ALLEGHENIAN DEFORMATION, SEDIMENTATION, AND METAMORPHISM IN SOUTHEASTERN MASSACHUSETTS AND RHODE ISLAND

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Introduction

The Narragansett Basin of southeastern Massachusetts and Rhode Island is a topographic and structural depression that contains a thick sequence of sediments and rests unconformably upon an older basement of dominantly granitic rocks (Figure 1). These clastic sediments are well indurated, and have been progressively metamorphosed and deformed to the south.

Recently there has been renewed interest in the coal-bearing strata, and an exploration of the coal deposits in the Narragansett Basin has just begun (Skehan et al, 1976). This project entails detailed field and petrographic studies coupled with an extensive drilling program. The early results of this project suggest that the metamorphic and tectonic history of this region is considerably more complicated than previously believed. The purpose of this trip is to give a preliminary account of this work and to point out the salient field relations we believe critical to any regional synthesis of this part of New England. This trip is meant to complement the other trips in this volume that deal with the Narragansett Basin (Chapple and Kay; Lyons and Chase; Mosher and Wood), and the 1963 NEIGC (which concentrated on the geology of the Narragansett Basin).

The first stop will focus on the Dighton conglomerate, the youngest unit in the Basin, where primary structures are well preserved. The next three stops, in the Portsmouth, Rhode Island area, will examine the sedimentary and structural relationships in the vicinity of the most productive coal mines in the Basin. Then stops at Beavertail (on Conanicut Island) and Narragansett Pier, in metamorphosed and multiply deformed rocks that may be significantly older than their assigned Upper Paleozoic ages, are scheduled. The final stop, in Providence, Rhode Island, will illustrate the fact that the accepted structural interpretation of the Pennsylvanian sediments - that they have been deformed into a northward trending syncline - may be an oversimplification.

An understanding of the evolution of the Narragansett Basin is critical to any model for the evolution of New England, as the Basin represents the largest exposure of Late Paleozoic rocks in New England. The rich body of literature,

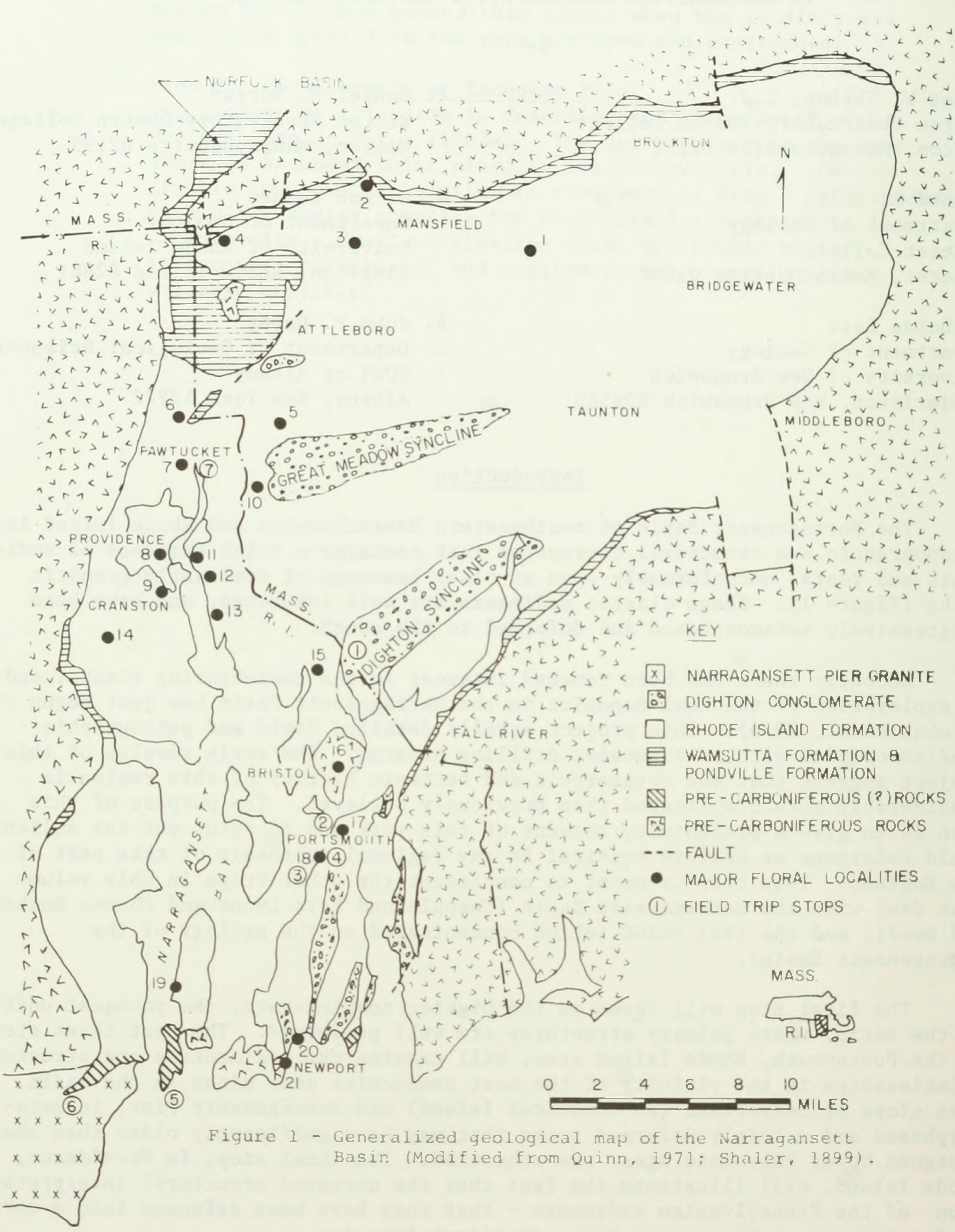


Figure 1 - Generalized geological map of the Narragansett Basin (Modified from Quinn, 1971; Shaler, 1899).

reaching well into the nineteenth century, underscores the realization. Recent articles that ably review the geology of the Narragansett Basin include Quinn and Oliver (1962), Quinn and Moore (1968), and Mutch (1968). In addition, the bedrock geology map of Rhode Island (Quinn, 1971) covers much of the Basin. The following sections summarize the geology of the Narragansett Basin; the reader is referred to the above-mentioned works for further information.

Stratigraphic Relationships

Four, or perhaps five, formations of Pennsylvanian sediments are recognized in the Narragansett Basin. They are briefly described below, going from oldest to youngest.

1. The Pondville Formation consists of arkosic sandstones and conglomerates and forms a discontinuous basal unit along the margin of the Basin. The type locale for the formation is the Norfolk Basin, a similar Pennsylvanian Basin to the north of the Narragansett Basin.

2. The Wamsutta Formation consists of conglomerate sandstone and shale characterized by a reddish color and the presence of volcaniclastic sediments and flows. It is restricted to the northwestern part of the Basin.

3. The Rhode Island Formation was originally defined as "all the horizons on which coal has been reported" (Shaler and others, 1899). It is now believed to consist predominantly of gray sandstone (arkoses and feldspathic graywackes), siltstone, conglomerate, shale and coal. The formation comprises 80+ percent of the Basin, and of the lithologies listed above, the sandstone is the most common.

4. The Dighton Conglomerate consists of three thick conglomeratic horizons that apparently form the cores of synclines (Figure 1). Lithologically, it is identical to the conglomeratic horizons within the Rhode Island Formation.

5. The Purgatory Conglomerate is confined to the southern (Newport) part of the Basin, and consists of a stretched pebble (to boulder) conglomerate. It is probably correlative with the lower part of the Rhode Island Formation (Mutch, 1968), and not the Dighton Conglomerate.

Scarcity of outcrop, rapid facies changes, and structural complexities restrict the measurements on the thickness of this stratigraphic sequence to rough estimates. The thickness probably lies between 2,000 and 12,000 feet, with the true value probably near the upper limit (Mutch, 1968). On the basis of an investigation of the sedimentary structures and petrology of the Narragansett Basin, Mutch (1968) concluded that the region was an isolated inter-montane basin, possibly fault bounded in some regions, and characterized by the rapid deposition of various types of fluvatile sediments.

The occurrence of well preserved floral assemblages in many parts of the Basin (see Figure 1 for locations) has allowed for the first time the widespread accurate dating of the sediments. The rocks range from Westphalian B to Westphalian D, and may be as young as early Stephanian (Lyons and Darrah, in press, 1976; Lyons and Chase, this volume. These ages are consistent with radiometric dates obtained on metamorphosed sediments in the southern part of the Basin, and with granites probably intrusive into these metasediments (Quinn and Moore, 1968).

Structure

As a first approximation, the Rhode Island portion of the Narragansett Basin forms a northeast-trending synclinal trough (Quinn and Oliver, 1962). On closer examination, however, the structure of this part of the Basin is considerably more complex, with easterly trending folds and thrusts having at least local importance (Stop 7). In Rhode Island and southernmost Massachusetts, structural patterns are conspicuously defined by stretched pebble conglomerates and bedding/cleavage relations (Stops 1 and 7 of this trip; Mosher and Wood, this volume). These very features have attracted the attention of geologists since the early nineteenth century. In the southernmost part of the Basin at Beavertail, at least two distinct episodes of folding, separated by periods of brittle deformation and vein formation, are evident (Stop 5).

The Massachusetts part of the Basin, which is less intensely deformed, contains three east-northeast trending synclines (Figure 1). The slightly deformed Dighton conglomerate, seen at Stop 1, lies within the southernmost syncline. Paucity of outcrop prevents recognition of the anticlines that presumably separate these depressions, as well as any structural relationships within the northeastern part of the Narragansett Basin.

The western margin of the Basin is known to be fault bounded (Quinn, 1971), while some sections of the eastern margin represent an unconformity between the Pondville Formation and the underlying granite gneisses (Mutch, 1968). North-south striking faults are common throughout the Basin, although east trending faults are also present (Stops 2, 7). It appears that the Rhode Island part of the Basin consists of a number of blocks elongate in a north-south direction. Whether these blocks are separated by predominantly normal or thrust faults is not clear, as both types are recognized in local field exposures.

