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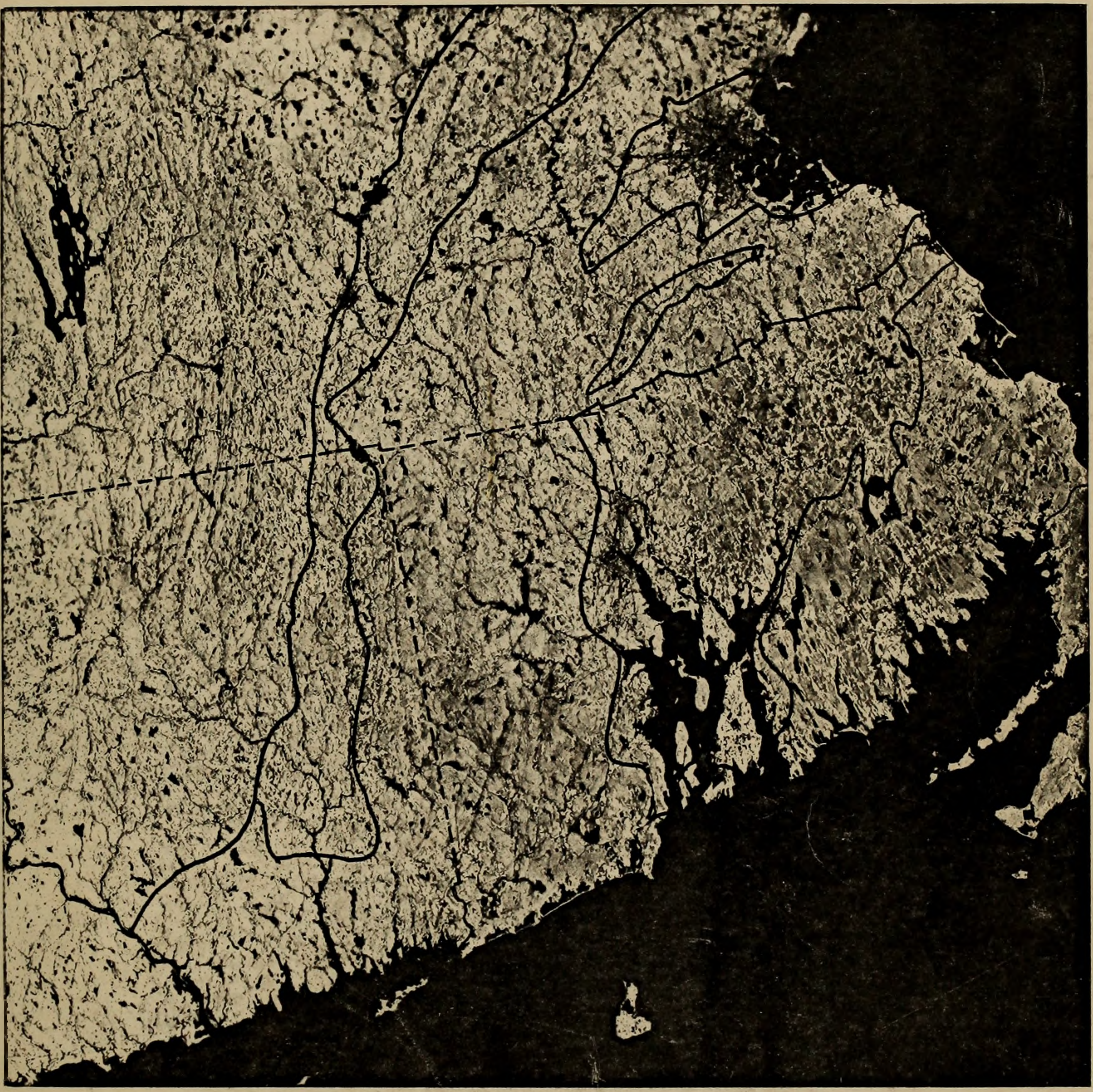
General Structural Setting of Rhode Island and Tectonic History of Southeastern New England

New England Intercollegiate Geological Conference (NEIGC)

Barosh, Patrick J.

Hermes, O. Don

GUIDEBOOK TO GEOLOGIC FIELD STUDIES IN RHODE ISLAND AND ADJACENT AREAS



The 73rd Annual Meeting
of the
New England Intercollegiate Geologic Conference
October 16-18, 1981

Edited by
Jon C. Boothroyd and O. Don Hermes
University of Rhode Island

Sponsored by
Department of Geology
University of Rhode Island
Kingston, Rhode Island 02881-0801

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FORWARD

The University of Rhode Island is proud to host for the first time the New England Intercollegiate Geological Conference. This 73rd annual meeting occurs eighteen years after the last conference held in Rhode Island, at which time eight trips were offered. This contrasts with the diversity of the twenty-two trips being run in 1981, which include emphasis on a variety of geologic problems that range from surficial to bedrock studies.

A resurgence in the interest of the bedrock geology of the area has taken place in the past decade; this new interest partly has been stimulated by recent plate tectonic models that emphasize the distinct character and geologic history of the Avalon Terrain of southeastern New England compared with lithotectonic belts to the west. It is increasingly clear that a better understanding of the geology of this part of New England is necessary in order to understand the geological evolution of the Appalachians as a whole. As elsewhere, the geologic history is complex. Recently initiated studies by a number of workers are adding new information to the data base collected by geologists of decades past. So far the results are leading to new and revised interpretations, but even these can be expected to undergo substantial modification as the early studies progress. Eventhough most of the current studies are imcomplete, we hope that the spirit of NEIGC will provide an opportunity for the geologists working in the area to share the results of their on-going studies with students, faculty, and commercial geologists. We seek an atmosphere for a positive exchange of concepts, interpretations, and ideas so that a better understanding of the geology of southeastern New England and the broader surrounding region will emerge.

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The editors extend their thanks to numerous University of Rhode Island graduate and undergraduate students for their assistance in the assembly of the NEIGC announcement and this guidebook.

