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Contact Relationships of the Late Paleozoic Narragansett Pier Granite and Country Rock

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CONTACT RELATIONSHIPS OF THE LATE PALEOZOIC NARRAGANSETT PIER GRANITE AND COUNTRY ROCK

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INTRODUCTION

The Narragansett Pier Granite (NPG) is a post-tectonic Permian pluton that exhibits complex intrusive relationships into country rocks of diverse ages, lithologies, and structures; these include the Hope Valley Alaskite (HVA), Ten Rod Granite (TRG), Blackstone Series (Plainfield formation of CT) and associated gneisses and amphibolites, and Pennsylvanian rocks of the Rhode Island Formation. The pluton exhibits many of the characteristics of an S-type granite (Chappell and White, 1974), and cross-cuts the structural trends of rocks within the Avalon Zone. The pluton, which is batholithic in size ($\sim$100 mi^2) (Fig. 1), extends eastward from southeastern Connecticut across southern Rhode Island to the eastern boundary of Narragansett Bay. The pluton may extend southward beyond the southern Rhode Island coastline, but recent off-shore geophysical measurements do not provide definitive evidence (McMaster et al., 1980).

The NPG is a remarkably homogeneous pluton, in terms of modal mineralogy and chemistry. However, some textural and color variations exist which have permitted three distinct and mappable facies to be recognized (Fig. 1): 1) pink, medium- to coarse-grained equigranular granite, 2) pink, coarse-grained porphyritic granite, and 3) a white, medium- to coarse-grained equigranular-porphyritic facies (Kocis, 1981; Kern, 1979). The batholith is cut by simple to complex veins of aplite, pegmatite, and quartz; in addition, dikes of Westerly Granite (generally thought to be late-stage, but co-magmatic) and lamprophyric dikes that contain mantle-derived lherzolite nodules and megacrysts, locally cut the granite and the older country rock.

Dikes of NPG and Westerly Granite (WG) occur to the west in southern Connecticut (Liese, 1979), and recently it has been demonstrated that the NPG extends well to the north of the general contact mapped by Moore (1959). Emplacement of dikes of the NPG into country rock north of the general contact is thought to have been controlled in part by earlier shear zones, that may have been reactivated following granite emplacement (Smith and Barosh, 1980). Many xenoliths and pendants are present in the NPG and the borders of the pluton generally have wide zones mixed with country rock. A remarkable alignment of the structural fabric between the blocks of country rock indicates a relatively passive manner of emplacement of the NPG.

The purpose of this trip is to investigate some of the diverse contact relationships exhibited by the NPG, and to see representative outcrops of most facies varieties of granite as well as adjacent country rocks.

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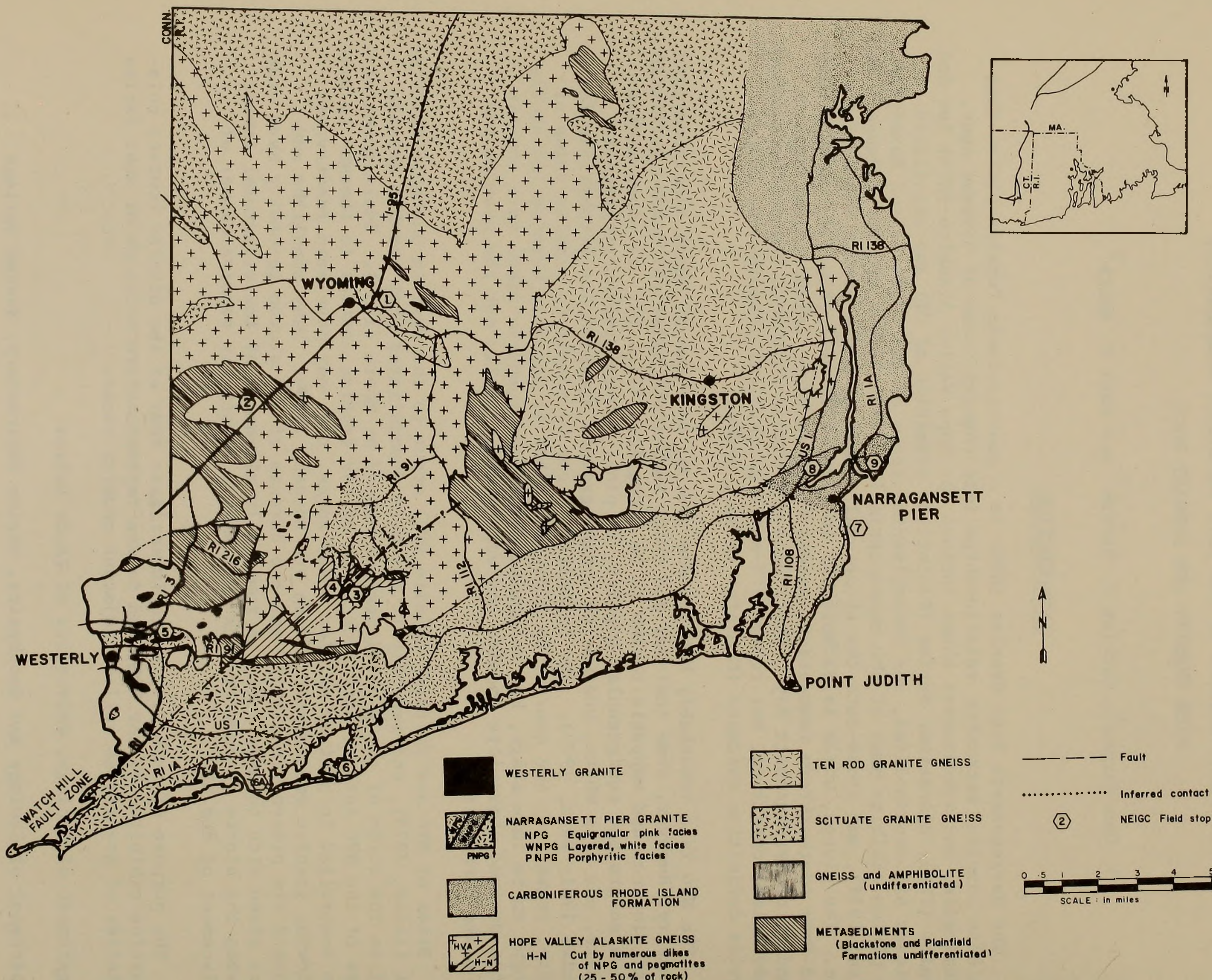


FIGURE 1. Generalized geologic map of southern Rhode Island west of Narragansett Bay, showing field trip stops.

REGIONAL SETTING

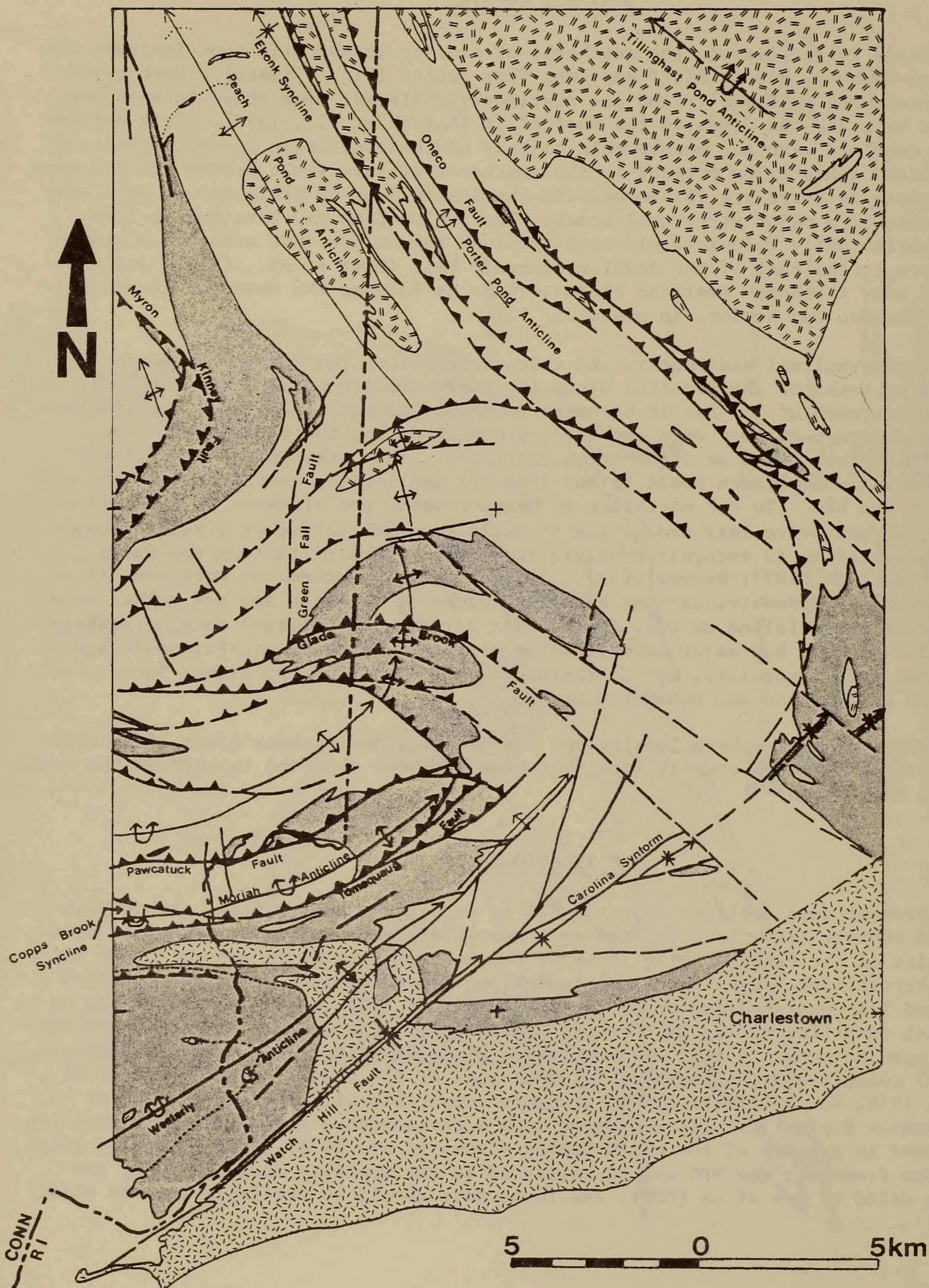
Rhode Island lies to the southeast of a major thrust belt that includes the Clinton-Newbury, Bloody Bluff and Lake Char faults (Fig. 1 inset). Rock types and structures in Rhode Island are distinctly different from those in both the thrust belt and the areas to the west of it (Barosh et al., 1977). This difference, combined with the metamorphic history and paleontologic investigations of fossilized fauna types present to the southeast of this fault system has led many geologists to correlate this area with the Avalon Zone of Newfoundland that also lies east of a major structural break. The Avalon Zone may have been a late Precambrian-early Paleozoic microcontinent or island arc that acted as a stable platform to the east of the Acadian orogenic belt (Rast et al., 1976), and was welded onto the North American plate perhaps as late as the Devonian (Gaudette, 1981; Zartman and Naylor, in press).