Several smaller Carboniferous basins also occur in southeastern New England (Worcester Basin, North Scituate Basin, Norfolk Basin, Woonsocket Basin, and possibly Boston Basin), and elsewhere (Quinn and Oliver, Jr., 1962; Mutch, 1968. Quinn has argued that the presence of older rocks near the mouth of Narragansett Bay suggests that this location is the southern terminus of the Pennsylvanian Basin, and if the rocks mapped as Rhode Island Formation at Beavertail (Stop 5) and South Kingston (Stop 6) are interpreted as representing older metasediments, Quinn's conclusion is strengthened.

Metamorphism

Nearly all of the Massachusetts part of the Basin lies in the subchlorite zones. In Rhode Island, the sediments are progressively metamorphosed to the southwest, and this terrain has been classified as intermediate between Miyashiro's (1973) Barrovian and Buchan metamorphic facies series by Grew and Day, 1972. Grew (1974) has also carried out a detailed study of carbonaceous material from sediments of the Narragansett Basin that have undergone varying degrees of metamorphism. His results show that a variety of systematic changes occur in this material, and that they may prove to be useful indicators of metamorphic grade.

The upper limit of metamorphism is uncertain as sillimanitic and/or migmatitic schists mapped as Rhode Island Formation may actually repreent pre-Pennsylvanian metasediments (Stop 6). In any case the metamorphism is at least staurolite grade. A related problem is the extent (if any)) to which the Pennsylvanian sediments are contact metamorphosed by the Narragansett Pier granite. In a migmatite taken as a typical example of the contact between these two rock types (Stop 6), the granite may not be the Narragansett Pier and the host rock is most similar to outcrops of Precambrian Blackstone Formation that are exposed in the vicinity. Finally, a recent study of the petrography of the Pennsylvanian metasediments in the southernmost part of the Basin (Milne, 1972) suggests that at least some of the rock reflects a polymetamorphic history. This observation, if true, can be most easily accounted for by having these rocks represent older metasediments that were metamorphosed again with the Pennsylvanian sediments.

Itinerary

The trip begins and ends at Stop 7, the parking lot of the University Heights Star Market on North Main Street, Providence, Rhode Island. To reach the market from Boston proceed south on I-95 towards Providence. Take Exit 24 (Branch Avenue Exit). Turn left on Branch Avenue and proceed 0.4 miles to North Main Street. At North Main turn right and continue for 0.2 miles to Doyle Avenue. Turn left on Doyle and make the first right turn into the Star Market parking lot. Depending on the size of the group, some stops may be eliminated. Departure time is 8:00 a.m., sharp, and participants are urged to arrive in time to consolidate the number of vehicles.

Mileage

0.0 From Star Market parking lot, take Doyle Avenue Exit, turn left on Doyle, then make an immediate right on North Main Street.

0.2 Bear left off of North Main Street onto Branch Avenue (fire station on left).

0.6 Turn left off of Branch onto I-95 south. Watch for I-195 signs using two left lanes.

2.8 Bear left onto I-195 from I-95.

12.4 Large roadcut of Dighton conglomerate with sandstone lenses, that is similar to the first stop. Bedding trends N.70^{o}E. 10^{o}S, and a well-developed fracture cleavage (N.70^{o}W. 80^{o}S.) is present.

14.9 Exit 19 (Swansea-Somerset). Leave I-195 and turn left (WNW) on Route 6 (Fall River Avenue). The outcrops along the exit ramp are the first stop. Caution: Do not take the first Route 6 exit traveling east from Providence.

15.5 At the traffic light turn left onto Maple Street.

15.9 From Maple Street turn left at Old Warren Road (marked by dangerous intersection sign) and drive to the end of the street. Park, and walk approximately 50 yards to outcrops on access ramps to I-195.

16.2 Stop 1. Dighton Conglomerate - Outcrops along access ramps.

This outcrop of Dighton conglomerate is typical of the formation, and is located on the northwestern limb of the Dighton Syncline (Figure 1). Here, it consists primarily of rounded quartzite cobbles with subordinate amounts of rounded granite cobbles and slate pebbles. There is very little matrix, and clasts commonly are mutually indented. Lenses of faintly cross-bedded sandstone form approximately ten percent of the exposure; one of them contains a few plant fragments. These features imply a fluvatile environment, and it has been suggested that these sediments were deposited by braided streams (J. Collinson, 1976, pers. comm.). Unfortunately, the three dimensional configuration of the conglomerate and sandstone bodies is not exposed; without this information one cannot prove the existence of braided streams.

These thick conglomerate beds of the Dighton Formation are indistinguishable from thinner conglomeratic lenses within the Rhode Island Formation. Some insight into the relation between these two formations may be gained from consideration of a drill core that was recently obtained from the middle of the Dighton Syncline (Figure 2). The core begins in typical Dighton conglomerate with brown matrix and grades downward into fresher, gray conglomerate. Gradually down the core, sandstone and siltstone layers become more abundant, and eventu-ally dominate. Bedding is almost horizontal. A fault near the bottom of the core is suggested by the abundance of calcite veins and slickensides. The preferred interpretation is that the Dighton conglomerate grades conformably downward into the Rhode Island Formation, and that there are no major breaks in the record. We consider the brown staining of the upper part of the core to represent weathering, and not to be a feature characteristic of the Dighton (as suggested by Shaler, (1899). The contact between the two formations is placed at the point where a dominant lithology of conglomerate gives way to a dominant lithology of sandstone and siltstone.

This outcrop of Dighton is also slightly metamorphosed, and chlorite, epidote, quartz, and calcite occur in the matrix and along joints. The structural relations observed at this outcrop are listed in Table 1, and the salient points summarized below.

1. Analysis of cross-bedding in the sandstone lenses indicates that the Dighton is not overturned; it also has a fairly uniform strike and dip at this outcrop.

2. The cobbles are slightly elongate, with the maximum direction of elongation (N.20^{o}E.) at an oblique angle to the general ENE trend of the Dighton syncline: The cobbles are also offset along shear fractures.

3. A prominent joint set controls the shape of the outcrop.

Table 1 - Structural Relationships at Stop 1

	Type of Measurement	Attitude
1.	Contact between conglomerate and sandstone layers	N.80^{o}E. 30-40SE.
2.	Cleavage	N.80^{o}E. 60SE.
3.	Longest axis of pebbles	N.20^{o}E 50
4.	Joint; not mineralized	N.80^{o}W 45-60NE.
5.	Joint; mineralized, parallel to plane of flattening of pebbles, most prominent	N.30^{o}E.55SE.
6.	Mullions on mineralized joints	N.85^{o}E. 35
7.	Quartz veins	N.90^{o}E. 65N.

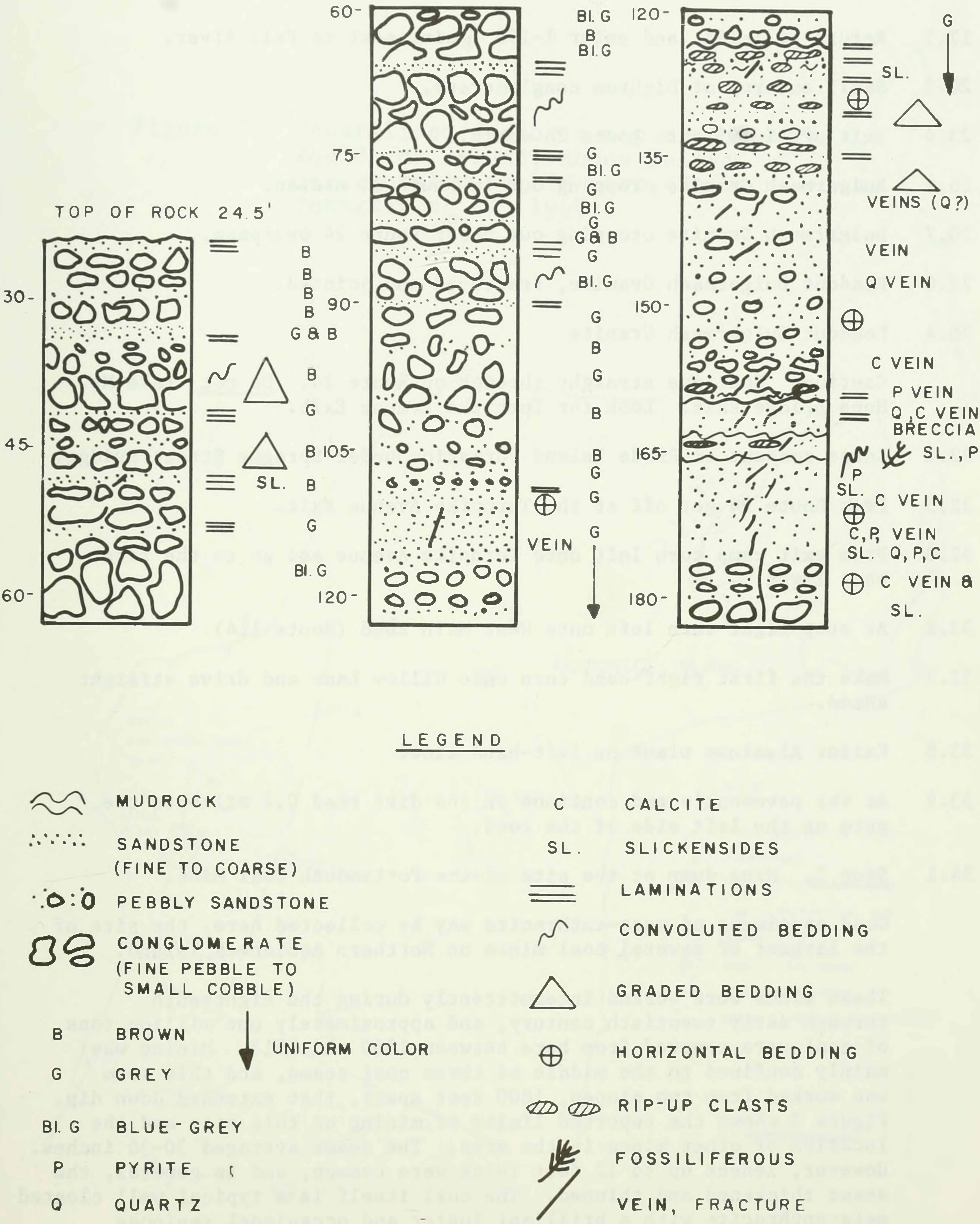


Figure 2 - Diagrammatic representation of a drill core from Rehoboth, Massachusetts. The core passes downward from Dighton Conglomerate into Rhode Island Formation. (Paul Lyons and Linda Oliver, Analysts)

17.1 Return to I-195, and enter I-195 going east to Fall River.

20.3 Samll outcrop of Dighton conglomerate.

23.4 Exit off I-195 onto Route 24 south..

26.4 Bulgarmash Granite cropping out in Route 24 median.

26.7 Bulgarmash Granite cropping out under Route 24 overpass.

27.0 Roadcut Bulgarmash Granite, fractured and jointed.

28.4 Roadcut Bulgarmash Granite

Caution: Continue straight through on Route 24. Do not take Mt. Hope Bridge Exit. Look for Turnpike Avenue Exit.

