and plutonic rocks of Siluro-Devonian age (Hussey and others, 1967) are present in the area near the fault-bounded blocks of the unit inferred to be Carboniferous.

DESCRIPTION OF THE UNIT INFERRED TO BE CARBONIFEROUS

Rocks of the unit inferred to be Carboniferous were described by Larrabee, Spencer, and Swift (1965) and Stoeser (1966). The present writer uses the description provided by Stoeser. The unit is separated into two members, the siltstone arkose member and the nonarkosic conglomerate member.

Nonarkosic conglomerate member.—The nonarkosic conglomerate member consists of a red silt/sand matrix enclosing clasts of green and red micaceous quartzite, siltstone, and shale and a small percentage of weathered granitic clasts. The source of the clasts is the siltstone arkose member. The nonarkosic conglomerate member is estimated to be 30 m thick.

Siltstone arkose member.—The siltstone arkose member consists of reddish-brown to purple interbedded arkosic conglomerate, arkosic sandstone, and red siltstone. The source of clasts found in this member is presumed to be nearby Acadian or Late Acadian orogenic plutons of mid-Devonian age. This member is estimated to be 520 m thick.

Economic deposits.—No evidence exists of any economic materials within the unit. Carbonaceous material is absent.

EVOLUTION OF CARBONIFEROUS TERRANES IN NEW ENGLAND

By JAMES W. SKEHAN, S.J., and DANIEL P. MURRAY

PALEOENVIRONMENT AND PALEOGEOGRAPHY

The generally similar ages, lithologies, stratigraphy, and structure of the deposits in the Narragansett and Norfolk Basins and of the deposits at and near Worcester (fig. 1) suggest that their origins are related and that they may have been laid down in a single basin (Quinn and Oliver, 1962). Large-scale faulting, deep erosion, and limited studies of the sediments over the Avalonian terrane in which these basins are situated permit only a general reconstruction of the paleoenvironment and paleogeography.

The ages of the Boston, Woonsocket, and North Scituate Basins are uncertain. All three basins have geologic features similar to those of the Pennsylvanian basins and are close enough to them to have been correlated with them. On the other hand, striking dissimilarities in lithology and stratigraphy exist between these three basins and the fossiliferous Pennsylvanian basins. For example, C. A. Kaye (oral commun., 1977) has noted that the Cambridge Argillite of the Boston Basin may be the equivalent of the Middle Cambrian trilobite-bearing Braintree Argillite. Moreover, structures in the Roxbury Conglomerate that were previously assumed to be plant fossils have been shown to be sandstone pipes (Bailey and Newman, 1978). The recent discovery of Middle Cambrian trilobites (Skehan, Murray, Palmer, and Smith, 1977) in southern Narragansett Bay in rocks previously mapped as Carboniferous underscores the plausibilty of Kaye's suggestion.

The fossiliferous Cambrian rocks in the southern Narragansett Bay were considered by Dale (1884) to be a southern marine facies of an otherwise fluvial basin. The Pennsylvanian deposits of the Norfolk and Narragansett Basins are thought to have been deposited in an upper fluvial environment because (1) the Narragansett and Norfolk Basins do not contain any marine fossils, (2) the Narragansett Basin coal has extraordinarily low sulfur and trace-element contents (Jack Medlin, unpub. data, 1977), and (3) coarse conglomerates are widespread throughout several parts of the Pennsylvanian section in both basins.

The deposits of the Narragansett and Norfolk Basins, moreover, contain a great variety of sedimentary structures, including graded bedding, crossbedding, scour and fill, mud cracks, loadcasts, raindrop impressions (Chute, 1940; Quinn and Oliver, 1962; Stanley, 1968), and sandstone dikes (Lyons, 1969). These features, together with the paleontological evidence, indicate that the known Pennsylvanian rocks were deposited in a fluvial nonmarine environment and were exposed to air (Lyons and others, 1976, p. 193–194). Thus, we envision, for that part of the Carboniferous represented by the known Pennsylvanian deposits and by the deposits considered to be possibly Carboniferous, a region of high relief following the late Acadian episodes in which previously formed nappe structures in central New England (west of this Carboniferous terrane) were domed.

STRUCTURAL EVOLUTION OF THE NARRAGANSETT BASIN

The following sequence, from oldest to youngest, of structural events represents a working model for the deformational history of the Narragansett Basin.