Eugeosynclinal sedimentary and volcanic rocks of the Blackstone Series intruded by rocks of the Sterling Group (Scituate Granite Gneiss, HVA and TRG) constitute much of the Avalon basement in Rhode Island. These rocks were intensively deformed as they were intruded, probably during the Late Precambrian, into folds that broke as deformation continued. This structure is especially complex in southwestern Rhode Island (Fig. 2) and locally controlled the emplacement of the NPG. To the northeast in Massachusetts and offshore in the Gulf of Maine, an extensive late Ordovician to Early Devonian period of alkaline-peralkaline magmatism is recognized within the Avalon terrain (Zartman and Marvin, 1971; Zartman, 1977; Hermes et al., 1978). Recent geochemical work and zircon geochronology demonstrates that alkalic plutons of Devonian age are rather widespread in Rhode Island as well (Hermes and Zartman, unpublished data; elsewhere in this volume), but major calc-alkaline plutonic events of mid-Paleozoic age have not been recognized, nor is there convincing evidence of either Taconic or Acadian deformation and metamorphism.

Dikes of lamprophyre locally cut the granite, and diabase dikes of Mesozoic age cut the adjacent country rock, but have not been observed to intrude the rocks of the NPG pluton.

AGE RELATIONSHIPS

Present data confirm that the NPG is an Alleghenian granite, probably intruded shortly after (and perhaps as a result of) the peak deformation and metamorphism of the Pennsylvanian rocks of the Narragansett Basin and the older adjacent crystalline rocks. Previous lead-alpha determinations on zircon (208-275 m.y.) and K/Ar measurements on biotite (230-260 m.y.) may be subject to errors or to partial resetting during the "Permian disturbance" (Zartman et al, 1970). Recent U/Pb ages on monazite from two samples (a pink and white facies sample, respectively) collected at Narragansett yielded ages of 276 and 277 m.y. (Kocis et al., 1977, 1978; Kocis, 1979). These ages are compatible with the recent find of Stephanian B plant fossils recovered from a carbonaceous-rich layer in a xenolith enclosed in granite of the white facies (Brown et al, 1978) (Stop 9 of this trip). Zircons from both the NPG and WG collected in the Westerly area presently are being dated by one of us (ODH), and these data should be available for the NEIGC trip.



N
Peach
Ekonk Syncline
Tillinghast Pond Anticline
Oneco Fault
Pond Anticline
Porter Pond Anticline
Myron
Kinney Fault
Fault
Green Fall Fault
Glade Brook Fault
Pawcatuck Fault
Moriah Anticline
Tomaquag Fault
Copps Brook Syncline
Carolina Synform
Charlestown
Westerly Anticline
Watch Hill Fault
CONN
RI
5 0 5km

Figure 2: Bedrock geologic map of southwestern Rhode Island and south-eastern Connecticut.

Explanation for bedrock geologic map of southwest Rhode Island and Southeast Connecticut.

Narragansett Pier Granite.

Scituate Granite Gneiss.

Hope Valley Alaskite Gneiss and other granitic gneisses.

Metasedimentary and Metavolcanic rocks

Fault, dashed where approximately located, teeth on upper plate of thrust fault.

Anticline, axial trace showing plunge, barbs show dip where overturned.

Syncline, axial trace showing plunge, barbs show dip where overturned.

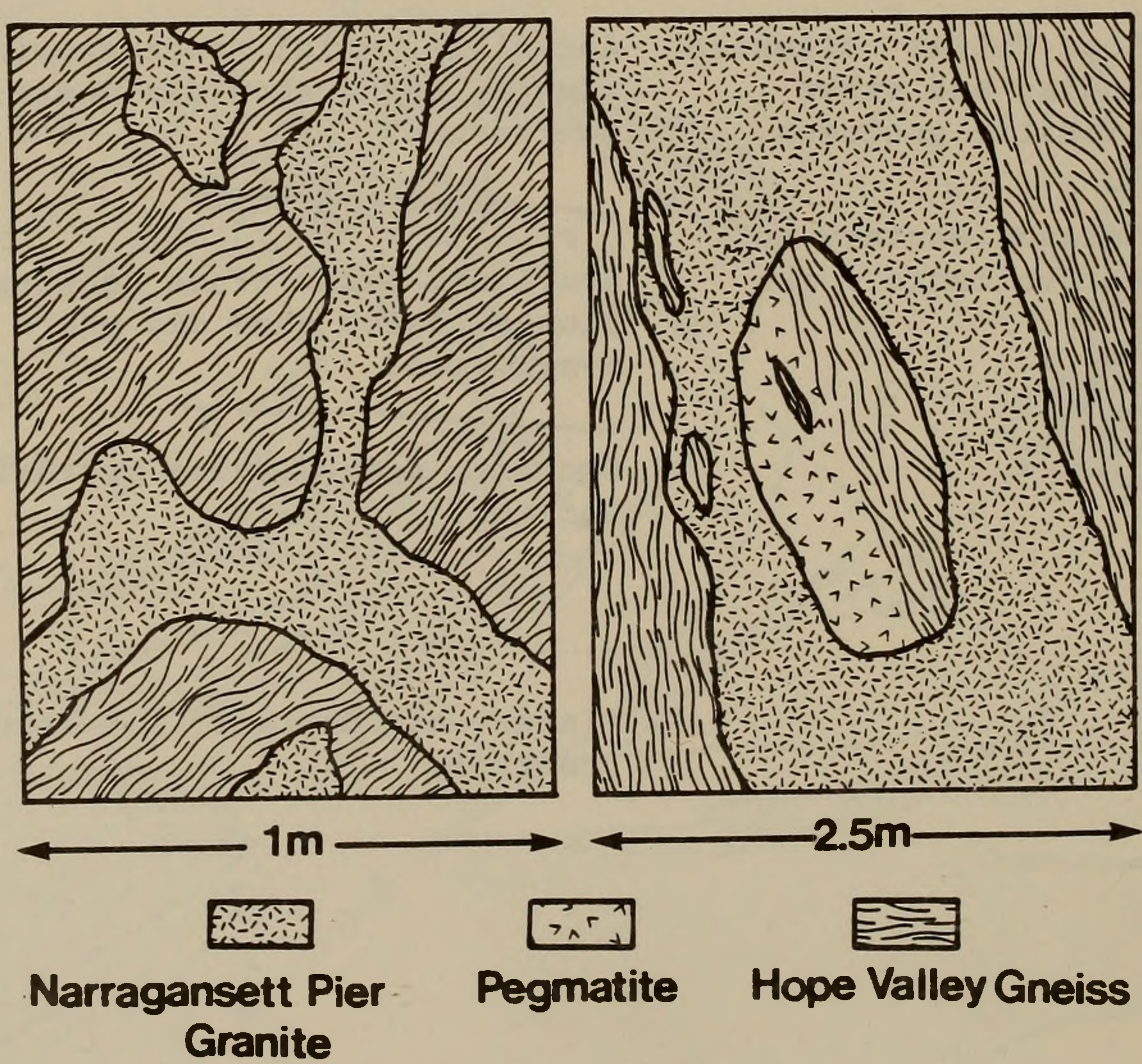
Contact, dashed where approximately located.

Inter-unit contact, for structural control.

The Permian age of the NPG makes it the youngest pluton thus far recognized in Southeastern New England. It is roughly contemporaneous with the Milford Granite of New Hampshire (Aleinikoff et al, 1979), and with the group of granitic plutons in the SE Appalachians dated at 265-325 m.y. (Fullagar and Butler, 1979).

STRUCTURE AND FIELD RELATIONSHIPS

Contacts between different facies of the NPG are nowhere exposed, and it is unclear whether they are gradational, intrusive or faulted. On the other hand, contacts with country rock are exposed in a number of places; in nearly all cases they exhibit a complex lit-par-lit relationship, generally concordant with the foliation and/or bedding of the intruded rock. Such is the case at Cormorant Point (Stop 9 in the NE part of the pluton), and in the Woody Hill and Charlestown areas. In many places cross-cutting dikes connect the lit-par-lit sills to form a patchwork of enclosed xenoliths (Figs. 3 and 4). The simplest exposed contact is in Westerly (Stop 5) where the NPG truncates the foliation of intruded amphibolite at a shallow angle, but even here, concordant veins of granite, aplite, and pegmatite cut the amphibolite a few tens of meters to the north.



FIGURES 3 and 4. Geologic sketches of typical intrusive relationships of Narragansett Pier Granite to country rock at Stop 2. Figure 3 shows irregular cross-cutting relationships; Figure 4 shows sill with enclosed xenoliths.