32.2 Large roadcut of Rhode Island Formation under Sprague Street Bridge.

32.5 From Route 24 get off at the Turnpike Avenue Exit.

32.8 From exit ramp turn left onto Turnpike Avenue and go to the first stop light.

33.1 At stop light turn left onto West Main Road (Route 114).

33.3 Make the first right-hand turn onto Willow Lane and drive straight ahead.

33.8 Kaiser Aluminum plant on left-hand side.

33.9 At the pavement's end continue on the dirt road 0.2 miles to the gate on the left side of the road.

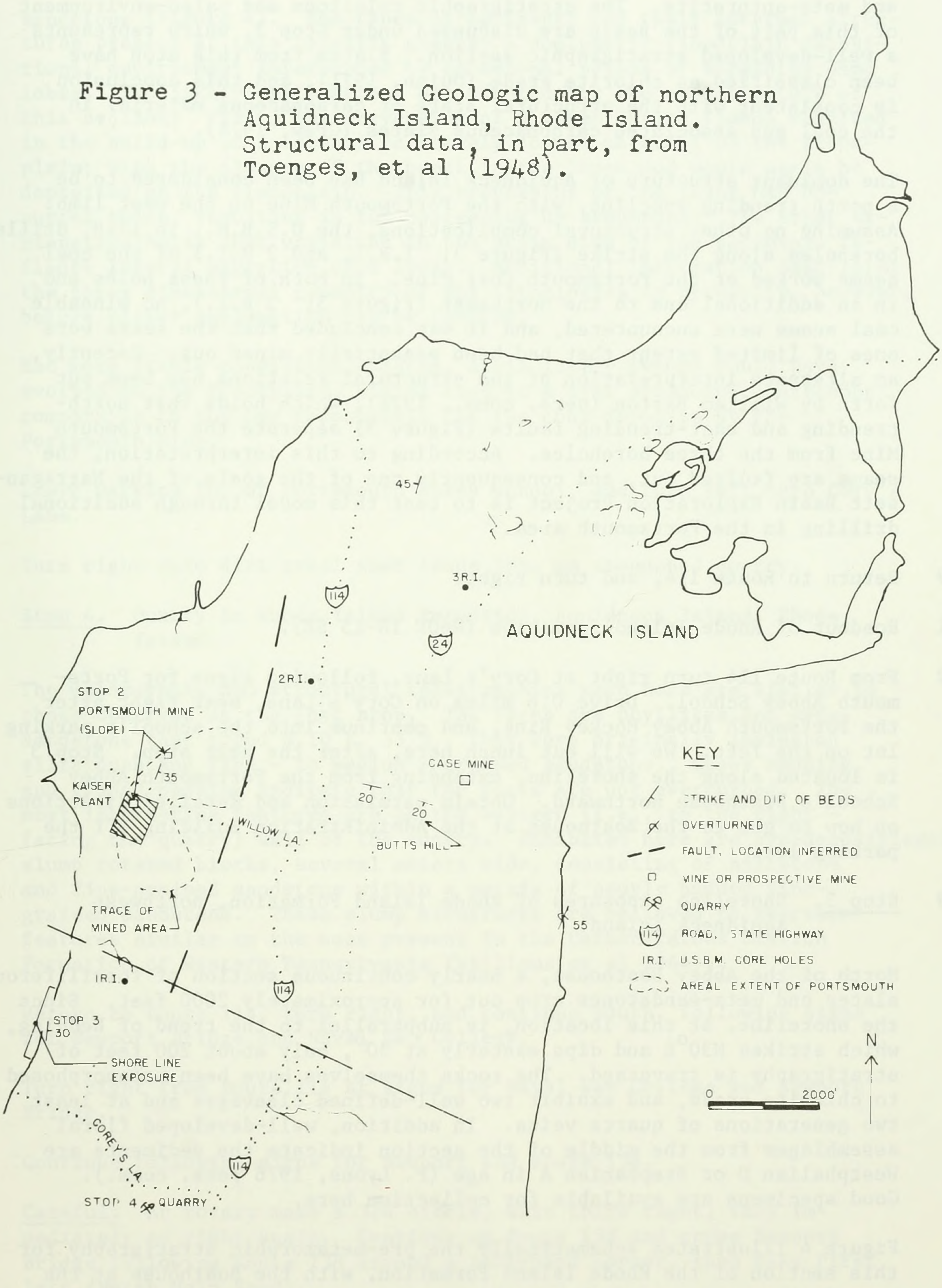
34.1 Stop 2. Mine dump at the site of the Portsmouth Coal Mine.

Good specimens of meta-anthracite may be collected here, the site of the largest of several coal mines on Northern Aquidneck Island.

These mines were worked intermittently during the eighteenth through early twentieth century, and approximately one million tons of coal were removed from here between 1860 and 1913. Mining was mainly confined to the middle of three coal seams, and this seam was worked from two slopes, 1800 feet apart, that extended down dip. Figure 3 shows the reported limits of mining at this site and the location of other mines in the area. The seams averaged 30-36 inches. However, lenses up to 12 feet thick were common, and in general, the seams thickened and thinned. The coal itself is a typical well cleated meta-anthracite with a brilliant luster and occasional resinous (exinite) layers within a predominantly vitrinite matrix. Recent analyses of dump samples from the Portsmouth Mine by the United States Bureau of Mines indicate the coal varies in volatile matter from 4.4 percent to 7.2 percent (d.a.f.), in B.T.U.'s from 12 to 13,000 and in sulfur content from 0.1 percent to 0.4 percent. A more complete description of the history of mining at Portsmouth, Rhode Island, is given in Toenges et al (1948), and the geology of the region is summarized below.

The lithologies are black slate, medium-to fine-grained sandstone,

Figure 3 - Generalized Geologic map of northern Aquidneck Island, Rhode Island. Structural data, in part, from Toenges, et al (1948).



and meta-anthracite. The stratigraphic relations and paleo-environment of this part of the Basin are discussed under Stop 3, which represents a well-developed stratigraphic section. Slates from this stop have been classified as chlorite grade (Quinn, 1971), and this conclusion is consistent with the structural state of carbonaceous material in the coal and associated carbonaceous slates (Grew, 1974).

The dominant structure of Aquidneck Island has been considered to be a north trending syncline, with the Portsmouth Mine on the west limb. Assuming no other structural complications, the U.S.B.M., in 1948, drilled boreholes along the strike (Figure 3; I.R.I. and 2 R.I.) of the coal seams worked at the Portsmouth Coal Mine. In both of these holes and in an additional one to the northeast (Figure 3; 3 R.I.), no mineable coal seams were encountered, and it was concluded that the seams were ones of limited extent that had been essentially mined out. Recently, an alternate interpretation of the structural relations has been put forth by William Barton (pers. comm., 1976), which holds that north-trending and east-trending faults (Figure 3) separate the Portsmouth Mine from the three boreholes. According to this interpretation, the seams are faulted out, and consequently one of the goals of the Narragansett Basin Exploration Project is to test this model through additional drilling in the Portsmouth area.

34.9 Return to Route 114, and turn right.

36.1 Roadcut of Rhode Island Formation ($N60^{o}E$ 10-15 SE).

36.2 From Route 114 turn right at Cory's Lane, following signs for Portsmouth Abbey School. Drive 0.6 miles on Cory's Lane, bear right after the Portsmouth Abbey Hockey Rink, and continue into the school's parking lot on the left. We will eat lunch here, after the next stop. Stop 3 is located along the shoreline, extending from the Portsmouth Abbey School's Boathouse northward. Obtain permission and detailed directions on how to get to the Boathouse at the Administration Building off the parking lot.

36.9 Stop 3. Shoreline exposures of Rhode Island Formation, northwest Aquidneck Island.

North of the Abbey Boathouse, a nearly continuous section of fossiliferous slates and meta-sandstones crop out for approximately 2000 feet. Since the shoreline, at this location, is subparallel to the trend of bedding, which strikes $N30^{o}E$ and dips easterly at 30^{o}, only about 200 feet of stratigraphy is traversed. The rocks themselves have been metamorphosed to chlorite grade, and exhibit two well-defined cleavages and at least two generations of quartz veins. In addition, well-developed floral assemblages from the middle of the section indicate the sediments are Westphalian D or Stephanian A in age (P. Lyons, 1976 pers. comm.). Good specimens are available for collection here.

Figure 4 illustrates schematically the pre-metamorphic stratigraphy for this section of the Rhode Island Formation, with the Boathouse at the top of the section, and the northernmost outcrop at the bottom; the section is best seen walking from the northernmost outcrop of metamorphosed mudstone south towards the Boathouse (i.e., up section).

The section consists of two coarsening up sequences, in which the sediments grade upward by alternation between mudstone and medium-grained sandstone (Figure 4). The types of sediments and their internal structures present at this locality suggest a dominantly floodplain depositional environment interrupted by occasional pulses of spreading sand lobes. Two likely explanations are offered for the cyclic nature of this section: First, the crevassing of a levee during floods resulted in the build-up of a lobe of relatively coarse material on the floodplain; with the closure of the break in the levee mud would again be deposited on the floodplain. This crevassing of the levee has occurred twice, resulting in two coarsening up sequences. The other explanation holds that variation in the grain size of the sediments reflects lateral migration of a levee. Additional information describing the three dimensional geometry of the lithologies is necessary, however, before either explanation can be favored.

Had more stable conditions existed, it is likely swamps would have evolved on the floodplain, giving rise to a coal producing environment comparable to the one responsible for the coal deposits at the Portsmouth Mine.

Leave parking lot of Portsmouth Abbey School, and turn left onto Cory's Lane.