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GENERAL STRUCTURAL SETTING OF RHODE ISLAND AND TECTONIC HISTORY OF SOUTHEASTERN NEW ENGLAND

Patrick J. Barosh[1] and O. Don Hermes[2]

INTRODUCTION

A great deal of new information has been learned about the geology of Rhode Island and the surrounding region since Quinn summarized the geology of the state in 1971. The new data compliment the earlier work of Quinn and others, and offers the opportunity to make new geologic interpretations, as well as allowing a more precise definition of key problems and areas for future study. Extensive geologic quadrangle mapping and stratigraphic studies by the U.S. Geological Survey have been done in eastern Connecticut and eastern Massachusetts, and adjacent offshore surveys have been completed. Geological and geophysical studies sponsored by the U.S. Nuclear Regulatory Commission have been performed by the New England Seismotectonic Study. The Narragansett Basin has been studied as part of a coal investigation program with the support of the U.S. Bureau of Mines. A variety of work has been done by consultants to public utilities, and a number of topical studies have been undertaken by university personnel and students in the region. More reliable radiometric age dates are now available as a result of improved laboratory techniques and better geologic control on the sample localities. New information also is available on fossil localities. Good aeromagnetic and gravity data now exist or are in preparation for most of this region and excellent Landsat images are available. The close match of magnetic and gravity data with surface geology has led to the discovery of important regional features and now provides a way to map through the glacial cover. Moreover, the increased network of seismographs in the region is greatly improving our knowledge of present day tectonic activity.

This new information has greatly altered our understanding of the structure, geologic history, and tectonic development of the region. The region has undergone a long and complex history of sedimentation, igneous activity, metamorphism, and deformation. As the details of these events become better known, we are more able to draw knowledgeable comparisons and contrasts with adjacent lithotectonic belts, which in turn add to our understanding of the role of plate tectonics in the formation of the Appalachian mountain belt.

The purpose of this introduction to the geology of the Rhode Island region is to present a generalized summary of the structural setting and the geologic history as it is now understood, and to show how the individual field guides pertaining to bedrock geology fit into the overall geology. Several articles that include discussion of general evolutionary geologic models for the larger New England region have been published recently and should be of interest to the reader

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(e.g., Rast and other, 1976; Osberg, 1978; Skehan and Osberg, 1979; Rast, 1980; Robinson and Hall, 1980; Skehan and Murray, 1980). The brief nature of our summary does not allow mention of many important geologic features, or the citation of all important studies. For this shortcoming, we ask the reader for tolerant understanding.

GEOLOGIC SETTING OF SOUTHEASTERN NEW ENGLAND

Rhode Island lies along the western side of the Southeastern New England platform, a structural block that is in general the same as the Boston platform (Zartman and Naylor, in press), which a larger scale correlates with the Avalon province of Canada (Rast and others, 1976; Williams, 1978). The Southeastern New England platform is separated from the Merrimack province to the northwest by the narrow Nashoba thrust belt, and is overlapped to the south and east by Cretaceous and Tertiary deposits that form the submerged northward extension of the Atlantic Coastal Plain (Fig. 1).

The Southeastern New England platform consists of a late Proterozoic batholithic complex and associated metasedimentary and metavolcanic rocks that were intruded by younger plutons and covered by sediments at various times during the Paleozoic. The sediments are preserved in basins that are largely fault bounded (Fig. 1). These include the Boston Basin, which contains late Proterozoic to Middle Cambrian conglomerate, argillite, and volcanic rock (Kaye and Zartman, 1980; Kaye, 1981), the Narragansett and Norfolk Basins which contain Carboniferous stream deposits that overlie trilobite-bearing Cambrian phyllites (Shaler and others, 1899; Skehan and others, 1979), and offshore basins of Triassic to Jurrassic sandstone, siltstone, and basalt (Ballard and Uchupi, 1975). Locally common are Mesozoic dikes of diabase and lamprophyre.

The composition of the late Proterozoic intrusions ranges from quartz-rich alaskite and granite to diorite or gabbro. They contain xenoliths and large pendants of metasedimentary and metavolcanic rock. The western edge of the batholith is strongly foliated and syntectonically deformed into a series of large folds. These folds generally trend and plunge to the north along the Rhode Island-Connecticut border but trend westward farther south in southeastern Connecticut. The late Proterozoic intrusives generally are much less deformed to the east where they commonly are not foliated, except in local areas where closely spaced shear zones are abundant. The western border of the platform trends to the northeast in Massachusetts where the structure more characteristically exhibits northeast trending faults rather than folds. The dominant fault trends within the platform are to the northeast and north with more easterly trends near the Boston Basin.

The Nashoba thrust belt northwest of the platform forms a major structural discontinuity. The stratigraphy, structural style, and ages of plutons on either side are strikingly different Barosh and Pease, 1977; Barosh and others, 1978a; Zartman and Naylor, in press). The belt forms a major boundary between tectonic blocks across which no stratigraphic correlation has been made. The Nashoba thrust belt is composed largely of pre-Ordovician andesitic to basaltic volcaniclastic rock, now at high metamorphic grade. These rocks are cut by a series of high angle, west-dipping fault slices that are invaded by granitic intrusive rock of Ordovician to Devonian ages (Dixon, 1964; Alvord and others, 1976; Bell and Alvord, 1976;