In Rhode Island:

1. Northeast-trending isoclinal overturned to recumbent folds formed with associated east-dipping to subhorizontal cleavage and northwest-directed thrust faults.
2. A milder episode of folding was associated with northwest-dipping cleavage and southeast-directed northwest-dipping thrusts.
3. Cleavage was gently warped, and kink bands formed.

In Massachusetts:

1. Open folds trending east-northeast and having northwest-dipping cleavage formed in most of the Massachusetts part of the basin.
2. Possible southeast-directed thrusting may have emplaced the Blake Hill thrust sheet in Plainville and possibly other thrust sheets not yet well defined. This episode may have been contemporaneous with event 2 (listed above) of Rhode Island.

Several episodes of normal faulting took place following these compressional phases of deformation. Faults formed include:

1. Northwest-striking faults, such as the Portsmouth Abbey fault (William R. Barton, oral commun., 1975), that had significant left-lateral strike motion; such faults are detected by drilling (Skehan and others, 1976).
2. Northeast- and northwest-striking faults.
3. North-striking faults.

STRUCTURAL EVOLUTION OF SOUTHEASTERN NEW ENGLAND

In southeastern New England, the basins known or thought to be Carboniferous have been deformed by folds and faults that are north trending in the south and are east-northeast trending in the north. This post-Conemaugh (post-Stephanian A) deformation was characterized by northwest-dipping southeast-moving thrusts and highangle reverse faults over most of the Avalonian platform. The southern part of the platform is dominantly characterized by southeast-dipping, northwest-directed thrusts that are cut by later northwest-dipping, southeast-directed thrusts.

TIMING AND CAUSES OF THE ALLEGHANIAN OROGENY

A complex structural history is recorded in the pre-Carboniferous and Carboniferous rocks of the Avalonian terrane of New England. The following two-stage working hypothesis is presented to explain the known data.

1. The Acadian orogeny represents the collision of the Eur-Asian and North American plates; the Avalonian terrane formed the leading edge of of the Eur-Asian plate and was sutured to the North American plate approximately along the zone between the Clinton-Newbury and the Bloody Bluff fault zones (fig. 1). This suturing defines the final closure of the Proto-Atlantic Ocean (Iapetus).
2. Closure of the Hercynian Ocean began in late Paleozoic times and resulted in the collision of Gondwana with Laurasia. This event is recorded as the Alleghanian orogeny in eastern North America and the Variscan-Hercynian orogeny in northwest Europe.

Whether the Avalonian plate was overridden by the North American plate or vice versa, the Clinton-Newbury and Bloody Bluff fault zones (fig. 1) may define the suture and mark the northwestern and southeastern boundaries of underplating. Thus, the faults on these plates initially formed during the Acadian; however, their present geometry (such as the east-directed, west-dipping, high-angle reverse faults in the northern part of the Avalonian platform) was defined during the Alleghanian orogeny. Here the Alleghanian (Variscan) orogeny was a major orogenic event consisting of the following elements: (1) isoclinal folding and refolding associated with thrusting; (2) upper amphibolite facies Barrovian regional metamorphism; and (3) intrusion of probably anatectic granites.

The Alleghanian orogeny may either represent: (1) subsequent interactions between the Eur-Asian and North American plates or (2) the collision of the South American parts of Gondwana with Laurasia. The latter interpretation is a logical extension of Irving's (1977) data.