37.2 Turn right onto dirt trail that leads into an abandoned quarry.

37.2 Stop 4. Quarry in Rhode Island Formation, Aquidneck Island, Rhode Island.

The metamorphic and structural relationships seen here are similar to those observed at the last stop. The rocks are phyllites and metasandstone that trend N.10^{o}E. 33^{o}E. They were originally laminated siltstones and fine - to medium - grained sandstone. Cross bedding and graded bedding indicate that the rocks are not overturned. The most interesting features are on the western (i.e., to the right - facing the quarry) wall of the quarry. Exhibited here are syn-depositional slump rotated blocks, several meters wide, consisting of siltstone and fine-grained sandstone within a matrix of poorly bedded fine-grained sandstone. These slump structures are believed to represent features similar to the ones present in the Carboniferous Clarion Formation of Western Pennsylvania (Williams et al 1964).

Return to Route 114, turn right, and continue south, following signs for Newport Bridge and Naval War College.

43.3 Turn right from Route 114 at signs for Naval War College and Newport Bridge.

44.2 Continue following signs for Newport and Route 138.

45.0 Careful. At rotary make a 3/4 circle, exit third right, then immediately go right again. Continue on Route 138 and cross Newport Bridge following Route 138 around a left-hand corner, then take first left (North Main Road).

50.2 From Route 138 turn left on North Main Road and continue.

52.4 At warning light proceed ahead on Southwest Avenue.

53.0 After crossing beach continue following Beavertail Road.

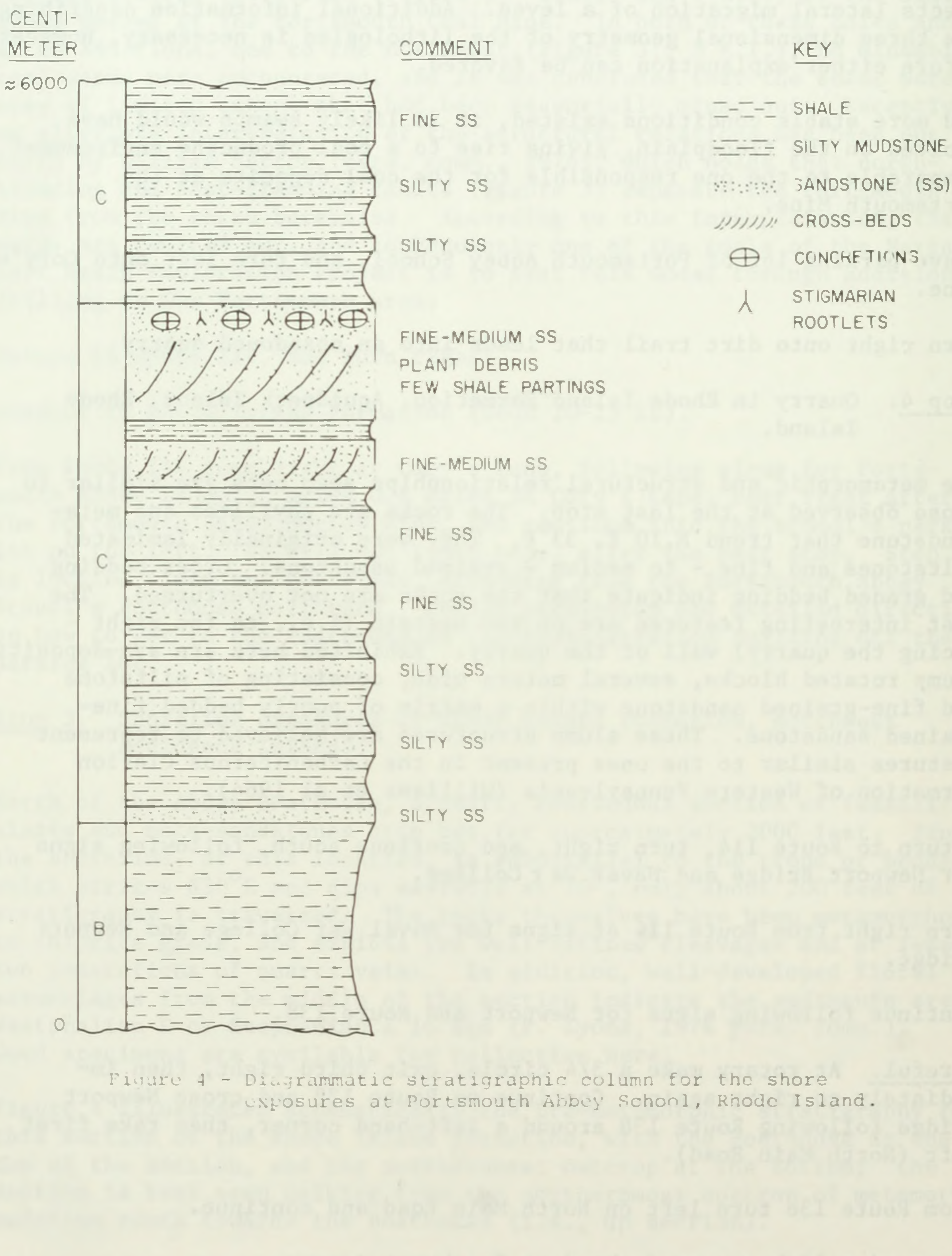


Figure 4 - Diagrammatic stratigraphic column for the shore exposures at Portsmouth Abbey School, Rhode Island.

55.4 Go left and park at Beavertail Park.

55.6 Stop 5. Beavertail, Conanicut Island. (Note: Alternate parking site at Beavertail Lighthouse.)

The phyllite at Beavertail (Figure 5) has long been considered of Carboniferous age by reason of: 1) its presumed stratigraphic continuity with Pennsylvanian dated metasediments near the Jamestown Bridge, and 2) its apparent structural compatibility with the general synclinal nature of the Narragansett Basin (Nicholls, 1956; Chapple, 1963). We feel that these shoreline exposures contrast sharply with other Carboniferous rocks in the region, and that a careful analysis of the geology of Conanicut Island in general and Beavertail in particular is crucial for an understanding of the evolution of the Narragansett Basin. The following sections describe preliminary and tentative interpretations of the field relations at Beavertail. A workshop approach to this stop is proposed as much as a mechanism for us to share in the insights of participants as to present the results of early stages of our study of the Basin.

Structure

The structural features at Beavertail suggest that the rocks may have a history of repeated deformation that is more complex than other parts of the Narragansett Basin and may therefore antedate the fossiliferous schist (of Pennsylvanian age) of Northern Conanicut Island near Jamestown. A preliminary chronology of structural events for this area is presented below; the numbers in parentheses refer to field stations (see Figure 5).

1. Deposition of beds occurred in the stratigraphic sequence as shown in Figure 5 (unit a is the youngest). Tops and bottom indicators imply that at least along the eastern shore of Beavertail, the stratigraphic section is for the most part overturned.

2. The first tectonic event is isoclinal folding characterized by a bedding plane cleavage (Station 9) and accompanied by greenschist facies metamorphism. An axial plane cleavage, that is deformed by later tectonic events, is also thought to have formed during this period of folding.

3. A third tectonic event is chiefly recognized by similar folds and localized decollement-style faults. The folding is developed about approximately the same axis (N-S horizontal) as the earlier folds, but has a different axial plane orientation (Stations 1, 14, 15). The sub-horizontal axial plane cleavage is pervasive and is the dominant one seen along the seacoast exposures here. In particular, note how the earlier cleavage and mineralized joints and faults are folded about this axis (Stations 3,9, 10, 13). This period of deformation is probably the same as the one recorded in the Carboniferous rocks in the northern part of the Basin.

5. An additional period of deformation is responsible for a broad warping and local folding (?) of the second cleavage. This last episode of folding was about a new axis.

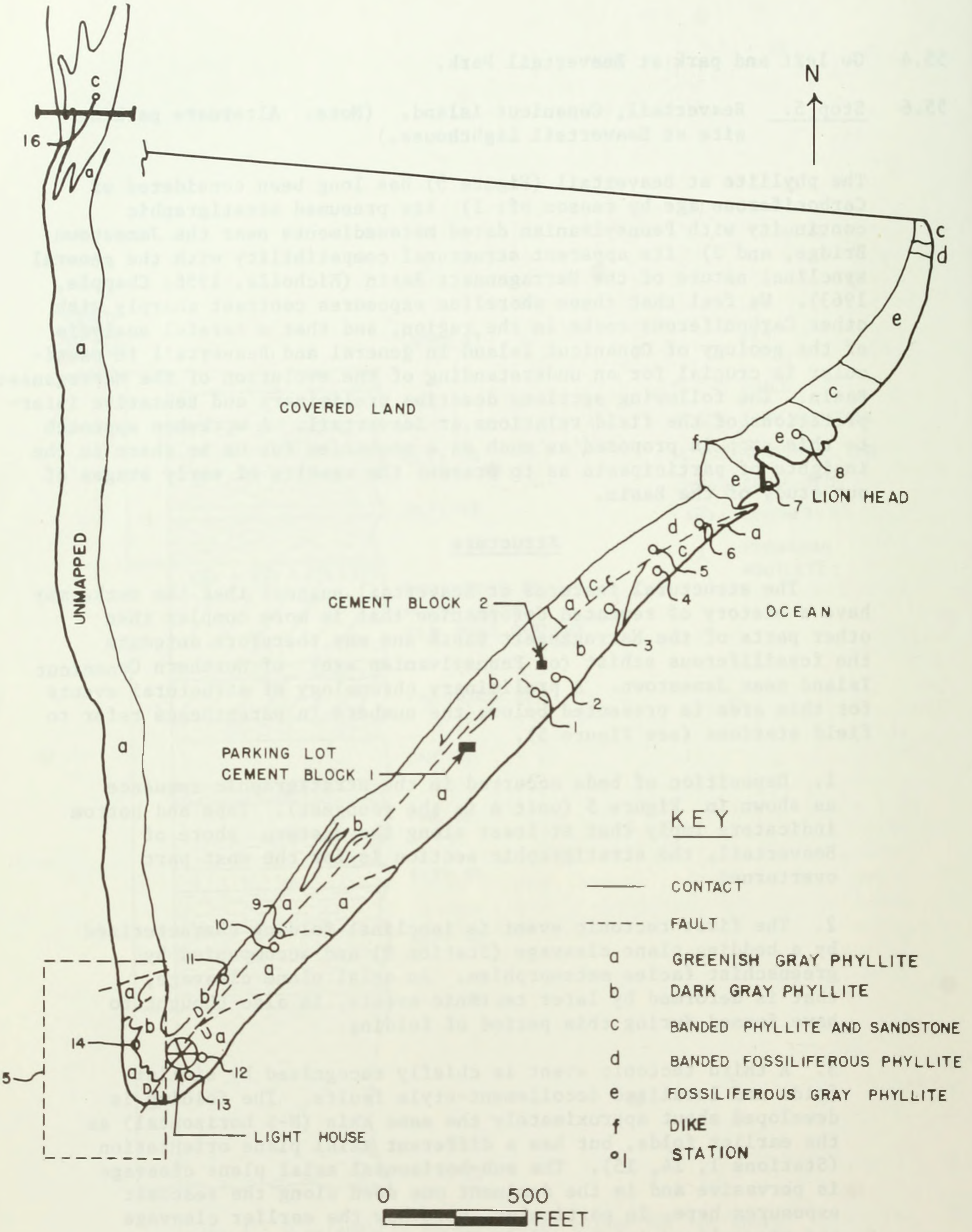


Figure 5 - Sketch map of the geology along the shore at Beavertail, Rhode Island. The stations are described in the text and figure 6.