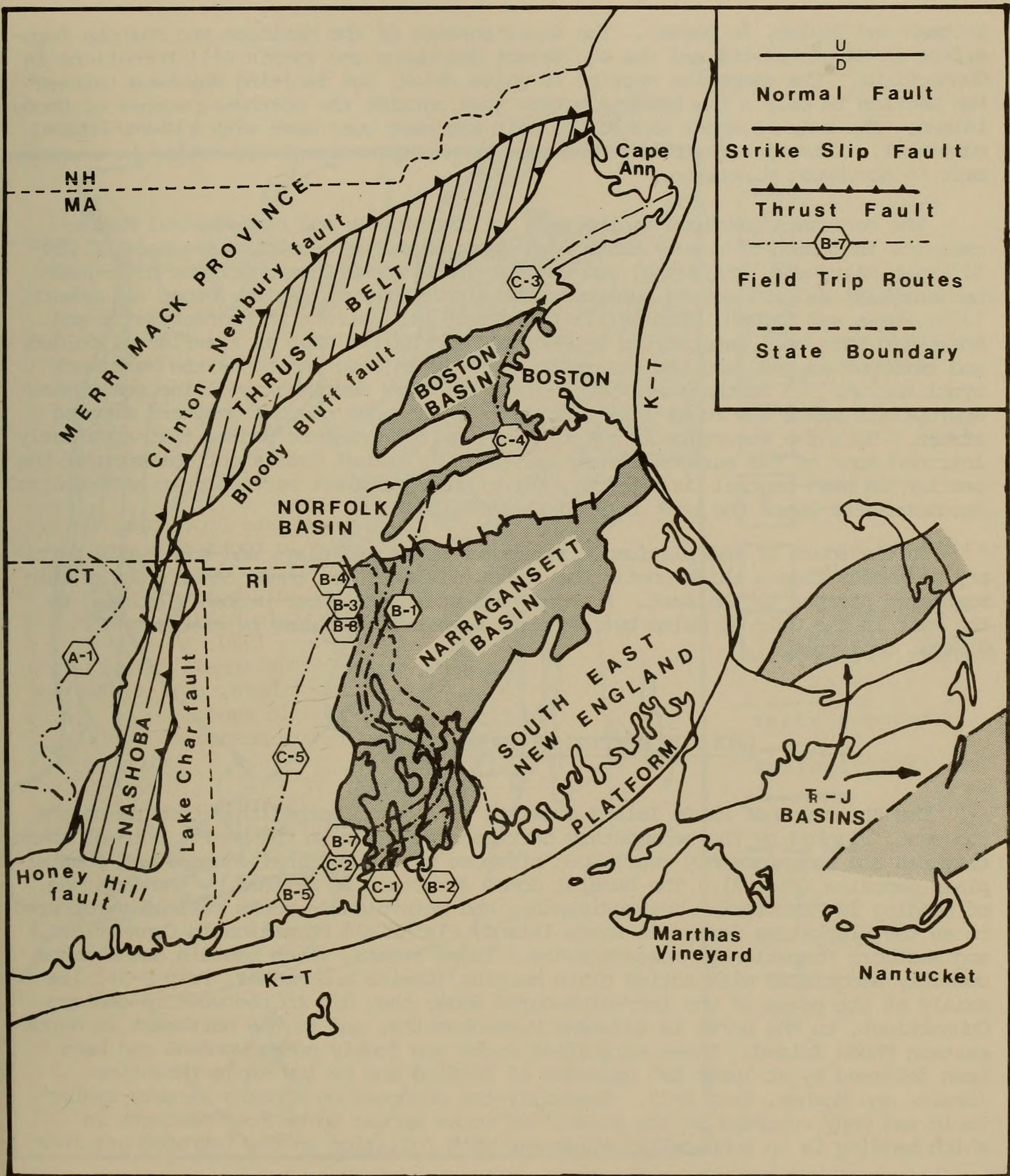

Figure 1. Sketch map of southeastern New England showing major tectonic provinces and basins and general location of field trips.

Zartman and Naylor, in press). The rocks consist of the Marlboro and Nashoba Formations in Massachusetts and the equivalent Quinebaug and Tatnic Hill Formations in Connecticut. The composite section is quite thick, but faulting may have thinned the section to only a few hundred meters just outside the northwest corner of Rhode Island. The main movement within the belt was east over west with a right-lateral component. This appears to have been due to a compressive force acting in a northeast to southwest direction.

The Merrimack province to the west in Connecticut and east-central Massachusetts is formed of a very thick west-dipping and west-topping sequence of pre-Silurian siltstone, graywacke, and shale. These rocks have undergone high-grade metamorphism and are cut by numerous west dipping thrust faults (Peper and others, 1975; Pease and Barosh, Trip A-1). Conversely, the strata in Massachusetts and northward have been interpreted by Robinson and Hall (1980) as a series of folded and refolded nappes, and the structure commonly is referred to as the Merrimack synclinorium. In southeastern New England the term Merrimack geocline seems more appropriate since the rocks form a homoclinal sequence of northwestward dipping strata. Here the structure is cut by long, narrow granitic bodies that apparently intruded some of the earlier thrust faults. The thrust faults cut out much of the section in east-central Connecticut, but offset decreases northward in east-central Massachusetts where the rock is much less faulted.

To the south of the platform, Cretaceous sands and clays and some Early Tertiary sediments form a thick continuous cover offshore, but these occur only as thin scattered patches to the east. A thin, but continuous cover probably existed to the east in the Gulf of Maine but may have been stripped away by glaciers (C. O'Hara, oral comm.).

GEOLOGIC SETTING OF RHODE ISLAND

The structure of Rhode Island consists of a domal batholithic complex on the the west, flanked by the sedimentary Narragansett Basin to the east. Both of these features are unconformably overlapped offshore by a homoclinal sequence of coastal plain deposits (Fig. 2). The general domal structure is defined by the attitude of bedding in Precambrian metasedimentary and metavolcanic rocks variously referred to as the Blackstone Series in Rhode Island, Plainfield Formation in Connecticut, and Westboro Formation in Massachusetts. These strata, which contain assemblages commonly associated with active plate margins (Dreier and Mosher, Trip B-3), lie mainly at the edges of the intrusive-cored dome; they dip to the west in eastern Connecticut, to the north in adjacent Massachusetts, and to the northeast in northeastern Rhode Island. These stratified rocks are feebly metamorphosed and have been deformed by at least two episodes of folding and by low angle thrusting (Dreier and Mosher, Trip B-3). Generally the deformation appears largely syntectonic and many outcrops of the stratified rocks appear to be roof pendants in which bedding is in subparallel alignment with foliation in the intruded granites.