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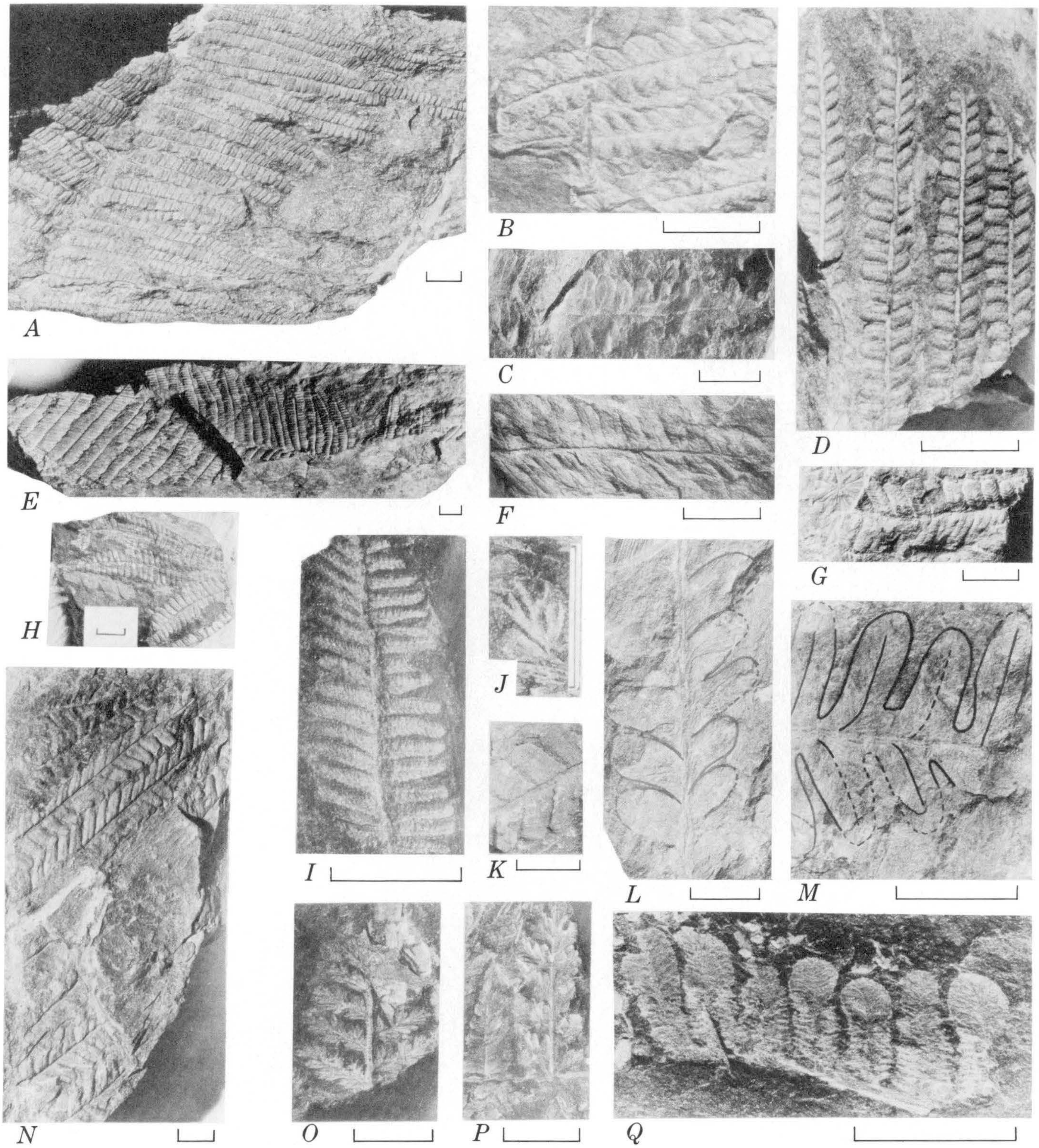
PLATE 1

A contact photograph of the plate in this report is available, at cost, from U.S. Geological Survey Library, Federal Center, Denver, Colorado 80225

PLATE 1

[All specimens are from Easton, Mass. E number is original specimen number; HU number is Harvard University, Paleobotanical Collections, specimen number. Line scale equals 1 cm.]

Figure A. *Pecopteris arborescens* Schlotheim, E-232a, HU-45708.
B. *Pecopteris* sp., E-116, HU-45709.
C. *Pecopteris unita* Brongniart, E-216, HU-45710.
D. *Pecopteris* aff. *hemitelioides* Brongniart, E-97, HU-45711.
E. *Pecopteris arborescens* Schlotheim, E-120, HU-45712.
F. *Pecopteris lamuriana* Heer, E-110, HU-45713.
G. *Pecopteris* aff. *hemitelioides* Brongniart, E-113, HU-45714.
H. *Pecopteris* cf. *lamuriana* Heer, E-141, HU-45715.
I. *Pecopteris lepidorachis*(?) Brongniart, E-132, HU-45716.
J. *Eremopteris* cf. *lincolniana* D. White, E-202a, HU-45717.
K. *Alethopteris*(?) sp., E-195a, HU-45718.
L. *Odontopteris* cf. *reichiana* Gutbier, E-194, HU-45719, pinnules outlined for clarity.
M. *Alethopteris*(?) (Brongniart) Goeppert, E-143, HU-45720, pinna and medial veins outlined for clarity.
N. *Neuropteris obliqua*(?) Brongniart, E-243a, HU-45721.
O. *Eremopteris missouriensis* Lesquereux, E-74, HU-45722.
P. *Sphenopteris* aff. *subalata* Geinitz, E-204, HU-45723.
Q. *Neuropteris rarinervis* Bunbury, E-47, HU-45724.