Drill core from the once proposed Nuclear Power Plant site at Charlestown, R. I., verify the complex interlayering of rock types within a few km. of the northern contact. The thickness of rock types and their relative positions vary abruptly over short distances (Fig. 5). These changes are interpreted to represent stoped blocks and roof pendants of country rock within the NPG (New England Power Co., 1975). Based on other exposed outcrops it seems likely that this zone itself is representative of the complex lit-par-lit style of intrusion that is characteristic of the contact zone. These relationships make it difficult to pinpoint the exact contact of the pluton, and necessitate invoking the use of the term "contact zone."

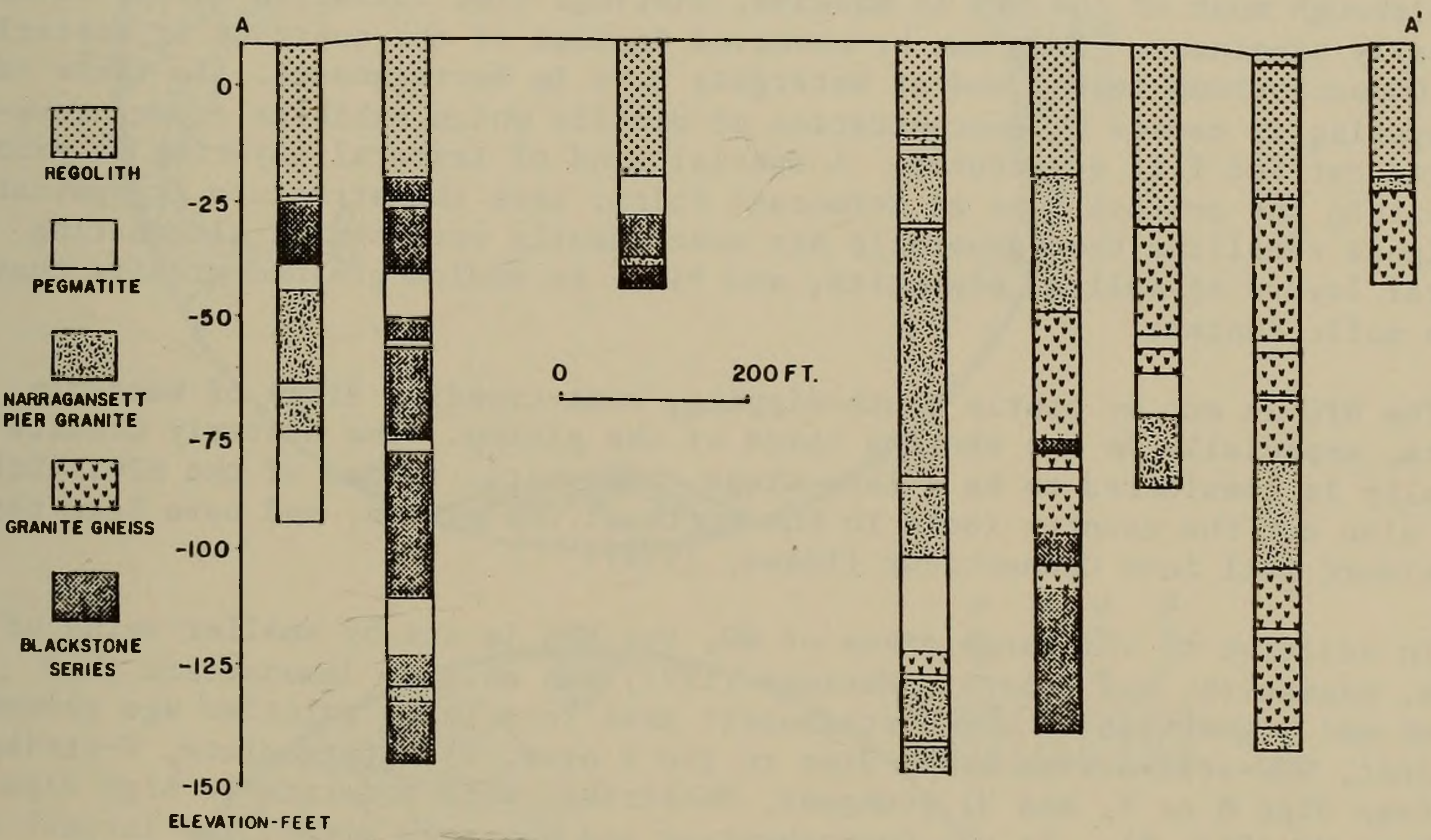


FIGURE 5. Representative core logs from contact zone of NPG (Charlestown, R. I.). The highly variable lithologies from hole to hole are similar to most exposed contact zones, and appear to represent the lit-par-lit nature of the intrusion as exposed elsewhere at the surface (from Preliminary Safety Analysis Report).

Xenoliths in the granite are common near the contact zone and become less prominent southward within the main pluton. Xenolith type correlates with the adjacent country rock, and in no cases have "restite-type" xenoliths been observed. For example, xenoliths at Westerly are exclusively varieties of amphibolite and biotite schist that contain mineral assemblages and modal proportions quite similar to the adjacent country rock (Kern, 1979). A short distance to the east, HVA forms most of the xenoliths as well as the country rock. The long dimensions of xenoliths are parallel to foliation, and moreover, the foliations exhibit similar orientations to foliations in the country rock. On a local scale, both Kern (1979) and Smith and Barosh (1981) have demonstrated that foliation in xenoliths wraps around, following the contact and the foliation in the country rock NE of Westerly. Xenoliths in the white granite facies near Narragansett are schists, sandstones, and conglomerates (some carbonaceous) identical to rocks of the intruded Pennsylvanian Rhode Island Formation (Kocis, 1981), and similarly exhibit foliation conformable to that in the country rock.

This consistent orientation of xenoliths and their structures testifies to the rather passive nature of the intrusion, in which only a few blocks were stoped and rotated. The country rock was pried apart along bedding and foliation planes to permit the lit-par-lit emplacement as a result of this gentle mode of emplacement, and the resultant screens of included rock represent a crude ghost stratigraphy that locally reveals the pre-NPG structure.

Although most of the NPG is massive, distinct flow foliation and/or layering is locally prominent. This can be observed in some of the quarries at Westerly, along Quonochontaug Beach, and at Watergate Cove in Narragansett. In these cases the layering is caused by concentration of biotite which exhibits crude cross-bedding and cut and fill structures. A special kind of textural layering is exhibited within the contact zone at Cormorant Point; here the structure is dominated by aligned xenoliths that generally are concordantly enclosed in alternating textural layers of aplite, pegmatite, and fine- to medium-grained granite that is low in mafic content.

The NPG is cut by gently south-dipping, west-trending dikes of Westerly Granite, especially in the western third of the pluton. The Westerly Granite generally is considered to be a late-stage, comagmatic facies of the NPG. Dikes of WG also cut the country rocks to the north of the pluton, and have been reported westward well into Connecticut (Liese, 1979).

In addition to the large dikes of WG, the NPG is cut by smaller veins of aplite, pegmatite, and quartz. Maczuga (1977) was able to demonstrate that aplites and pegmatites in the Narragansett area form three relative age groups: 1) oldest, NNW-strike with steep dips to the E or W, 2) intermediate, W-strike and steep dips N or S, and 3) youngest, NW-strike, with moderate to high dips to the SW or NE (Fig. 6). In the Quonochontaug and Westerly areas, the largest concentrations of veins of aplite and pegmatite strike W and have shallow dips to the S (Fig. 7); age relationships are not so apparent as at Narragansett, but suggest that these are the youngest veins. A second smaller maximum of veins with N to NW-strike exists.

Orientations of fractures in the Westerly area are mainly NE-striking with NW or SE dips, and less prominent NW- to N-striking fractures with steep dips. A fracture zone cuts the NPG along the extension of the Watch Hill fault zone and appears to be a reactivation of it (Stop 4). This fracture zone is broken by both N and NW offsets (Smith and Barosh, 1980) (Fig. 1). The NE-trending fractures with NW dips are also the most prominent at Narragansett, but N- and W-striking groups are present as well.

PETROGRAPHY AND GEOCHEMISTRY

All granite facies are structurally massive and non-foliated, except for local areas where flow foliation has developed.