This general domal structure is cut by numerous faults and is distorted by smaller folds. A series of north-trending, north-plunging folds, designated the West Rhode Island fold belt (Barosh, 1976), lies along the Connecticut-Rhode Island border (Fig. 3). These folds are broad and open in the north, but become progressively more compressed to the south where they are overturned and broken by thrust

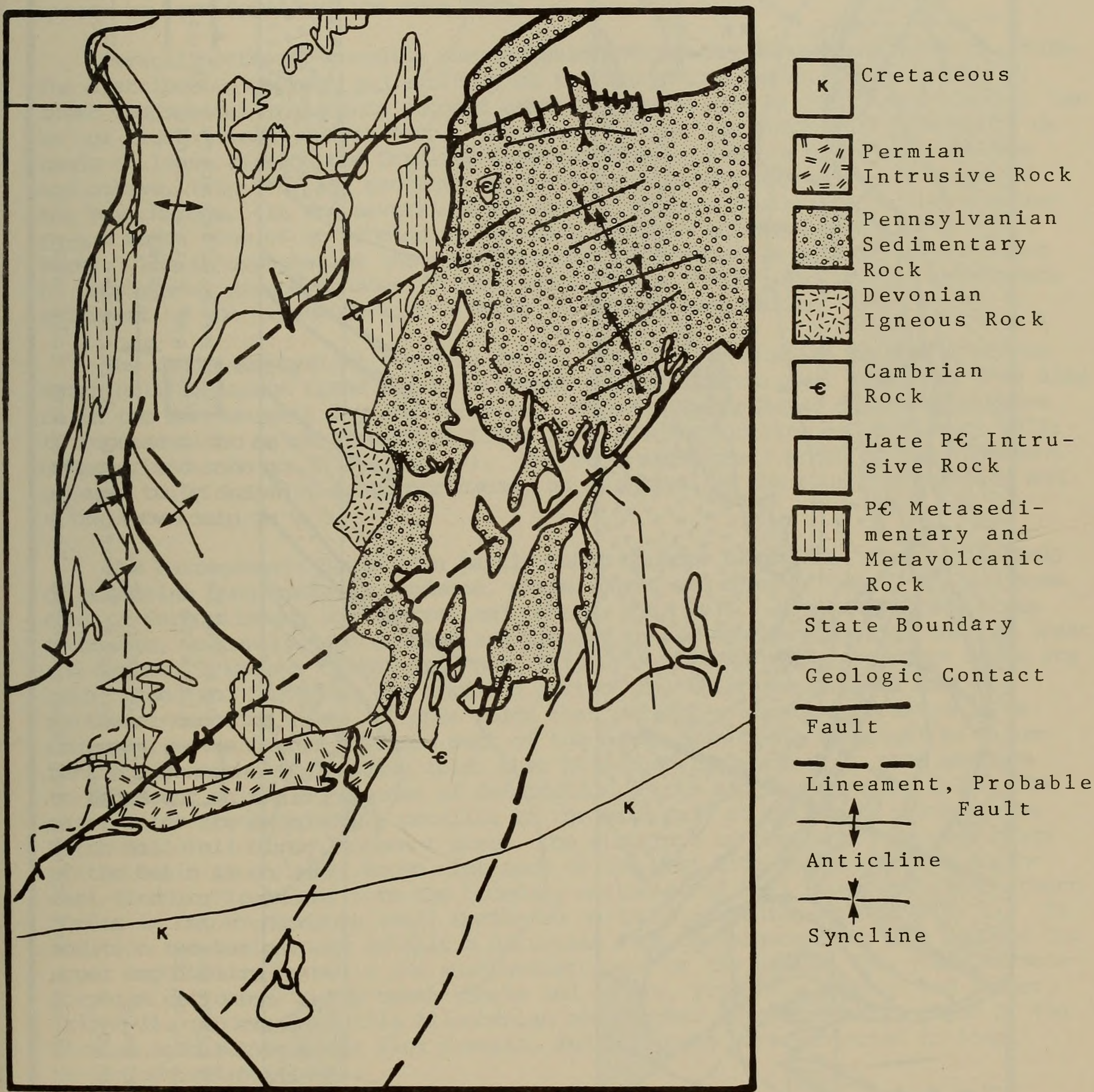

Fig. 2. Sketch map of Rhode Island and vicinity showing major structural features.