6. Kink bands are widespread and well developed on cleavage surfaces of the second generation of folds; they are truncated by the faults described in the next stage.

7. Northeasterly striking normal faults are mineralized (Quartz ± calcite) and offset older structures (Stations 5 and 11). This episode of faulting has displaced and tilted the blocks along the shore, and is illustrated by the discontinuity and angular discordance of the second cleavage from block to block. The major fault, and its consistently more easterly-striking splay faults, are referred to as the Beavertail Fault system; it has been previously described by Nichols (1956) and Chapple (1963).

Stratigraphy

The phyllites at Beavertail have been divided into five field units, based upon differences in color, layer geometry, and type of sedimentary structure. All are characterized by horizontally laminated and horizontally bedded muds with variable, though generally subordinate amounts of fine sand. Graded bedding and ripple cross bedding are found to varying degrees in all field units. The diagnostic features of these lithologies, together with those of a sixth unit that may be a "dike", are described below. Gradational to sharp sedimentary contacts exist between all five units, implying that there are at least two different gray phyllites. Our most recent mapping at other locations to the north of Beavertail has revealed the same lithologies; whether they are a repetition of the five field units so far identified is uncertain. From oldest to youngest, the field units are as follows:

a. Greenish gray phyllite. This unit is characterized by grains pyrite porphyroblasts and occasionally boudinaged by fine-grained sandstone layers.

b. Dark gray phyllite. This distinctive unit is characterized by the following features: (1) especially well developed laminar bedding; and (2) abundant concretions (Figure 6), pyrite-rich layers parallel to bedding.

c. Banded phyllite and sandstone. These two lithologies are present in approximately equal amounts. The buff colored sandstone layers contain cross bedding and graded bedding, while the phyllite layers are similar to ones found in the greenish gray phyllite.

d. Fossiliferous banded phyllite. This consists of alternation layers of very fine grained sandstone to phyllite alternating with dark gray phyllite. Of special significance is the presence of (1) unusual sedimentary structures that may be worm burrows or reqorked volcaniclastic sediments (Figure 6 d); and (2) patches of black objects that may represent deformed fossil fragments. The dark layers show graded bedding.

e. Greenish gray phyllite. This unit differs from the first in that (1) it contains less pyrite; (2) a ubiquitous mineral (anatase or altered detrital glauconite (?)) that defines a lineation; and (3) it contains shredded fragments of sandstone laminae; and (4) it has particles of material, similar to ones described for the last unit, that are comprised of possible trilobite fragments.

f. A unit previously mapped as a minette dike (Nichols, 1956) is confined to the last stratigraphic unit. Its assemblage is zoisite + quartz + biotite + quartz + plagioclase + calcite + accessories. It may actually be a dike, or else a stratigraphic horizon within the sedimentary record. In any case, it has been deformed and records at least the last five structural events.

The sedimentary sequence of Beavertail, in spite of the complexity of its deformation, has its sedimentary structures preserved to a high degree. The amount of megascopically recognizable recrystallation is small, and the two minerals now visible in hand specimens of phyllite are pyrite (previously mistakenly identified as garnet) and a phase that may be anatase or glauconite. In thin sections the matrix of the phyllites is seen to consist of quartz, calcite, and micas. A deep water, quiescent depositional environment is favored for these rocks, based upon the following observations. First, all field units are fine grained. Second, the scale of laminations, cross bedding, and graded bedding is on the order of a few centimeters or less. Such an environment could exist either at the bottom of a deep lake or in a deep water marine environment. If possible fossiliferous material does in fact represent trilobite fragments and/or if detrital glauconite is identified, then a marine origin would be implied.

Reconnaissance studies by the authors on Conanicut Island suggest that the meta-sediments of Beavertail may be older than the fossiliferous rocks near the Jamestown Bridge and younger than the porphyritic granite at Fort Wetherwill. These sediments may be correlative with part of the sequence described by Chapple and Kay (this volume) in Newport on Aquidneck Island (just northeast of Beavertail). We hope that the fossil fragments from the phyllites will have yielded dates that can be reported on at this conference. Meanwhile, we regard the sediments as of Lower to Middle Paleozoic age, since they record episodes of deformation that antedate those found in the Carboniferous rocks.

<u>Stop 5.</u> Field Stations

The locations of the stations described below are shown on Figure 5.

1. Contact between greenish gray and dark gray phyllite. Figure 6a illustrates this contact, which outlines a first generation isoclinal fold that has been refolded about the same axis S.25°E. 5°S. but a different axial plane (N.40°W. 5°W.).

2. Lensoid bodies that are most abundant within the dark gray phyllite (Figure 6b). They consist of chirt margins with phyllite matrix (calcite-rich). The ubiquitous mineral and color layering in the host phyllite passes undeflected through the center of the bodies, and their long axes parallel the axis of the second generation of folds. They are believed to represent concretions, and possible are analogous to ones described recently from the Lower Carboniferous of Great Britain (Dickson and Barber, 1976).

3. Folded fault within the dark gray phyllite (Figure 6c).

4. Cross-bedding and graded bedding within the banded phyllite and sandstone. These deformed sedimentary structures are especially abundant in this cut.

5. Series of splay faults associated with the major northeast striking normal fault (N.75°E. 65°NW.). Slickensides are oriented N.65°W 60° . Near Lion Head several repetitions of the sequence of field lithologies are produced by this fault system.

6. Sedimentary structures in the fossiliferous banded phyllite. This lithology consists of alternating layers of light and dark phyllite. The dark phyllite has a sharp lower margin and fines upward (very fine sand to mud) over a few centimeters. The upper contact of the dark phyllite with gray phyllite is highly irregular, and suggests bioturbation (Figure 6d).

7. Possible fossiliferous debris within the greenish gray phyllite (unit e) near Lion Head.

8. Minette dike (Nichols, 1956) at Lion Head. This probable dike has been metamorphosed, folded and brecciated. There are no obvious chill zones along the dike margin or contact metamorphism of the surrounding phyllite.

9. A folded cleavage is well displayed here, with the fold axis bearing N.70°W., plunging 60° to the NW., and the axial plane striking N.80°W dipping 75° to the N.

10. The two dominant cleavages (N10°W., 30°W.; and N.10°E., 20°W.) are present at this locality.

11. The main branch of the normal fault, striking N.60°E. dipping 75°NW. is well developed and clearly shown at this exposure.

12. The second generation of folds are cut by a thrust fault, and both folds and fault may be folded.

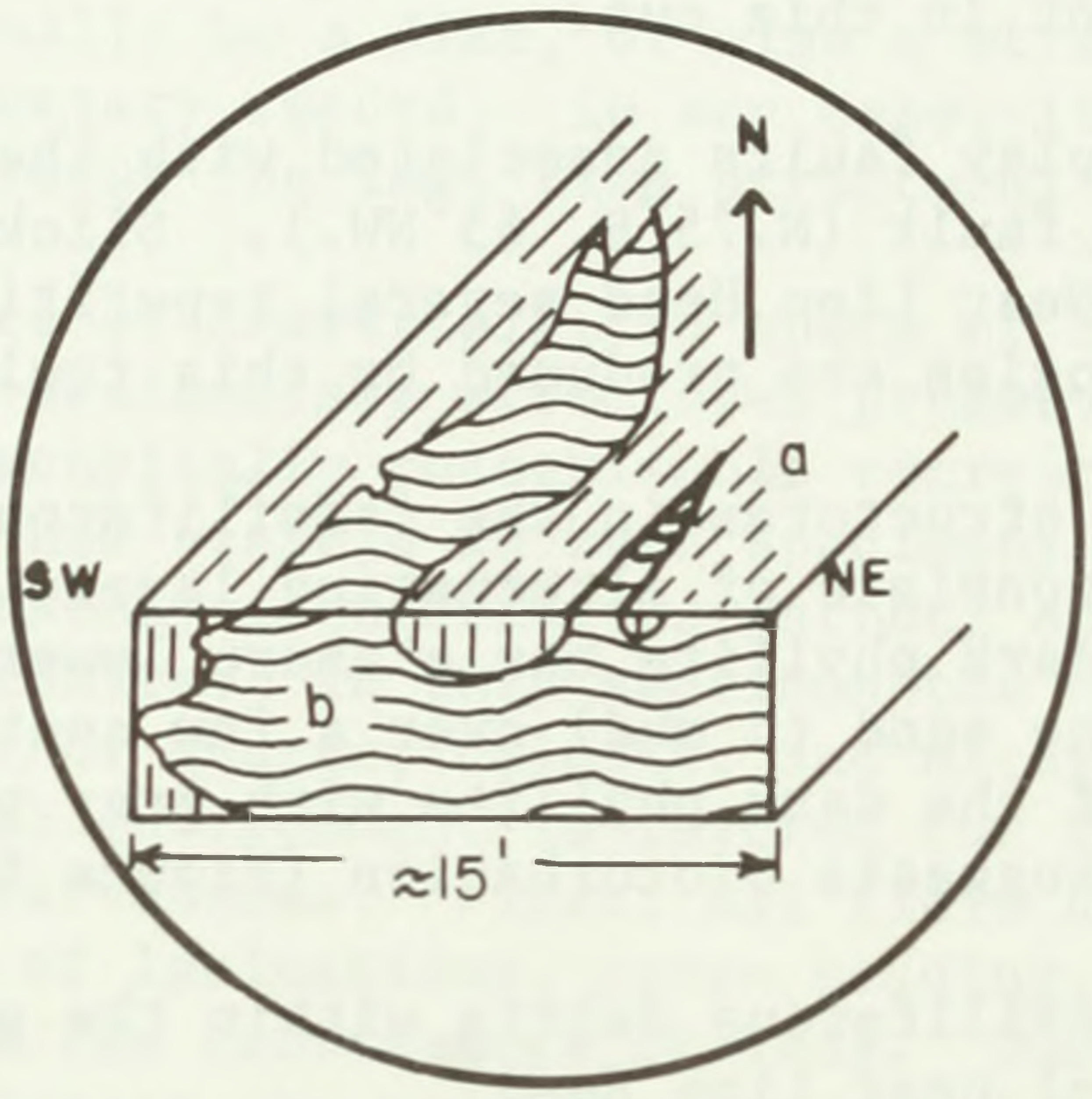
13. Relationships between bedding and axial plane cleavage are particularly well displayed in cross-sectional exposures just south of the lighthouse. A good place to show students these features!