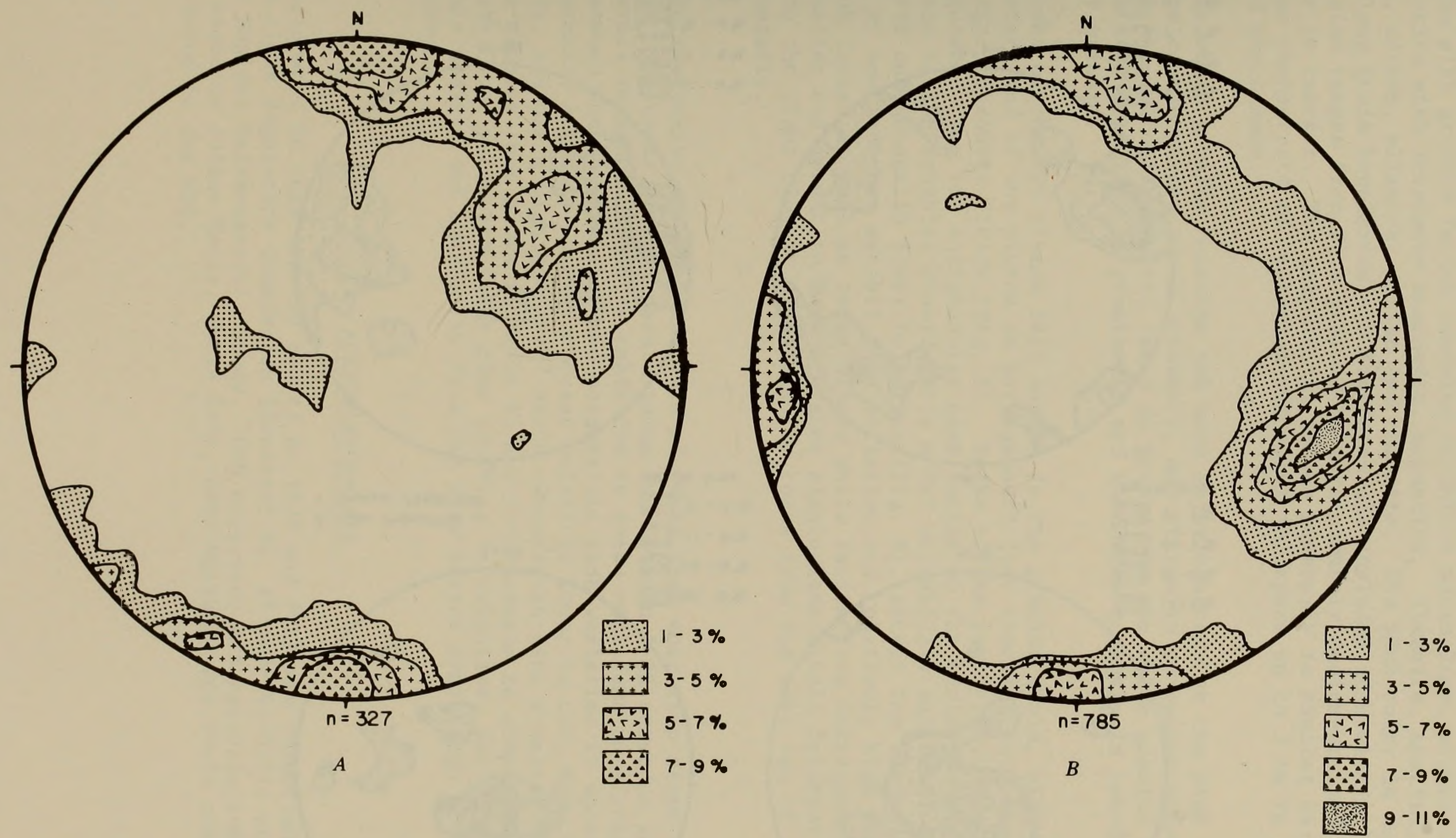


FIGURE 6. Lower hemisphere plot of (A) pegmatites/aplites and (B) fractures from NPG outcrops along the eastern shore of Narragansett Pier (data from Maczuga, 1977).

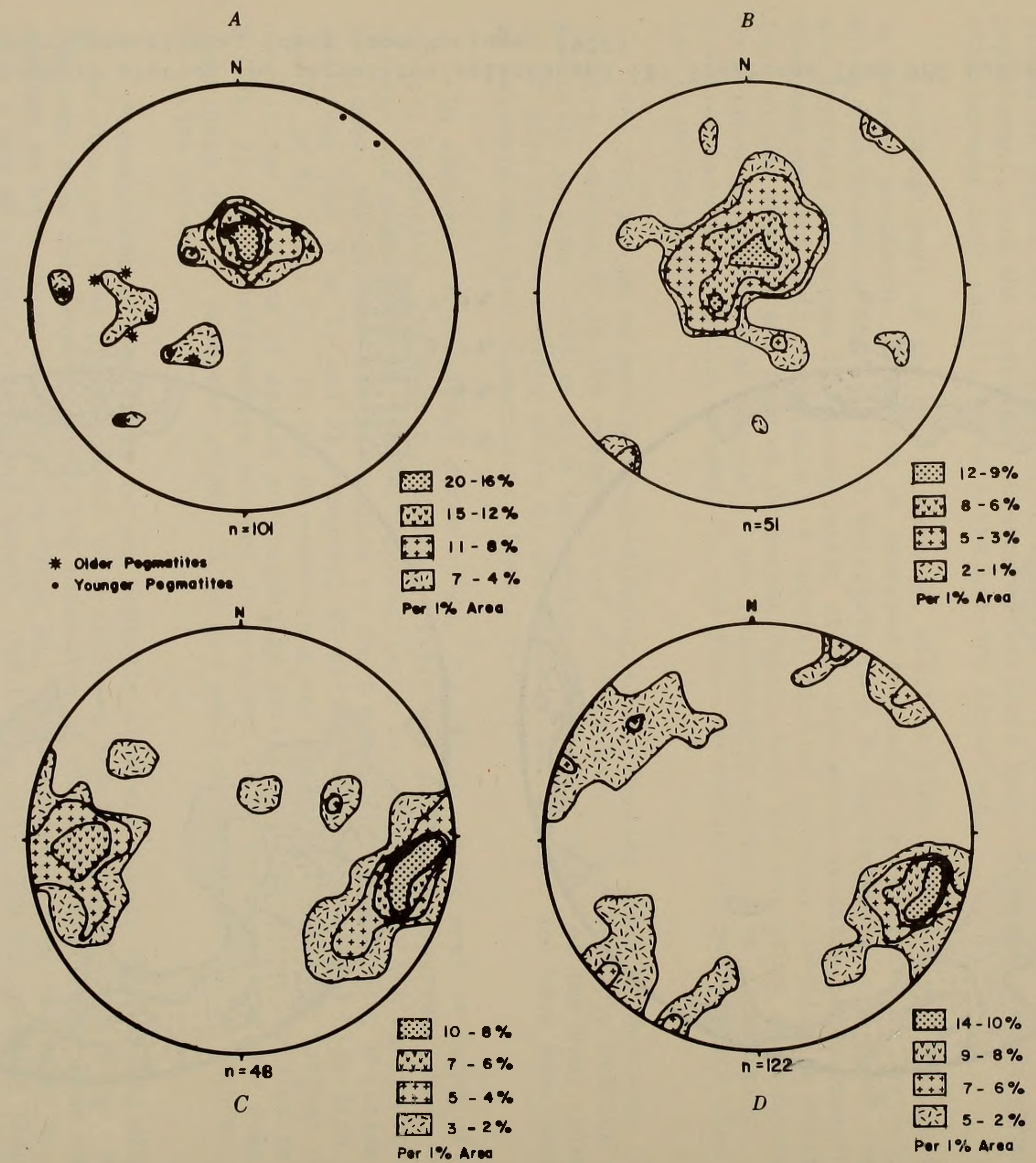


Figure 7: A, B. Lower hemisphere plot of pegmatites and aplites from the Quonochontaug/Weekapaug and Westerly areas, respectively. C and D illustrate fractures from these two respective areas (data from Kern, 1979).

The pink granite facies contains perthitic microcline, plagioclase, quartz, and biotite with accessory muscovite, magnetite, ilmenite, apatite, monazite, sphene, zircon, allanite, pyrite and chlorite. The pink color is due to oxidized iron along grain boundaries and fractures and included iron within feldspars. Grain size ranges from fine-grained to more commonly medium-grained (1-3 mm), but locally is coarser. The porphyritic facies generally is similar except that it contains phenocrysts of euhedral-subhedral feldspars up to 3 cm in a medium-grained groundmass.

The white granite contains the same major minerals as the pink variety, but contains common garnet as an accessory, and virtually no opaque minerals. In general the muscovite/biotite ratio is greater in the white granite (except where certain flow foliation is prominent) and muscovite commonly is euhedral and clearly primary.

Rocks of the NPG pluton fall mainly in the granite field, with a few from the eastern end of the pluton in Narragansett just crossing into the granodiorite and quartz monzonite fields (Fig. 8). Rocks of the porphyritic facies can not be distinguished from the equigranular pink facies on the basis of modal mineralogy. The white facies exhibits considerable modal variability and tends to be richer in quartz and generally lower in mafics (Fig. 8), except for varieties rich in garnet or samples that exhibit flow foliation and relatively high biotite contents. The pink facies as well as rocks of the white facies from Narragansett exhibit more scatter and appear to have a higher plagioclase/alkali feldspar ratio compared to the tight cluster of points for rocks from the west end of the pluton near Westerly.

Representative chemical analysis of rocks from most trip stops are shown in Table 1. The rocks are all peraluminous and contain 1-3% corundum in the norm. The overall range of chemistry exhibited is quite small and no significant difference between the equigranular and porphyritic pink varieties is apparent. The white granite at Thule Cove (Cormorant Point) is lower in CaO, MgO, TiO_2, and total Fe, and has a high Fe^{+2}/Fe^{+3} ratio compared to pink granite. Other white granite samples (not shown in Table 1) are intermediate in composition, and at Watergate Cove, where prominent flow layering is exhibited, the rock is indistinguishable modally and chemically from the pink facies eventhough it maintains its white color.

ACKNOWLEDGEMENTS

Field work in this area by two of us (PJB and PVS) was supported by the U. S. Nuclear Regulatory Commission (Contract No. AT (49-24)-0291) as part of the New England Seismotectonic Study. ODH expresses his appreciation to three former students (Diane Kocis, Chris Kern, Dave Maczuga) for their contributing work related to the NPG.