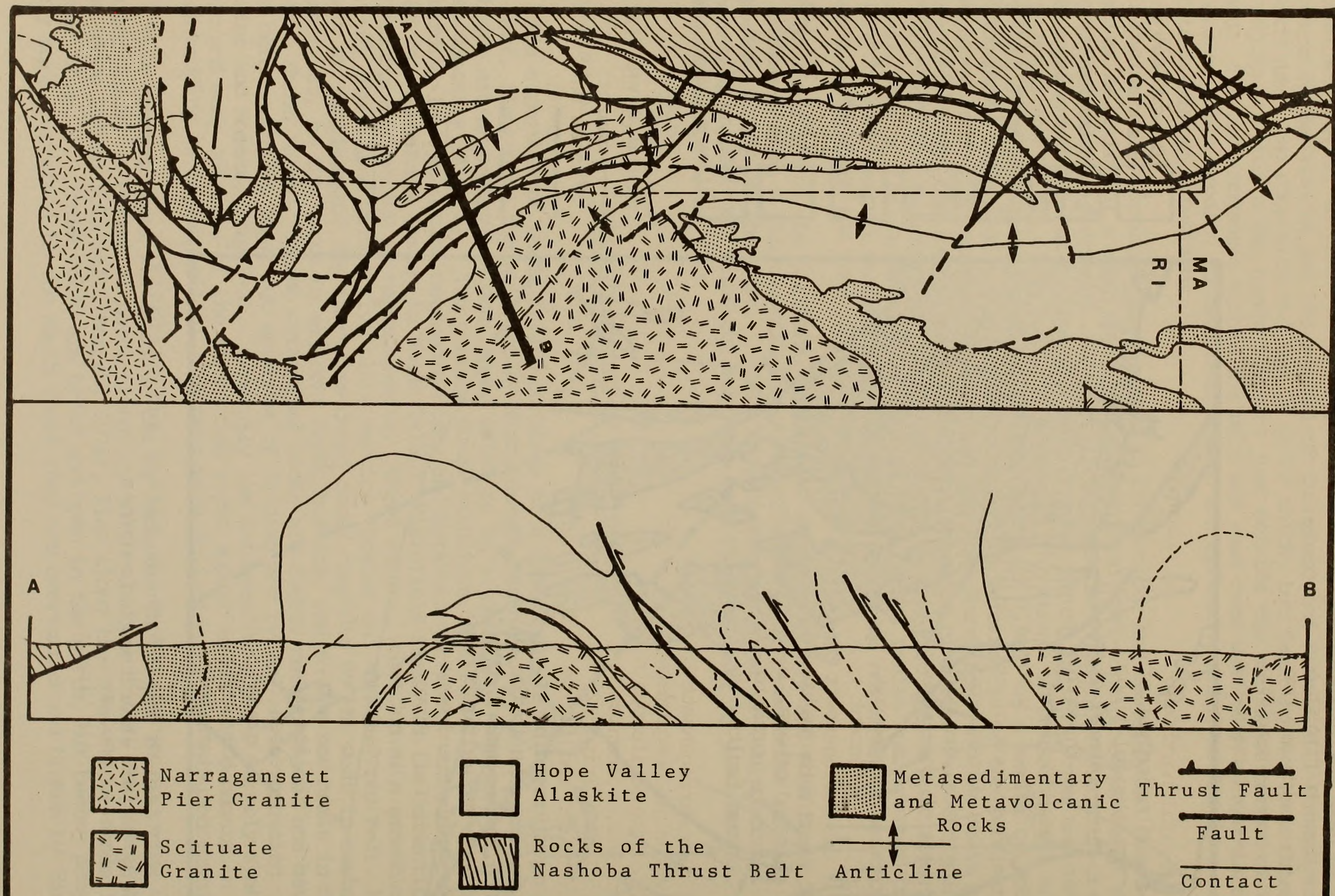

Fig. 3. Sketch map and cross section of West Rhode Island fold belt.

faults. The faults tend to cut out the synclines. The western part of the fold belt swings southwest and west approximately parallel to the Honey Hill fault zone where the folds are overturned to the northwest. The eastern part swings southeast across southwestern Rhode Island and is overturned to the northeast. Both the northwest- and northeast-dipping overturned folds and associated thrust faults appear to have formed at the same time.

Several northeast-trending aeromagnetic and gravity lineaments cross the dome. The distribution pattern and attitude of the Blackstone Series where crossed by these geophysical lineaments suggest that they may be cut by fault zones with a few km of right-lateral offset each. The southern one, the Watch Hill lineament, extends at least through the Carolina Quadrangle as a possible fault zone (Hermes and others, Trip B-5) and projects into the Narragansett Bay where the shape of the bay changes. It and several geophysically defined faults in the bay area may form a major zone of en echelon faults that continue northeastward through Fall River. The interpretation that the Watch Hill lineament is a fault is supported by geophysical ground studies (Schwab and Frohlich, 1976), and by the approximate alignment of the lineament with a fault in Narragansett Basin.

The major geophysical features in the poorly exposed areas southeast of the Watch Hill lineament trend north-northeast (R.K. Frohlich, oral comm.) as they also do in the Narragansett Bay and offshore. This north-northeast direction appears to represent the major structural trend in this area (Collins and McMaster, 1978; McMaster and others, 1980) (Fig. 4). The structural grain north of the lineament appears to be north to north-northwest, as expressed by the trend of contacts and a few known faults.

The Narragansett Basin is a partly fault bounded basin that consists largely of nonmarine conglomerate, sandsone, shale (Burks and others, Trip C-2), and some coal of Carboniferous age (Murray and others, Trip B-7). Horsts of Precambrian sediments, volcanics, and granite are present in the southern part of the bay (Rast and Skehan, Trip B-2; Skehan and Rast, Trip C-1). Rocks of Narragansett Basin are both folded and faulted. The northern part of the basin exhibits an east-northeast-trending group of open folds that reflect a single deformation. In contrast, rocks in the southern part of the basin form tight isoclinal to recumbent north-northeast-trending folds that have been interpreted by some workers to represent multiple episodes of deformation (Burks and others, Trip C-2). The major folds trend generally parallel to the main axis of the basin north of the Watch Hill-Fall River lineament zone. The structure of the poorly exposed parts of the basin is not well known, but much of the west side is faulted. A north-east-trending fault may form the boundary northeast of Fall River and the northern border is cut by numerous small north- to northwest-trending faults (Fig. 1). In addition the basin rocks exhibit a Barrovian type of metamorphism that reached the upper amphibolite facies in the southwestern part of the basin. The grade of metamorphism decreases to the north (Burks and others, Trip C-2; Hepburn and Rehmer, Trip B-1). Isograds of this Alleghenian metamorphic episode are truncated by the Permian aged Narragansett Pier Granite, and the rocks were subjected to local retrograde metamorphism.

The Cretaceous deposits offshore form a northward-facing cuesta of sorts at the inner margin (O'Hara and Oldale, 1980). The consolidated Cretaceous clays and sands exposed at a few places on Block Island may be in place, but those exposed at Martha's Vineyard to the east have been thrust up by glacial push (Kaye, 1964 a, b).