14. Refolded fold, as outlined by the contact between units a and b. The schematic cross-section in Figure 6e illustrates this feature.

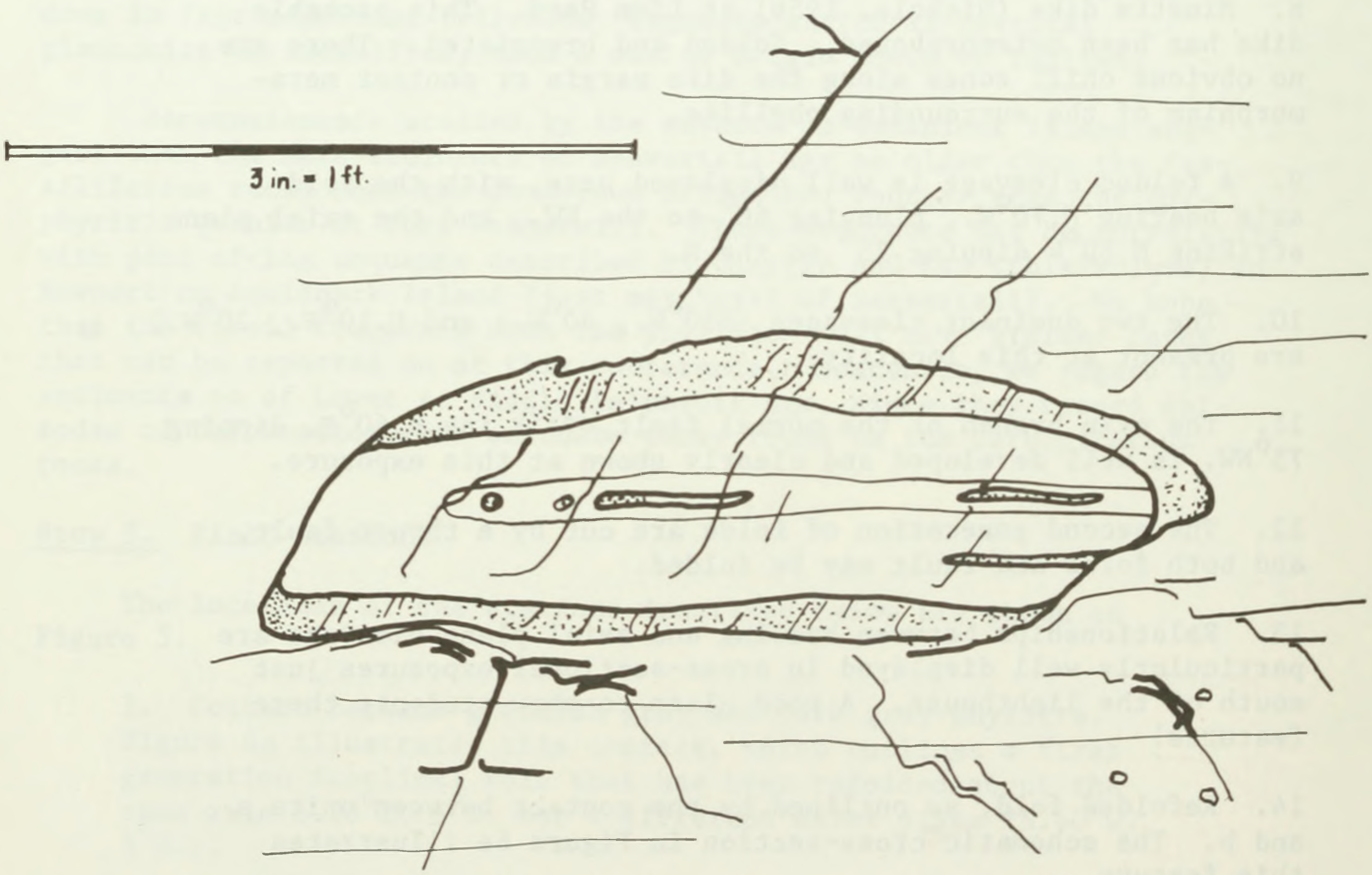
15. The faulted and refolded contact between units a and b, from the lighthouse extending northwestward along the shore (Figure 6c).

16. Refolded fold, as outlined by the contact between units a and c. Isolated sections of the coastline have been mapped on both sides of Beaverneck. This station represents one of these sections. Figure 6f shows schematically this structure in cross-section.

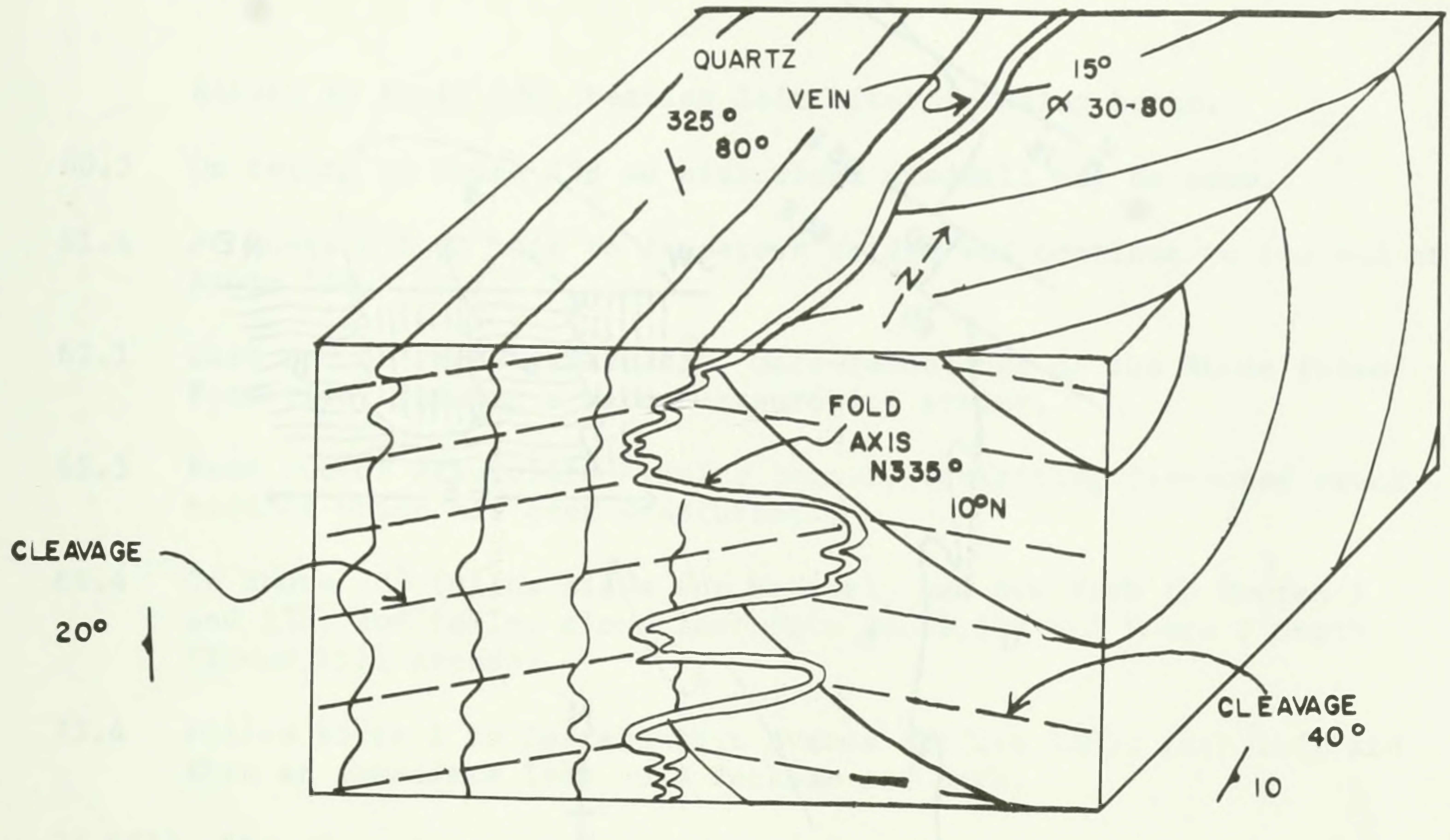
Figure 6 - Sketches of Field relations at Beavertail (stop 5), Rhode Island.