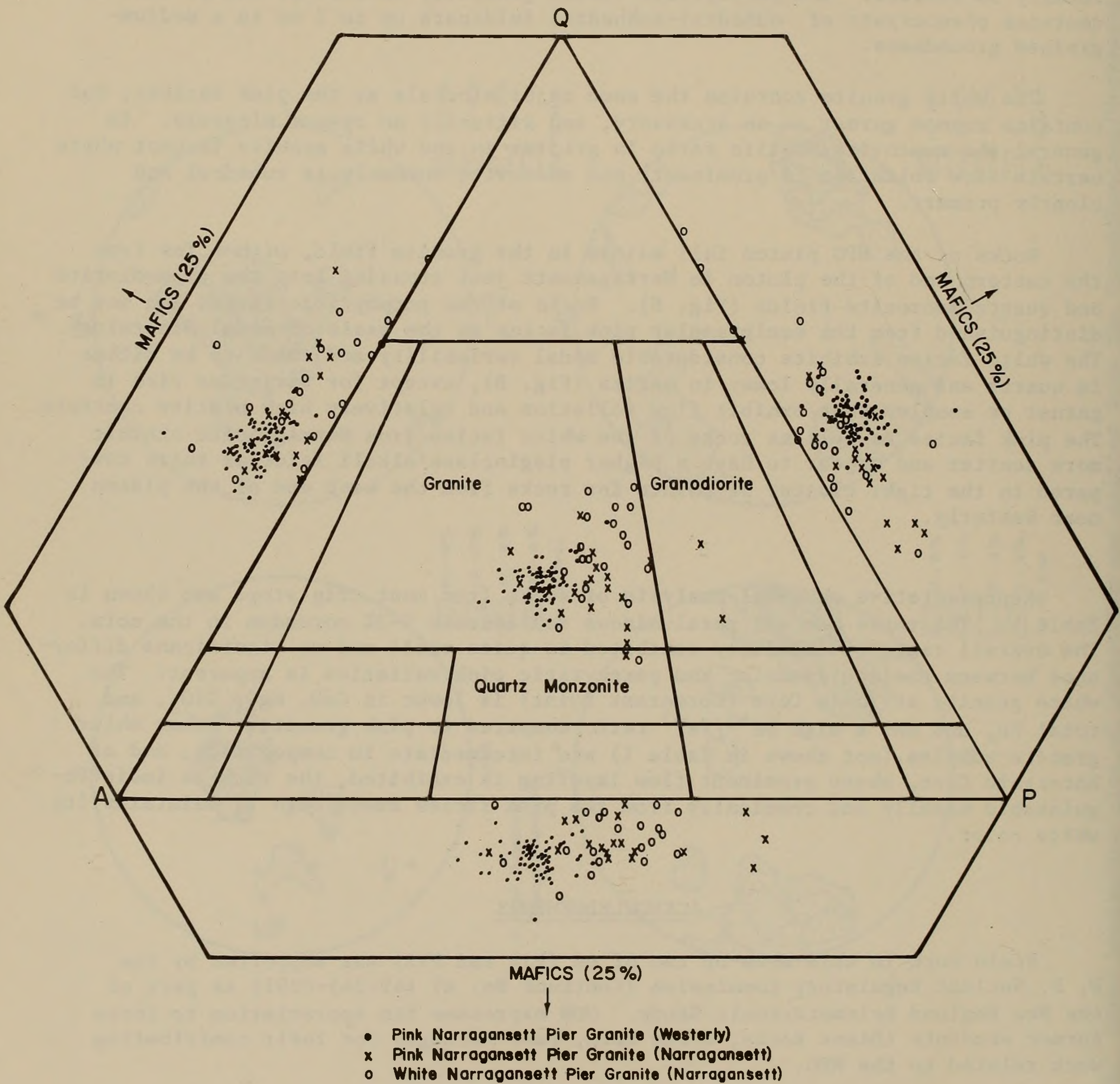


FIGURE 8. Plot of modal data for NPG (data from Kern, 1979; Kocis, 1981).

TABLE 1: Chemical compositions and CIPW norms of selected rocks of the Narragansett Pier pluton.

	1	2	3	4	5
SiO_2	71.96	70.45	70.59	74.30	74.89
Al_2O_3	14.26	14.09	15.76	15.18	14.71
Fe_2O_3	.86	.79	1.13	.39	.01
FeO	1.29	.96	.69	.26	.21
MgO	.49	.34	.42	.18	.07
CaO	1.58	1.18	1.14	1.05	.77
Na_2O	3.37	3.55	4.08	3.27	3.75
K_2O	5.06	5.13	4.99	4.35	4.88
H_2O	.17	.39	.91	1.34	.78
TiO_2	.45	.24	.29	.11	.08
P_2O_5	.10	.06	.05	.03	.03
MnO	.03	.02	.03	.01	.01
Total	99.54	97.36	100.09	101.15	100.21
Q	28.79	27.59	26.28	33.22	32.56
C	.61	.71	2.10	2.50	1.94
OR	29.98	31.14	28.44	29.36	28.75
AB	28.59	30.85	34.43	27.38	31.65
AN	7.20	5.61	5.05	4.96	3.59
EN	1.22	.87	.89	.44	.17
FS	.97	.77	.35	.08	.33
MT	1.25	1.18	.77	.43	.01
HM			.44	.09	
IL	.86	.47	.49	.21	.13
AP	.24	.15	.07	.07	.08

[1] Sample S78-1, pink, equigranular granite (Stop 5) Westerly (Kern, 1979).

[2] Sample NBF-1, pink, porphyritic granite (Stop 6) Quonochontaug area (Kern, 1979).

[3] Sample HA, pink, equigranular granite (Stop 7, average of 3 samples), Hazard Avenue, Narragansett (Kocis, 1981).

[4] Sample NA, white, equigranular granite (Stop 8, average of 3 samples), Narragansett Avenue, Narragansett (Kocis, 1981).

[5] Sample TH, white, equigranular granite (Stop 9, average of 3 samples), Thule Cove, Narragansett (Kocis, 1981).

ROAD LOG AND STOP DESCRIPTION

Miles

cum.	int.	Log starts at intersection of road to Keaney parking lot (University of Rhode Island athletic complex) and RI 138, Kingston, Rhode Island. Travel west on RI 138
10.1	10.1	Take entrance ramp to I-95 N.
11.0	.9	Road cuts on both sides of highway.

Stop 1: INDICATIONS OF THE NORTHERN EXTENT OF THE NPG AND CHARACTERISTICS OF THE HOPE VALLEY ALASKITE (HVA) AND BLACKSTONE SERIES (Fig. 9).

The HVA intrudes metasedimentary rocks and is cross-cut by non-foliated pegmatite dikes of the type associated with the NPG. The HVA is characteristically light pinkish gray, medium- to coarse-grained, and foliated, with quartz rodding that appears as strong foliation in one direction and weak foliation in a perpendicular direction. The HVA occurs here as several sill-like bodies with sharp to broadly gradational boundaries with the Blackstone and contains xenoliths at various stages of digestion. The HVA is fine-grained along a few contacts that, therefore, appear slightly chilled. The metasedimentary rocks consist of several slightly different layers of medium- to dark-gray, fine- to coarse-grained biotite-hornblende gneiss, that locally is thinly layered and may be volcaniclastic. Intrusive relationships of the HVA exhibited here and at nearby outcrops discount the suggestion by Day and others (1980a,b) that the HVA may consist of a metamorphosed pile of volcaniclastic rocks.

Thin, 2-80 cm thick dikes of non-foliated pink pegmatite with aplitic borders irregularly cut the outcrop. These are typical of those associated with the NPG and are indicative of the northern extent of the intrusive.

A normal fault offsets a large xenolith in the HVA downward to the north a few meters in the center of the outcrop. This may have occurred during later stages of the HVA magmatic episode. A few late brittle faults with slickensides are also present.

Return to cars and continue N on I-95.

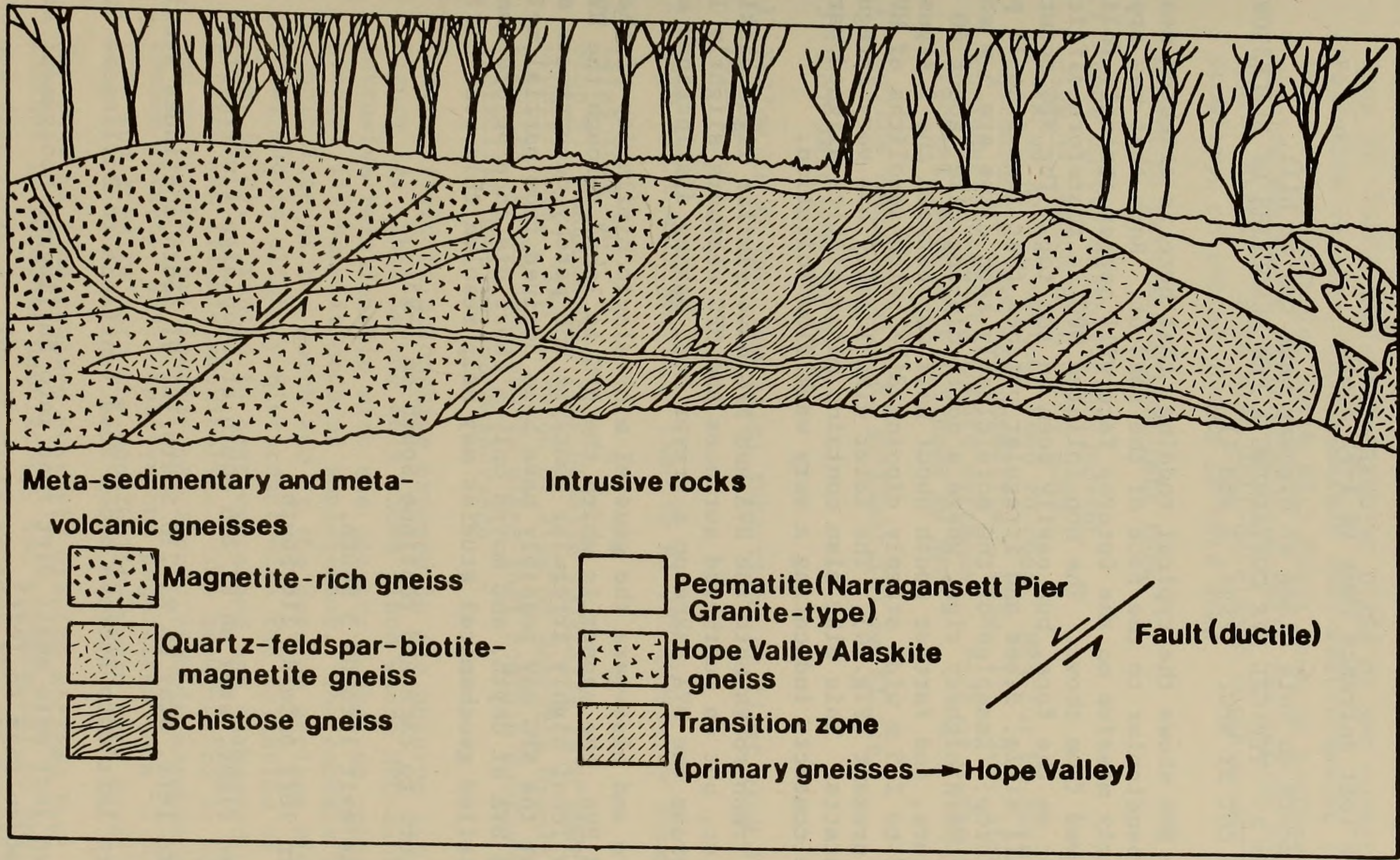


FIGURE 9. Geologic sketch of roadcut on southeast side of U.S. 95, miles north of R.I. Rt. 138, showing general rock types. View southeast (Stop 1).

cum.	int.	
12.3	1.3	Take exit 4 to stop sign; turn left onto US 3 South.
12.6	.3	Take left entrance ramp to I-95 South.
18.5	5.9	Roadcuts on both sides of highway near top of hill.