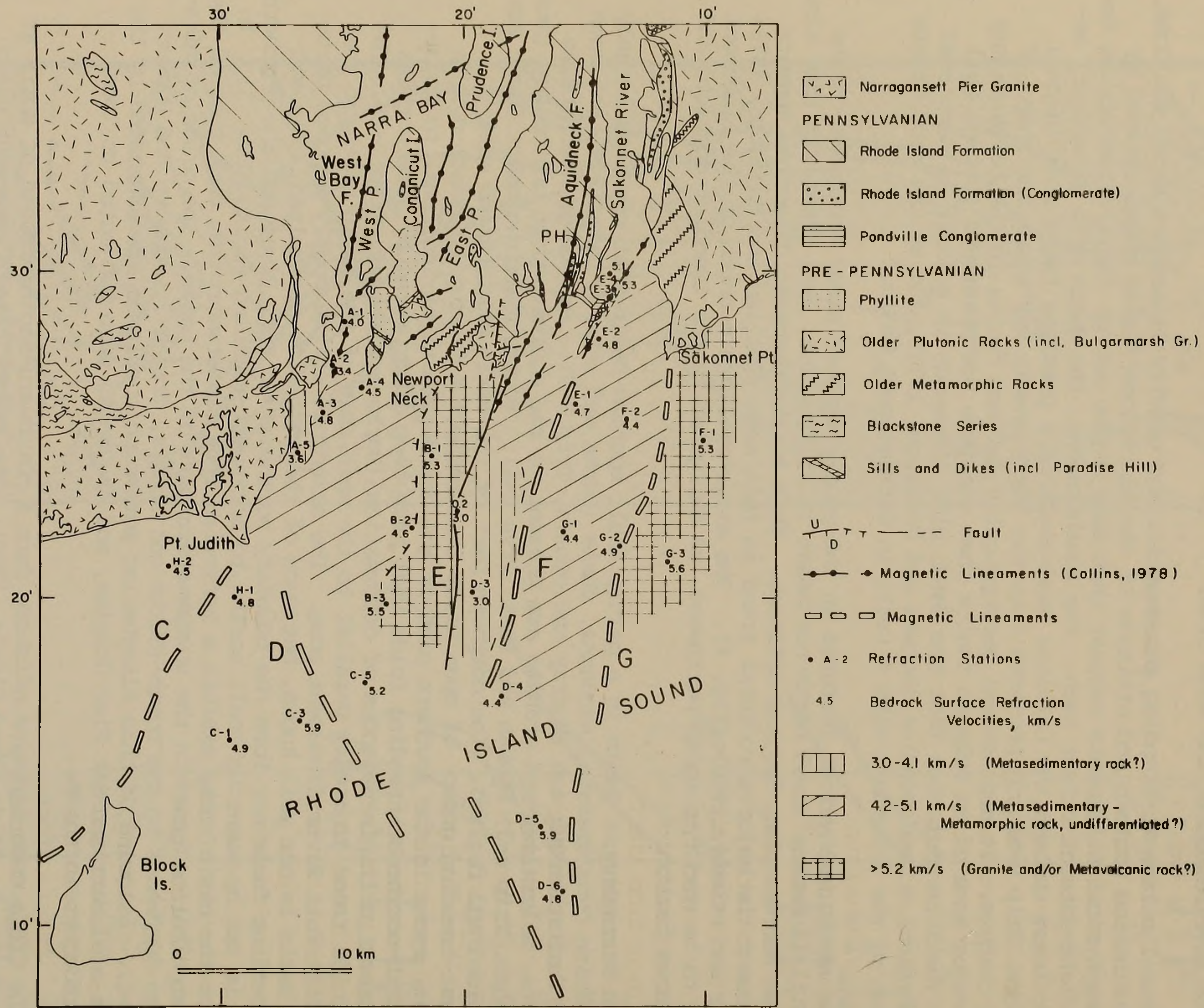

Fig. 4. Geologic and tectonic map of the southern Narragansett Bay and adjacent offshore areas (McMaster and others. 1980).

GEOLOGIC HISTORY

The known geologic history of the southeastern New England platform began in the late Proterozoic when the interbedded Blackstone sequence of quartzite, graywacke, shale, limestone, and volcanic rocks (Carr and Edwards, Trip B-8; Dreier and Mosher, Trip B-3) was intruded by granitic to dioritic rock (Hermes and others, Trip C-5). The late Proterozoic platform rocks in Rhode Island and Connecticut that lie east and south of the Lake Char and Honey Hill fault zones are foliated gneisses and schists. These include the Sterling Group of plutonic rocks and the intruded metasedimentary and metavolcanic rocks. Platform rocks of similar age in eastern Rhode Island and nearby Massachusetts, as well as those adjacent to the Bloody Bluff fault zone in Massachusetts, are less- to non-foliated and have undergone only weak metamorphic recrystallization. The Esmond Group, Newport Granite Porphyry, Dedham Granodiorite, and Milford Granite are the principal Proterozoic plutonic rocks in this part of the platform. Contact metamorphosed xenoliths and roof pendants are all that is left of the intruded country rock.

Especially westward, along the present western boundary of the platform in western Rhode Island and southern Connecticut, the metamorphic fabric of the Sterling Group and related rocks appears to have been imposed syntectonically during emplacement of the plutonic rocks. The Sterling Group rocks are emplaced as sills parallel to foliation and layering in the country rock, and these structures are folded to accommodate the configuration of the Lake Char-Honey Hill fault zones as its trace is warped from south to west in the southeastern corner of Connecticut. The strong metamorphic fabric and high metamorphic grade in this area dies out to the east away from the boundary and also to the northeast in Massachusetts adjacent to the boundary.

These relationships suggest the possibility that a zone of deformation existed in the late Proterozoic along the approximate present trace of the Honey Hill-Lake Char fault zone that served as a precursor to the suture that joined the southeastern New England platform or Avalon plate to North America. Arguments based on radiometric age dating (Zartman and Naylor, in press) and the contrasting lithologies and degree of metamorphism across the boundary argue against juxtaposition of the Southeastern New England platform with tectonic blocks to the west prior to the beginning of the Devonian. Similarly, a maximum age for the North American-Avalonian collision to the north in Maine is interpreted to be 410 m.y. (Gaudette, 1981). On the other hand, Robinson and Hall (1980) have developed a model that juxtaposes the Avalon and North American plates in Ordovician time, whereas on paleomagnetic evidence, Kent and Opdyke (1978) concluded that Avalon rocks of southeastern New England were in the southern hemisphere during the Devonian and were distant from rocks of the North American plate with which they have been associated since Carboniferous time.