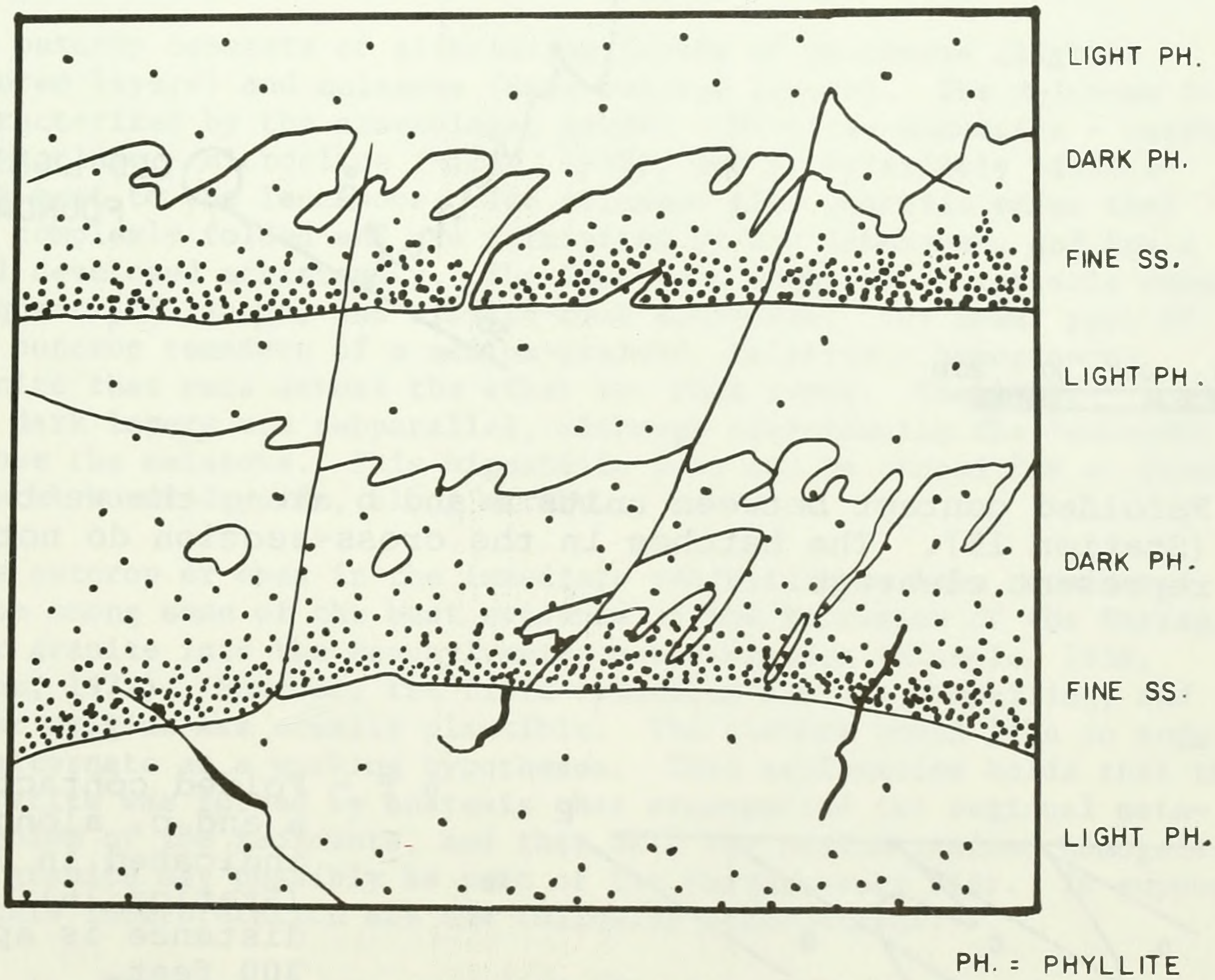
6 a - Refolded contact between units a and b (station 1).



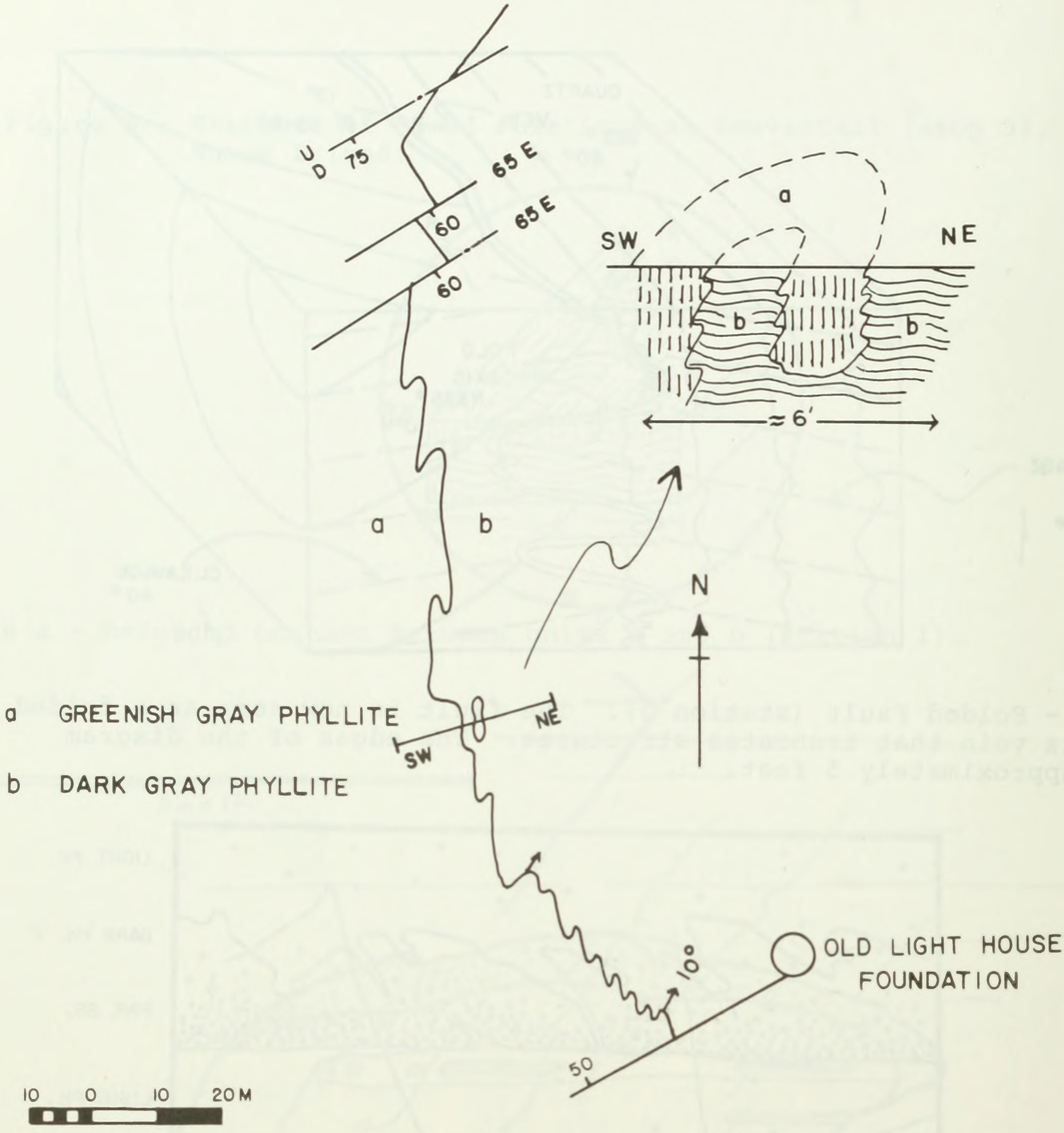
6 b - Concretions in unit b (station). The stippled areas are chert-rich, and the center and host rock are calcerous phyllite. The horizontal lines represent mineral layering.



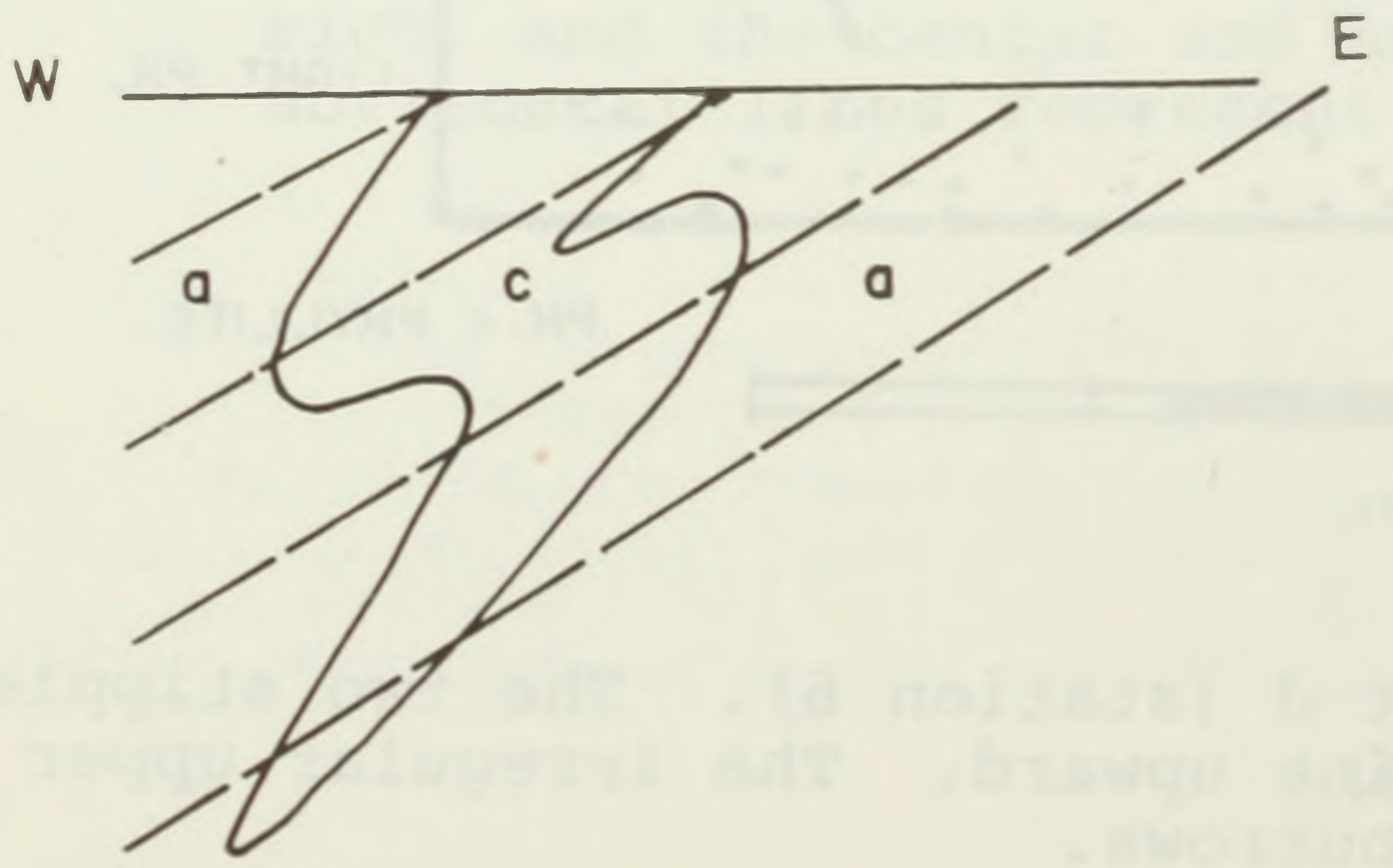
6 c - Folded Fault (station 3). The fault is now seen as a folded quartz vein that truncates structures. The edges of the diagram are approximately 5 feet.