Stop 2: TYPICAL HVA CONTAINING A FEW XENOLITHS OF BLACKSTONE AND CUT BY NPG. (Figs. 3 and 4).

The HVA shows the typical rodding, that here is oriented nearly perpendicular to the face of the roadcut. Rock that may appear nearly massive on the outcrop face will appear strongly foliated when viewed from above. The non-foliated NPG is therefore difficult to spot on the face, but easily seen on the top. The NPG occurs as small sills, dikes and irregular patches that form 5 to 15 percent of outcrop. Examples of the more clearly seen dikes are 5 m south of the northern highway sign, where a north dipping dike (about 40 cm wide) occurs, and farther south about half way between the 2 signs, where a 2 to 2.5 m wide steeply dipping dike, with xenoliths of HVA, is present (Fig. 4). The later dike locally has very irregular contacts. This dike also contains minor biotite aligned parallel to the contacts indicating a very weak flow foliation.

On fresh rocks both the HVA and NPG have similar light pinkish-gray color, but on weathered surfaces the NPG weathers slightly lighter whereas the HVA takes on a grayer hue, making distinctions easier.

Here and elsewhere the general mineralogic similarity of the NPG and HVA, the manner in which the NPG is laced through the HVA and a few local highly irregular contacts and patchy occurrences suggest that the NPG may possibly have been derived from partial melting of the HVA at depth, and moved only a short distance before consolidation. Detailed geochemical studies may help resolve this possibility

Return to cars and continue South on I-95.

21.0	2.5	Take exit 1 to US 3 South.
23.0	2.0	Turn left onto RI 216 South
25.4	2.4	Turn right, stay on RI 216 South at stop sign (intersection RI 91).
26.3	0.9	Turn left, stay on RI 216 South (RI 91 South continues straight).
27.6	1.3	Turn left onto Buckeye Brook Road (entrance to Burlingame State Park).
29.5	1.9	Turn left onto small dirt road into Burlingame Management Area (wooden sign to left).

cum.	int.	
30.0	0.5	First fork in road. Stop 3: LARGE EAST-WEST-TRENDING DIKES OF NPG CUTTING HVA. (Fig.10). Foliation regular, approximately east-west-trending (part of structural block bounding Watch Hill Fault Zone on southeast side with regular east-west foliation, relatively few joints and relatively sparse dikes). Note also well-developed north-south jointing, prominent on aerial photos of this area. Return to cars and follow left fork.
31.3	0.7	Road curves sharply right (north). Stop 4: WATCH HILL FAULT ZONE. Walk up gulley east of bend in road. HVA cut by more numerous intrusions of NPG and pegmatite. (Fig. 11) Very strong jointing - dominantly trending toward northeast. Part of large northeast-trending joint zone intruded by NPG.
34.4	3.1	Retrace route to RI 216, go right (N) on RI 216.
35.7	1.3	Turn left onto RI 91 W.
40.8	5.1	Follow RI 91 into Westerly; take right at first stop light onto US 3 N.
42.0	1.2	Take right onto entrance ramp to RI 78S (Westerly Bypass).
42.3	0.3	Large road cut. Stop 5: NARRAGANSETT PIER GRANITE INTRUSIVE INTO AMPHIBOLITIC COUNTRY ROCK: NPG intruded by dike of Westerly Granite, and both granites cut by lamprophyre dikes that contain mantle-derived lherzolite nodules and megacrysts.

General field relationships exposed in the outcrop are illustrated in Figure 12. This is the only known place where NPG exhibits a simple intrusive relationship with the country rocks, as opposed to its more general lit-par-lit mode of emplacement. The contact with biotite amphibolite at the north end of the outcrop strikes N60^{o}E and dips 60^{o}N, and is slightly discordant with the foliation of the schist (E-W, 65^{o}N). Granite is coarse-grained and unsheared next to the altered and friable amphibolite. The amphibolite is rich in biotite and muscovite, but locally has layers rich in hornblende, and less common garnet. Small aplites and pegmatites (one $\sim$1 m. wide) extend from the granite into the amphibolite where they locally cut foliation.

The dike of fine-grained Westerly Granite strikes E-W; the lower contact is somewhat undulatory, but subparallel to the upper contact, and dips 15-20^{o}S. The contacts against NPG are unquenched, and commonly are characterized by discontinuous zones of pegmatite; commonly these pegmatites follow the contact for a short distance, and then abruptly cut into NPG or WG.

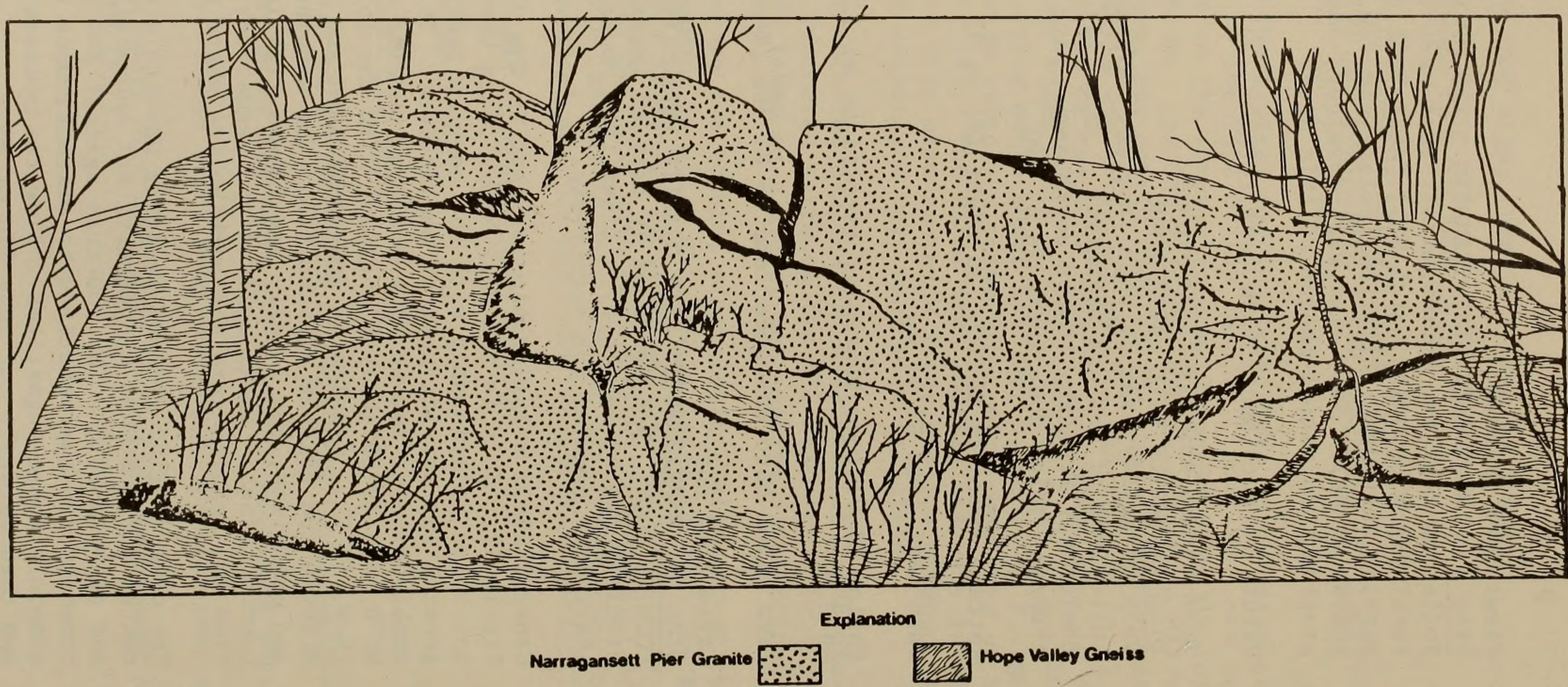


FIGURE 10. Geologic sketch of outcrop in Burlingame State Park, showing large like of Narragansett Pier Granite intruding Hope Valley Alaskite Gneiss. Foliation in gneiss trends east-west; northeast-trending joints are relatively absent. Pronounced north-south-trending joints. View north (Stop 3).