PECOPTERIS, *EREMOPTERIS*, *ALETHOPTERIS*(?), *ODONTOPTERIS*, *NEUROPTERIS*, AND *SPHENOPTERIS*

The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

1879 · CENTENNIAL · 1979
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GEOLOGICAL SURVEY PROFESSIONAL PAPER 1110–A–L

ON THE COVER

Swamp-forest landscape at time of coal formation: lepidodendrons (left), sigillarias (in the center), calamites, and cordaites (right), in addition to tree ferns and other ferns. Near the base of the largest *Lepidodendron* (left) is a large dragonfly (70-cm wingspread). (Reproduced from frontispiece in Kukuk, Paul (1938), "Geologie des Niederrheinisch-Westfälischen Steinkohlengebietes" by permission of Springer-Verlag, New York, Inc.)

The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—

A. Massachusetts, Rhode Island, and Maine, by James W. Skehan, S.J., Daniel P. Murray, J. Christopher Hepburn, Marland P. Billings, Paul C. Lyons, and Robert G. Doyle

B. Pennsylvania and New York, by William E. Edmunds, Thomas M. Berg, William D. Sevon, Robert C. Piotrowski, Louis Heyman, and Lawrence V. Rickard

C. Virginia, by Kenneth J. Englund

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H. Georgia, by William A. Thomas and Howard R. Cramer

I. Alabama and Mississippi
    Mississippian stratigraphy of Alabama, by William A. Thomas
    Pennsylvanian stratigraphy of Alabama, by Everett Smith
    Carboniferous outcrops of Mississippi, by Alvin R. Bicker, Jr.

J. Michigan, by Garland D. Ells

K. Indiana, by Henry H. Gray

L. Illinois, by Elwood Atherton and James E. Palmer

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FOREWORD

The year 1979 is not only the Centennial of the U.S. Geological Survey—it is also the year for the quadrennial meeting of the International Congress on Carboniferous Stratigraphy and Geology, which meets in the United States for its ninth session. This session is the first time that the major international congress, first organized in 1927, has met outside Europe. For this reason it is particularly appropriate that the Carboniferous Congress closely consider the Mississippian and Pennsylvanian Systems; American usage of these terms does not conform with the more traditional European usage of the term "Carboniferous."

In the spring of 1976, shortly after accepting the invitation to meet in the United States, the Permanent Committee for the Congress requested that a summary of American Carboniferous geology be prepared. The Geological Survey had already prepared Professional Paper 853, "Paleotectonic Investigations of the Pennsylvanian System in the United States," and was preparing Professional Paper 1010, "Paleotectonic Investigations of the Mississippian System in the United States." These major works emphasize geologic structures and draw heavily on subsurface data. The Permanent Committee also hoped for a report that would emphasize surface outcrops and provide more information on historical development, economic products, and other matters not considered in detail in Professional Papers 853 and 1010.

Because the U.S. Geological Survey did not possess all the information necessary to prepare such a work, the Chief Geologist turned to the Association of American State Geologists. An enthusiastic agreement was reached that those States in which Mississippian or Pennsylvanian rocks are exposed would provide the requested summaries; each State Geologist would be responsible for the preparation of the chapter on his State. In some States, the State Geologist himself became the sole author or wrote in conjunction with his colleagues; in others, the work was done by those in academic or commercial fields. A few State Geologists invited individuals within the U.S. Geological Survey to prepare the summaries for their States.

Although the authors followed guidelines closely, a diversity in outlook and approach may be found among these papers, for each has its own unique geographic view. In general, the papers conform to U.S. Geological Survey format. Most geologists have given measurements in metric units, following current practice; several authors, however, have used both metric and inch-pound measurements in indicating thickness of strata, isopach intervals, and similar data.

FOREWORD

This series of contributions differs from typical U.S. Geological Survey stratigraphic studies in that these manuscripts have not been examined by the Geologic Names Committee of the Survey. This committee is charged with insuring consistent usage of formational and other stratigraphic names in U.S. Geological Survey publications. Because the names in these papers on the Carboniferous are those used by the State agencies, it would have been inappropriate for the Geologic Names Committee to take any action.

The Geological Survey has had a long tradition of warm cooperation with the State geological agencies. Cooperative projects are well known and mutually appreciated. The Carboniferous Congress has provided yet another opportunity for State and Federal scientific cooperation. This series of reports has incorporated much new geologic information and for many years will aid man's wise utilization of the resources of the Earth.

H William Menard

H. William Menard
Director, U.S. Geological Survey

CONTENTS