6 d - Sedimentary structures in unit d (station 6). The two stippled bands are dark gray phyllite that fine upward. The irregular upper margins of these bands may be worm burrows.



6 e - Refolded contact between units a and b along the west shore (Station 15). The hatches in the cross-section do not represent cleavage.



6 f - Folded contact between units a and c, along the line indicated in Figure 5 (Station 16). Horizontal distance is approximately 300 feet.

Return to Route 138, bearing left after crossing beach.

60.5 On return to Route 138 an historical windmill may be seen.

61.4 At Route 138 go left to Jamestown Bridge and continue to the end of Route 138.

62.1 East end of Jamestown Bridge, meta-sandstones of the Rhode Island Formation, forming a garnet-staurolite schist.

65.5 Road cut of staurolite-Kyanite schist, exhibiting festooned cross bedding which has been overturned.

66.4 On Route 138 follow signs for Westerly and New York to Routes 1 and 138, and follow cloverleaf onto Route 138 and Route 1 South (Tower Hill Avenue).

73.4 Follow Route 1 to Narragansett Avenue (before 108); turn left and then an immediate left onto Peckham and park.

73.6(?) Stop 6 - Outcrop of migmatite in private yard.

Stop 6 is in the yard of the house on the corner of Narragansett Avenue and Peckham (5 Peckham). Please obtain permission from the owner (Joseph Rankin) to look at this outcrop.

The outcrop consists of alternating layers of leucosome (light colored layers) and melasome (dark-colored layers). The melasome is characterized by the assemblage, garnet - biotite- muscovite - quartz-plagioclase - microcline (Milne, 1972), and is relatively biotite-rich next to the leucosome. The melasome also contains veins that are complexly folded and are terminated by the leucosome, and has a well developed schistosity. The leucosome consists of variable amounts of quartz, feldspar, and biotite-rich schlieren. The lower part of the outcrop consists of a medium-grained, relatively homogeneous granite that cuts across the other two rock types. The light and dark layers are subparallel, although occasionally the leucosome cuts across the melasome. This migmatitic zone can be traced for at least several hundred yards, along strike.

This outcrop or ones in the immediate vicinity have been considered to be among some of the best evidence of the intrusion of the Narragansett Pier granite into the Pennsylvanian metasediments (Nichols, 1956; Milne, 1972). However, the field relations are not compelling, and other origins are equally plausible. The wirters would like to suggest an alternate as a working hypotheses. This explanation holds that the migmatite was formed by anatexis that accompanied the regional metamorphism of the sediments, and that only the medium-grained homogeneous granite may possibly be part of the Narragansett Pier. In support of this interpretation are the following observations:

1. The general appearance of the migmatite suggests formation during regional deformation.

2. The lack of chill zones in the leucosome indicates that the country rock was hot at the time of intrusion.

3. Away from the migmatitic zone, the melasome has a fine-sand layering that is complexly folded.

4. The unfossiliferous melasome is quite similar to a quartz-biotite schist of probably Precambrian age that occurs in the vicinity (Nichols, 1956).

5. This outcrop has been interpreted as a lit-par-lit zone (Nichols, 1956; Milne, 1972). However, despite its extensive development, there is no evidence of contact metamorphism of metasedimentary rocks in the area (Milne, 1972).

6. The Narragansett Pier granite has been dated as Pennsylvanian (or younger) in age. However, some of the gneissic border phases or it may in fact represent part of the basement. The report of an age of 343My for this granite (whole rock Rb/Sr; J. W. Barton, analyst) supports this interpretation.

7. The granitic material at this outcrop is more deformed than typical exposures of the Narragansett Pier granite. One of the writers (Hermes) plans to date the migmatite, and Pb^{207}/Pb^{206} ages on zircons from these rocks should be available by the time of the field trip.

In summary, the metasediments may actually be Pre-Pennsylvanian, and the granite may not be Narragansett Pier.

Return to Route 1; go right (north) and follow Routes 4 and 2 to I-95 back to Providence. Take I-95 to the Branch Avenue exit, Providence.

Alternate Stop. Directions to graphite mines.

Return to Route 1 (Tower Hill Avenue) and turn left

75.2 From Route 1 take Narragansett Exit and turn left off the exit ramp and go around rotary.

75.5 Following signs for Narragansett and Route 1A, exit from rotary at second right and proceed.

76.7 At second light turn left on Beach Street.

76.9 Left again at next light onto Bostoneck Road; continue for about four miles. The exact locations of the graphite mines may be obtained from Grew, 1974, Appendix 1.

Return to Bostoneck Road, turn left, and proceed to South Ferry Road, just beyond sign for U. R. I. Narragansett Bay Campus, turn left and follow South Ferry Road to Route 1. At Route 1 please follow preceding directions back to Providence.

105.9 Exit at Branch Avenue exit (Exit 24); go right to North Main and turn left, returning to Star Market.

106.5 Stop 7. Outcrop of Rhode Island Formation at University Heights, Providence, Rhode Island.

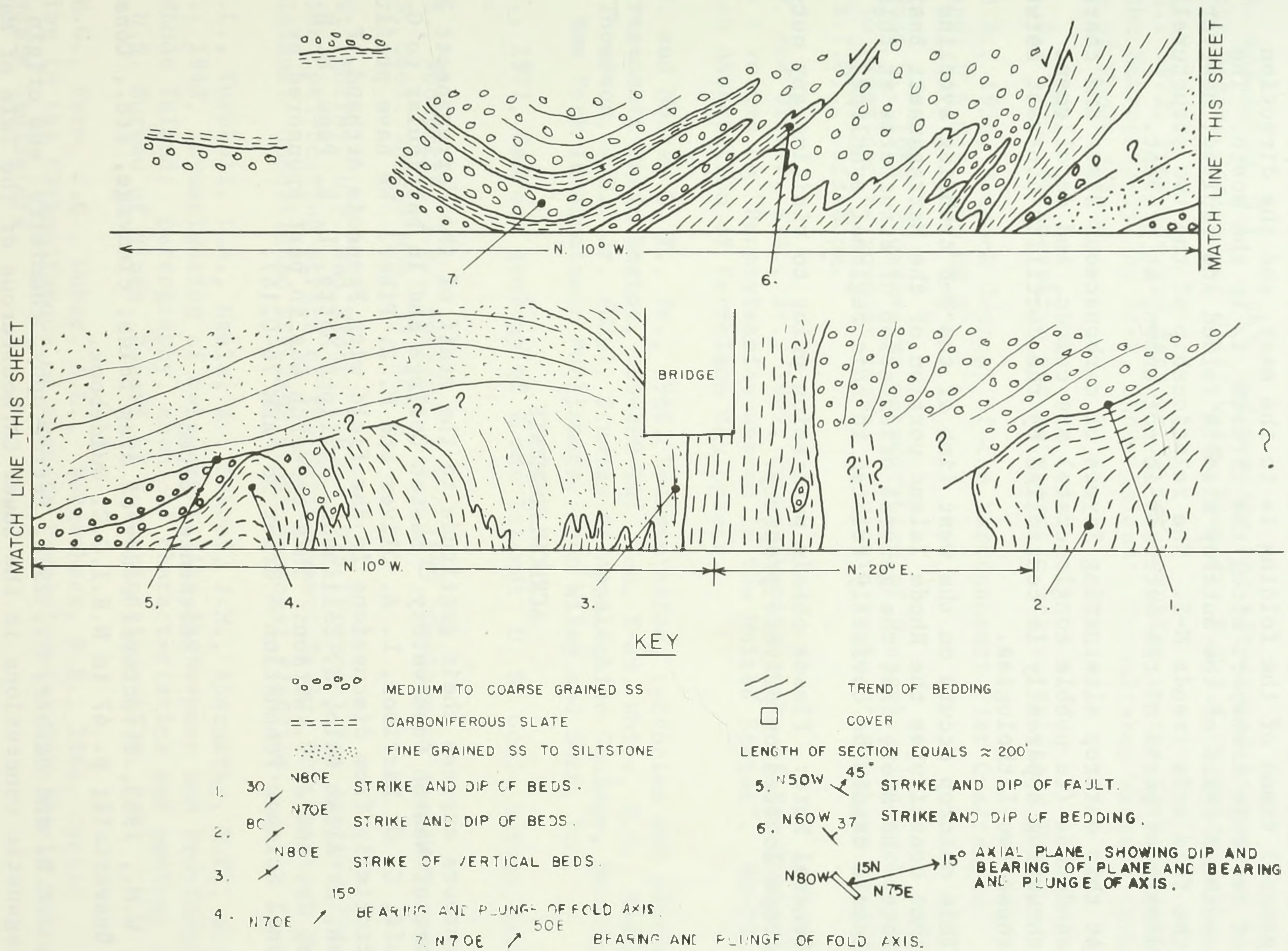


Figure 7. Sketch map of the geology along the hillside behind the University Heights Star Market, Providence, Rhode Island.

The outcrop consists of interlayered mudstone and fine - to coarse - grained sandstone that has been folded and thrusted (Figure 7). Poorly developed graded bedding implies that the section is not overturned. For the northern two thirds of the outcrop, the general trend of the folding is to the east, and the direction of tectonic transport along the thrusts is to the south. The southern third of the outcrop also is folded and faulted; however, the fold axis trends N-S. The relationship of the two structurally divergent parts of the outcrops is not known, at present.

At this outcrop alternating layers of carbonaceous slate and coarse sandstone (to pebble conglomerate) are common, and decollement thrusting apparently is controlled by the ductility contrast between these two lithologies.

This outcrop occurs on the west limb of the N-S trending syncline that constitutes the Rhode Island portion of the Narragansett Basin. Note, however, that the general orientation of structures at this locale cannot be obviously related to this regional syncline.

General Note: Please obtain permission prior to visiting any outcrops located on private property.

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