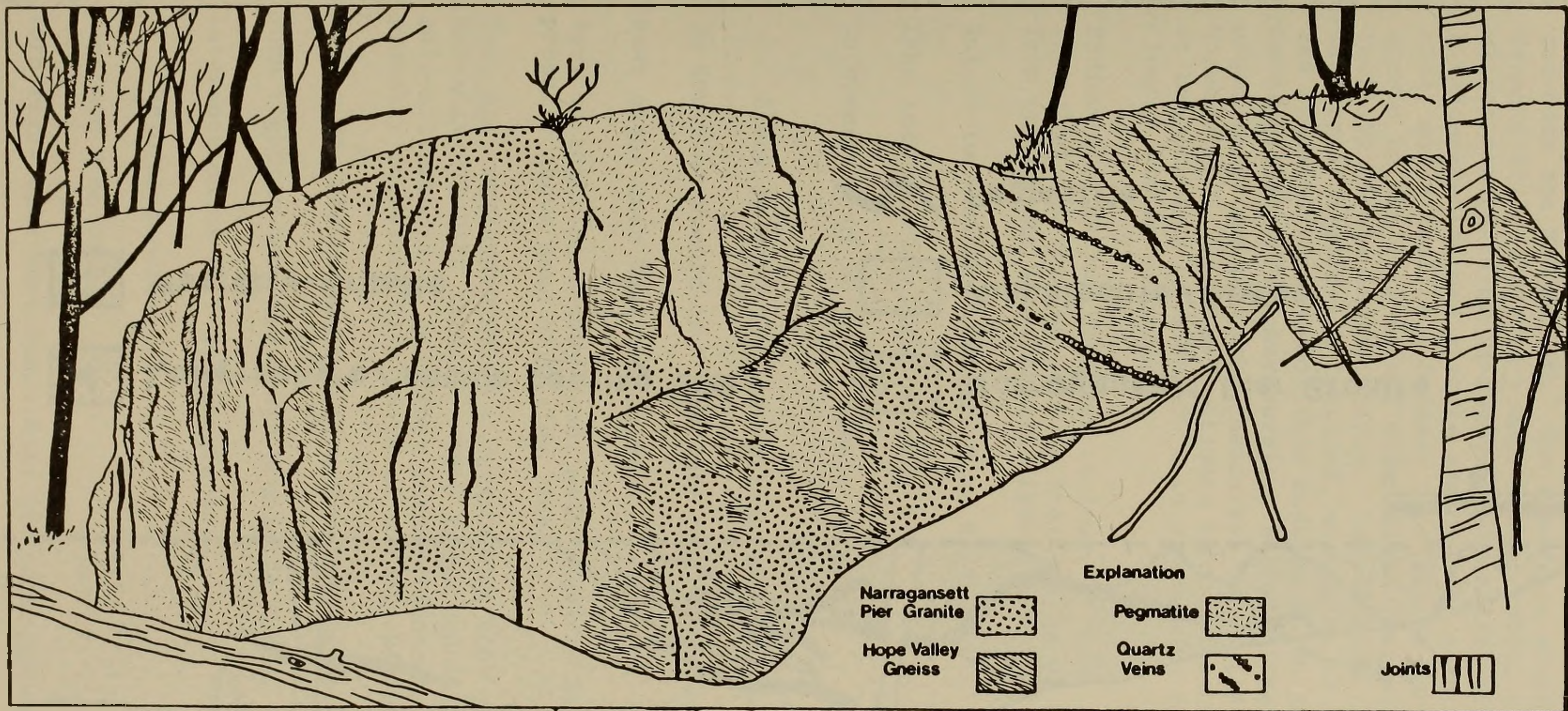


FIGURE 11. Geologic sketch of outcrop in Burlingame State Park in northeast-trending lineament zone extension of Watch Hill fault zone. Hope Valley Alaskite Geniss intruded by dikes of Narragansett Pier Granite and associated pegmatites. Northeast-trending joints, relatively absent outside zone, strongly developed within zone. View southwest (Stop 4).

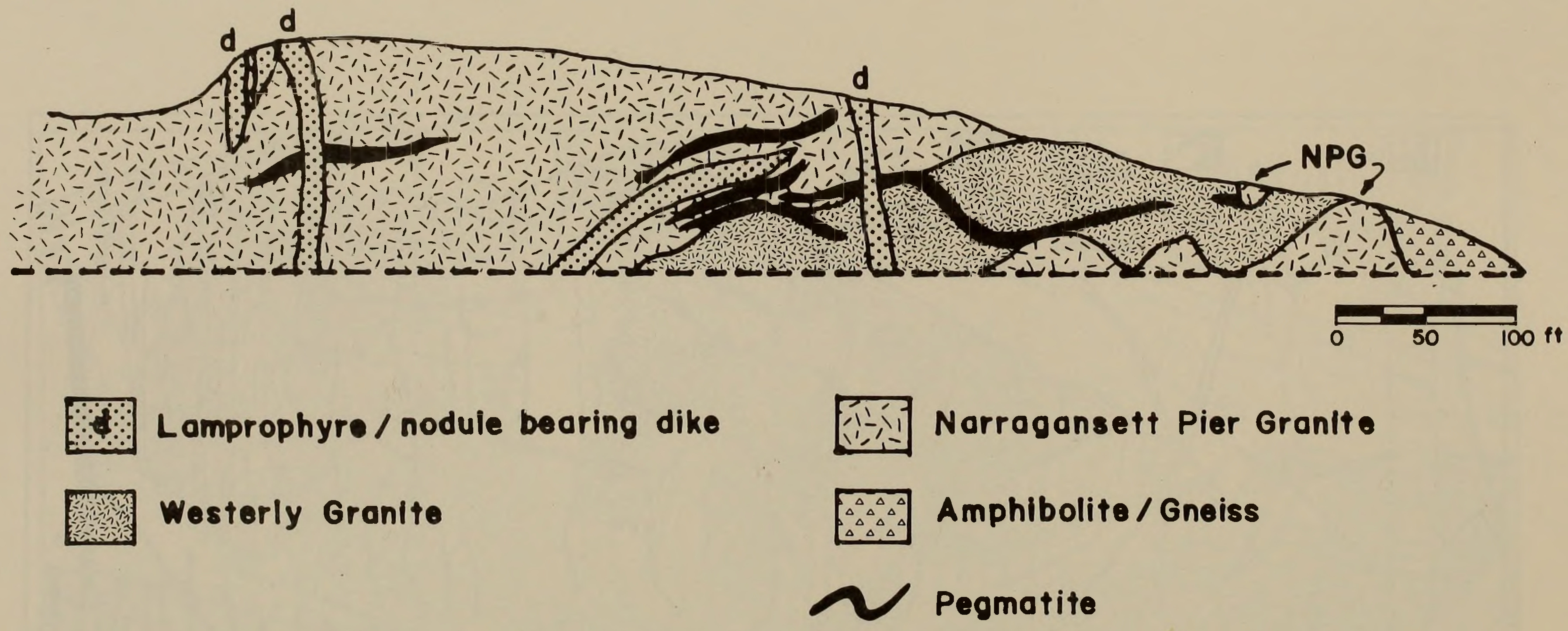


FIGURE 12. Generalized cross-section of Stop 5 road cut (west side) showing Narragansett Pier Granite intrusive into older amphibolitic gneisses. Westerly Granite cuts the NPG, and both granites are cut by lamprophyre dikes that contain lherzolite nodules (Stop 5).

cum. int. Two lamprophyre dikes that strike N 25° E with nearly vertical dips cut both the NPG and WG. The dikes are monchiquite (Leavy and Hermes, 1977, 1978, in press; Leavy, 1980), and are characterized by microphenocrysts of Ti-augite, kaersutite, olivine, phlogopite, titanomagnetite and apatite enclosed in a matrix of analcite, calcite, and a zeolite. Primary flow fabric parallel to contacts is common in the dike rocks, and ocellar textures are present that may indicate liquid immiscibility. In addition these rocks contain a variety of megacrysts (olivine, varieties of low Ti clinopyroxene, and ilmenites) and xenolithic nodules which include chrome spinel-bearing lherzolite, harzburgite, and wehrlite. Based on the mineral assemblages and pyroxene chemistry, Leavy (1979) and Leavy and Hermes (1977, in press) estimate that these nodules equilibrated at temperatures of 950-1200°C in a pressure regime between 9-25kb, clearly within the mantle.

Radiometric dating underway includes zircons from NPG and WG collected from this outcrop, as well as K-Ar dating of phlogopite and kaersutite from one of the lamprophyric dikes.

Return to cars and continue S on RI 78.

44.6 2.3 Take left at stop light onto US 1 N.

48.1 3.5 Intersection of US 1 and Scenic 1A south.

Break in road log for optional Stop 6A.

(0 .9) Go South on Scenic 1A, take left onto Noyesneck Road.

(1.9 1.0) Bear right onto Wawaloam Drive

(2.0 .1) Park on right on Fenway Road; walk south to outcrop on beach. Private property above mean high tide line.

Stop 6A: METASEDIMENTARY - METAIGNEOUS ROOF PENDANT WITHIN NARRAGANSETT PIER GRANITE. This large xenolith includes greenstone, calc-silicate rock, and other metasedimentary lithologies that probably correlate with units of the Blackstone Series.

Return to cars and continue on Wawaloam Drive.

(3.2 1.2) Turn right at stop sign onto Scenic 1A North.

(4.7 1.5) Intersection of US 1 and Scenic 1A.

Rejoins road log.

Continue N on US 1A.

49.9 1.8 Turn right onto West Beach Road (to Quonochontaug).

cum.	int.	
51.5	1.6	Turn left into private drive (just before line of mail boxes). Park at end of drive, walk south to outcrops on the shore. Private property.

Stop 6: PORPHYRITIC FACIES OF NPG

Much of the southern shoreline east of Westerly consists of sparse outcrops of a porphyritic facies of NPG. The contact relationships with other textural varieties is nowhere exposed, and it is not known whether the contact is gradational, intrusive, or faulted. The rock at this outcrop is typical of the porphyritic facies, and is characterized by euhedral phenocrysts of K-spar up to 5 cm enclosed in a finer but coarse-grained groundmass. This textural variety is modally and chemically similar to other textural varieties.