Closely following, and perhaps continuous with the emplacement of the late Precambrian plutons and the accompanying tectonic activity, was the deposition of stratified rocks in the Boston Basin. The sequence starts with late Precambrian near shore volcanic rock and conglomerate interbedded with argillite, that grades upward to Middle Cambrian marine argillite (Kaye and Zartman, 1980). The rhyolitic and andesitic volcanic rocks may reflect continuing activity along the eastern edge of the Avalon plate followed by a general transgressive sequence of offshore muds and turbidites. Other volcanic rocks to both the south and north of the Boston Basin also may be Precambrian in age (Naylor, Trip C-4). Fossiliferous carbonate and argillite strata of Cambrian age unconformably overlie Precambrian intrusive rocks at several other places on the platform, such as at Hoppin Hill just east of northern Rhode Island (Dowse, 1950; Shaw 1950; Fairbairn and others, 1967) and at Conanicut and Aquidneck Islands in the southern Narragansett Basin (Skehan and others, 1977; Rast and Skehan, Trip B-2; Skehan and Rast, Trip C-1).

Igneous activity of a generally distinct alkalic to peralkaline nature periodically occurred within the platform during the mid-Paleozoic (Rutherford and Carroll, Trip B-4; Hermes and others, Trip C-5). The mineralogy, textures, and chemistry of these rocks sharply contrast with the Proterozoic plutons which are more calcalkaline in character.

The older of these alkalic rocks range from Late Ordovician to Early Silurian, and include the Cape Ann and Quincy Granites, granites from the Gulf of Maine, and gabbroic bodies at Salem and Nahant (Zartman, 1977; Hermes and others, 1978). These hypersolvus granites and associated mafic rocks appear to be shallow intrusives, and probably were accompanied by volcanic activity. For example, the Quincy Granite appears to grade into rhyolite on its south side (C. A. Kaye, oral comm.), and comagmatic felsic dikes are associated with the Cape Ann pluton. Numerous mafic dikes also cut the Cape Ann rocks at this time (Ross, Trip C-3), and in some cases, there is evidence for the simultaneous coexistence of mafic and felsic magmas (Toulmin, 1964; Dennen, 1976). Other gabbroic plutons also may have been intruded at this stage, including the cumberlandite/gabbroic anorthosite complex of north-central Rhode Island, the Foster Gabbro of west-central Rhode Island (Pope, 1975), the Preston Gabbro (Zartman and Naylor, in press) at the south end of the Nashoba belt in Connecticut, and a probable but unexposed large pluton beneath the western end of Cape Cod (Barosh, and others, 1977b). Ordovician granitic rocks of calcalkaline affinity also intruded the Nashoba and Merrimack blocks (Zartman and Naylor, in press).

A second grouping of generally alkalic rocks range in age from Early to Middle Devonian. In Massachusetts, these include the Wenham Monzonite, Peabody Granite, and the Rattlesnake Hill pluton (Lyons and Kruger, 1976). Southward in Rhode Island, alkalic rocks of the East Greenwich Group and parts of the Scituate Granite Gneiss yield Devonian ages (Hermes and others, Trip C-5). Although generally contemporaneous with Acadian plutons in tectonic blocks to the west, these mid-Paleozoic plutons of the Southeastern New England platform generally maintain a distinct petrologic character.

Volcanic activity still affected the region in the Late Silurian-Middle Devonian as is shown by the variety of volcanic rocks mixed with marine sediments in the Newbury volcanic sequence (Shride, 1976). These occur in an unmetamorphosed fault slice along the contact with the Nashoba thrust belt north of the Boston Basin. Possibly a volcanic chain connected them with the contemporaneous coastal volcanic sequence of eastern Maine. Moreover, the Spencer Hill volcanics of central Rhode Island have been interpreted by Quinn (1971) to be comagmatic with the Devonian-aged Cowesett Granite.

Probably accompaning the mid-Paleozoic magmatic events, was the development of local contact metamorphic aureoles. The folding and faulting that affected the Late Silurian turbidite sequence in the Merrimack block north of Worcester may have developed at this time (Peck, 1976; Smith and Barosh, 1981). Unresolved is whether the low grade metamorphism of the rocks in the Boston Basin occurred in the Precambrian, during the mid-Paleozoic event, or later during Alleghenian time.

The platform may have experienced uplift and extensional faulting that led to the shedding of post-orogenic Late Devonian clastic deposits in the coastal volcanic zone of eastern Maine. Uplift, perhaps with associated extensional faulting, probably occurred on the Southeastern New England platform during the Carboniferous to produce the non-marine conglomerate, sandstone, shale and coal of the Narragansett and Norfolk Basins. These deposits may have overlapped the Nashoba thrust belt as shown by the presence of a fault sliver of Carboniferous rock on its west side in Worcester (Grew, 1973).

The sedimentary rocks in the Narragansett Basin probably were deformed and metamorphosed mostly before the intrusion of the Narragansett Pier and Westerly Granites in the Permian (Burks and others, Trip C-2; Hermes and others, Trip B-5). The highest grade of metamorphism roughly borders the southwestern margin of the basin and drops off to the north. Illite crystallinity studies hint that two Alleghenian thermal events may have occurred (Hepburn and Rehmer, Trip B-1). Although earlier work suggested that Alleghenian deformation and metamorphism was fairly localized, a number of recent studies indicate that it may be more widespread than formerly realized (Zartman and others, 1970; Day and others, 1980; Skehan and Murray, 1980; Dallmeyer, 1981).

The platform, along with the rest of southern New England, underwent uplift and extensional faulting during the Late Triassic and Jurassic as major rifting was initiated across the North Atlantic Basin. Deposition of continental clastic sediments and basalts occurred in local basins like that of the Connecticut Valley and numerous diabase dikes were injected into the older rocks (Ross, Trip C-3). Lamprophyric dikes also occur locally and may be of generally similar age. With the exception of a small fault sliver of fossil-bearing sediments exposed against the Nashoba thrust belt north of Boston (C. A. Kaye, pers. comm.), the remaining Mesozoic basins lie off-shore to the east (Ballard and Uchupi, 1975). During the Mesozoic there was reactivation of the Watch Hill fault zone which cuts the Narragansett Pier Granite as well as some displacement along the high angle faults that cross the Narragansett Basin. A regional tilt to the north, indicated by northward plunging structures and northward decrease in effects of different metamorphic events, also may have accompanied this episode.

The edge of the platform sagged to the south and east during the Late Jurassic and Cretaceous as the North Atlantic Basin continued to open, and an apron of clastic sediments of Cretaceous age was deposited on it. Deposition continued at least into the Early Tertiary (Weed, and others,1974). Post Creteceous movements formed the north to northwest-trending New Shoreham fault just west of Block Island (McMaster, 1971), and may have caused the small north- to northwest-trending faults that cut the Watch Hill fault zone on shore to the north (Hermes and others, Trip C-5).

During the Pleistocene the region was depressed by the weight of the glacial ice. The rebound of the crust that began soon after the ice started its retreat 13,500 years ago has resulted in a regional tilt to the south of about 1m/km. This tilt and the post-glacial rise in sea level have caused the Late Pleistocene shoreline to be deeply submerged off-shore to the south (O'Hara and Oldale, 1980), whereas it rises above the present sea level at the northern edge of the Massachusetts coast.

At present the Narragansett Bay area and adjacent southeastern Massachusetts exhibits mild seismic activity, with earthquakes occurring every few years (Fig. 5).

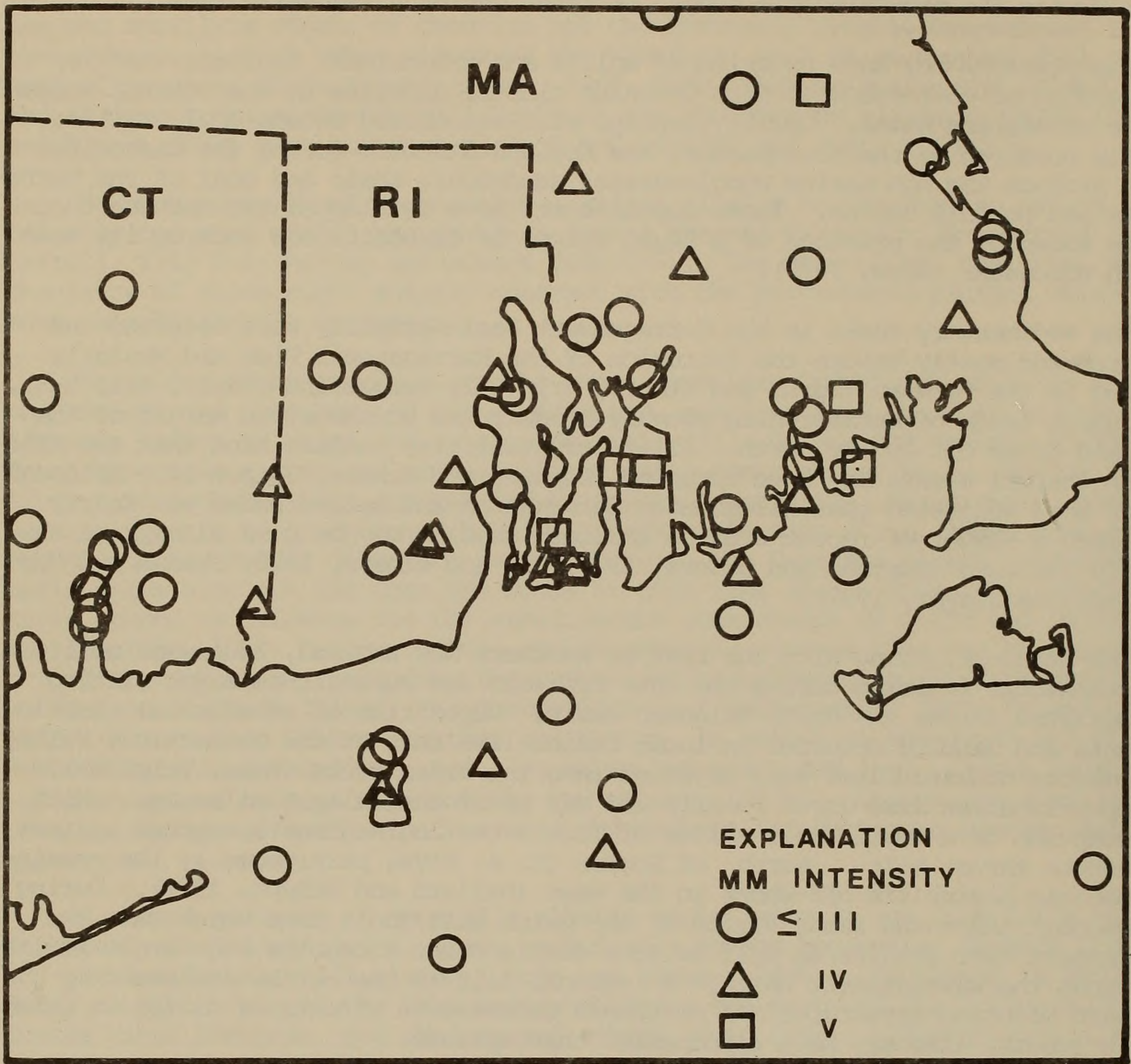

Figure 5. Sketch map of southeastern New England showing epicenters and intensities of historical earthquakes in the region.

The movements causing these earthquakes have yet to be determined, but they may be due to active subsidence in the bay area. Subsidence in the Passamaquoddy Bay area of Maine and New Brunswick appears to be related to the occurrence of earthquakes there (Tyler and others, 1979).

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