The outcrop is cut by N-trending (E dipping) aplitic and pegmatitic dikes as well as by subparallel, lenticular lenses of quartz. Some of the aplites exhibit a crude flow layering as evidenced by the alignment of biotite, and in some cases they have been stretched and disjointed and invaded by granite, indicating that the granite was still plastic and mobile at the time of dike intrusion. At least one E-W trending slickensided fault cuts the outcrop.

Several large glacial erratics of orbicular granite were found along the coastline approximately ¼ mile west of this outcrop. One is in the British Museum of Natural History, and a second is in the rock garden of the URI Geology Department. The latter shows the contact of the porphyritic NPG facies against the orbicular rock, which has the same mineralogy as NPG (see description in Kern, 1979). The occurrence of an orbicular-textured rock in this area as well as the porphyritic facies may indicate that a shallower part of the intrusion is exposed here as compared to the deeper seated exposures to the east in Narragansett.

Return to cars and retrace route on West Beach road to US 1 North.

53.1	1.6	Turn right onto US 1 North.
67.1	14.0	Take RI 108 exit (to Narragansett - Point Judith); turn right at stop sign onto South Pier Road, and continue straight through stop light.
68.9	1.8	Turn right onto Ocean Road (Scenic 1A South).
69.8	.9	Turn left onto Newton Avenue.
69.9	.1	Park at end of street, walk to outcrops along the coast. BE CAREFUL of slick, algae-covered black rocks.

cum. int.

Stop 7: PINK FACIES OF NPG

Equigranular, coarse-grained NPG typical of the NPG is exposed at this outcrop; it is in sharp contrast to the white facies to be seen at the next two stops. Cross-cutting aplites and pegmatites along these coastal exposures appear to consist of three different age groups as summarized in Figure 6.

Return to cars and return to Ocean Road.

70.0 0.1 Turn right onto Ocean Road

71.6 1.6 Take left onto Exchange Street, just past the "Towers" (building that straddles Ocean Road); Exchange Street becomes Kingstown Road.

72.2 0.6 Take left at stop light onto Narragansett Avenue.

72.5 0.3 Take right onto Mumford Road (just past tennis courts).

73.1 0.6 Park to right on Peckam Road. Walk to Mumford Road and down hill to outcrop in back of house. Private property.

Stop 8: INJECTION ZONE OF WHITE GRANITE FACIES OF NPG.

The white granite here is in sharp contrast to the typical pink facies seen before. The white facies is restricted to zones near contacts where the country rock contains carbonaceous- and graphite-rich layers. We interpret this to mean that the carbon in the metasediments kept fO_2 in the melt relatively low, and iron was kept mainly in the +2 state. Compared to the pink granite, the white facies is richer in muscovite, lower in biotite, contains locally abundant Mn-rich spessartine garnet, and is free of magnetite or other opaque minerals.

The outcrop consists of a lit-par-lit layered sequence of white granite injected into sandy metasediments. The metasediment contains the assemblage garnet-biotite-muscovite-plagioclase-microcline-quartz, and is enriched in biotite adjacent to the granite. The granite is not quenched against the metasediment, nor is there evidence of contact metamorphism in the area (Kocis, 1981; Milne, 1972), indicating that the country rock was hot at the time of intrusion. This injection zone can be traced northward along strike for ¼ mile, whereupon the proportion of granite to metasediment generally decreases.

The granite generally parallels the foliation of the metasediments, which is complexly folded, but locally cuts across and truncates layers, and in a few instances exhibits injected ptygmatic folds. in many respects, the outcrop is typical of an injection migmatite The lit-par-lit nature of the contact generally is representative of the contact wherever exposed.

cum.	int.	Return to cars and backtrack on Mumford Road to Narragansett Avenue.
73.7	0.6	Take left onto Narragansett Avenue.
74.3	0.6	Take left at second stop light, then bear right.
74.5	0.2	Take left at stop light onto Scenic 1A north.
75.7	1.2	Turn right onto Old Boston Neck Road.
76.0	0.3	Turn right into private drive; continue 0.2 miles to house on left and park along drive. Private property. Outcrops form Cormorant Point along the coast line.

Stop 9: LAYERED WHITE-GRANITE FACIES OF NPG OF CORMORANT POINT

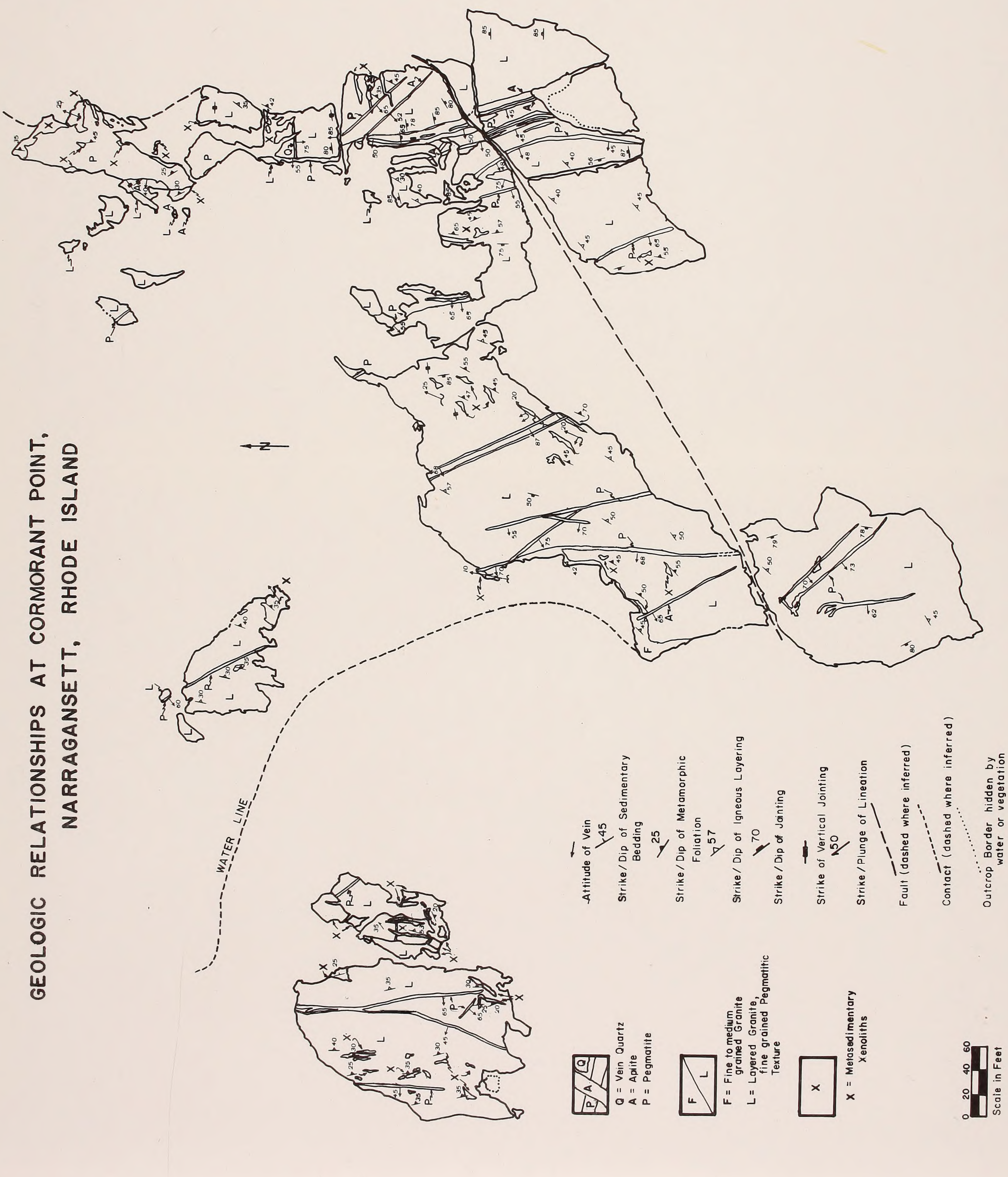
The white facies exposed here exhibits a locally prominent igneous layering characterized by parallel to subparallel layers of alternating textures (Fig. 13). Equigranular, medium-grained granite alternates and is interlayered with a fine-grained aplitic rock and with a coarse, pegmatitic textured rock. Locally the layering is more obvious than in other areas. The best places to observe it are on the island (accessible at low tide) and along the SW exposures of the point. A relatively thick, homogeneous fine-grained granite layer rich in garnet has been mapped separately.

Numerous xenoliths that comprise screens of metasediment are included in the layered white granite. These schistose rocks range in lithology from sandstones to conglomerates. Of importance is the fact that the lengths of these screens as well as their foliations are nearly all parallel and lie in the plane of layering of the granite. Moreover, the foliations are conformable to the foliations in the schists that constitute the country rock to the north. We interpret those features to mean that the granite was injected in this zone as a series of pulses that passively invaded the country rocks, preserving screens of generally unrotated metasediment. The diverse granite texture probably reflects local and temporal variations in H_2O pressure which resulted in grain sizes ranging from aplitic-pegmatitic.

Some xenoliths exhibit local folding and deformation, implying that they were deformed prior to granite emplacement. Some contain biotite enriched zones adjacent to the granite, and in some cases, garnet in these zones can be traced away from xenolith tails to form diffuse garnet trains in the granite. This suggests a certain amount of local assimilation and reaction with the granite. In addition some xenoliths have graphite-rich layers, and Stephanian B plant fossils have been identified from carbonaceous layers from one xenolith (Brown et al., 1978).

Return to cars and retrace route to Scenic 1A. To return to the University of Rhode Island, take right on Scenic 1A; take left onto RI138 W (about 4 miles); continue W for approximately 6 miles to Kingston.

Figure 13: Geologic relationships at Cormorant Point (Stop 9).
Geology by O. Don Hermes and C. Mandeville, 1980.



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