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The Hope Valley Shear Zone - A Major Late Paleozoic Ductile Shear Zone in Southeastern New England

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by

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INTRODUCTION

A variety of late Precambrian rocks are exposed to the south and east of the Honey Hill, Lake Char and Bloody Bluff faults in southeastern New England. Granitic plutons and granitic gneisses predominate, with lesser amounts of volcanic and sedimentary rocks of several associations. These rocks generally have been treated as an integral tectonic unit and considered part of the "eastern basement" of the Appalachians. They have been grouped with other similar rocks along the eastern margin of the orogen, forming an extensive lithostratigraphic belt commonly referred to as the Avalon zone (e.g., Rast et al., 1976).

Recent work centered in Rhode Island provides some important new insights into the development of the eastern basement in southeastern New England. This work has determined that this segment of the Avalon zone is composed of two distinct groups of late Precambrian rocks (Hermes and Gromet, 1983; Gromet and O'Hara, 1984; Hermes and Zartman, 1985) separated by a major but previously unrecognized Alleghanian shear zone (O'Hara and Gromet, 1984, 1985). The differing Paleozoic histories of the two groups of rocks, as revealed by contrasts in the timing and nature of Paleozoic magmatic and deformational events, has led to their treatment as terranes: an eastern Esmond-Dedham terrane and a western Hope Valley terrane (Fig. 1).

The boundary between the Esmond-Dedham and Hope Valley terranes, which is partly cryptic, has been located and characterized by a combination of field, petrographic and geochronological methods. The boundary is zone of highly strained, ductilely deformed gneisses derived from rocks of both terranes. Structural elements of these rocks show a close spatial and geometrical relationship to the boundary and suggest they formed within a major right-lateral shear zone.

The purpose of this trip is to examine some of the gneissic rocks that constitute the boundary between the two terranes, termed the Hope Valley shear zone. The Hope Valley shear zone is named for its proximity to the town of Hope Valley in southwestern Rhode Island. The Hope Valley shear zone extends from south-central Rhode Island northward along the Rhode Island-Connecticut border into adjacent Massachusetts (Fig. 1). The trip begins along the southern segment of the shear zone in southwestern Rhode Island, where Hope Valley alaskite and associated biotitic gneisses (Stops 1 and 2) are found against Devonian Scituate granite gneisses (Stops 3-5). At Stop 5, the Precambrian Ponaganset

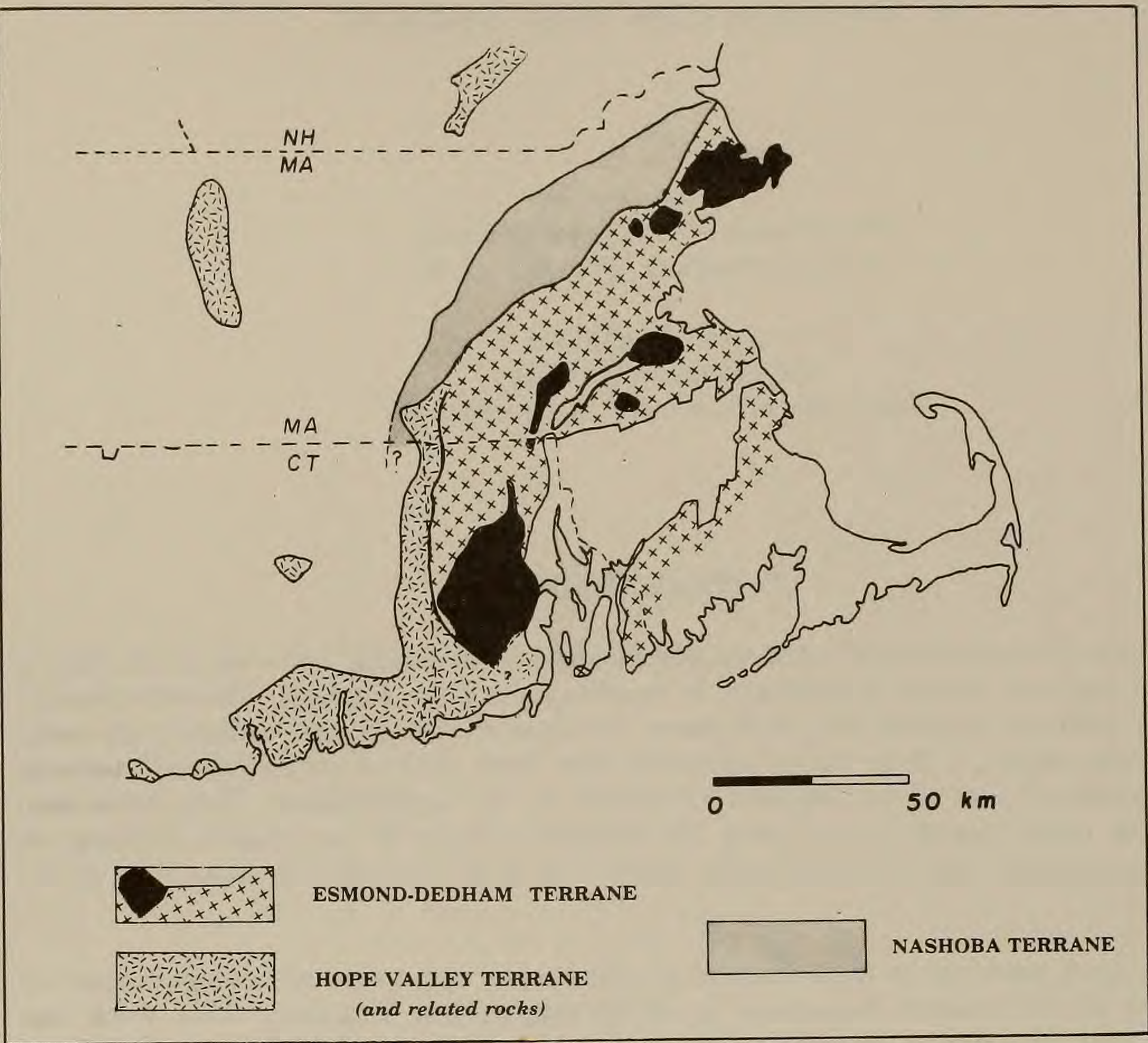


Figure 1. Terrane map of southeastern New England showing the distribution of the Esmond-Dedham, Hope Valley and Nashoba terranes. The Esmond-Dedham terrane is intruded by anorogenic Paleozoic plutons (dark shading), overlain by the Narragansett and Norfork basin sediments (unshaded), and bounded to the west by the Bloody Bluff fault and the Hope Valley Shear Zone. The precise location of where the HVSZ joins the Bloody Bluff has not been determined. The Nashoba terrane may continue further south along strike. Late Precambrian granite gneisses in the Massabesic anticlinorium, NH (top center of figure) may correlate with the Hope Valley rocks and underlie much of the Merrimack synclinorium. After O'Hara and Gromet (1985).

gneiss also is observed. Later stops will be along the northern segment of the shear zone where the Ponaganset gneiss (Stops 6,8 and 9) of the Esmond-Dedham terrane is found against Hope Valley alaskite (Stops 7 and 10). Trip stops are shown on Figure 2.

THE ESMOND-DEDHAM AND HOPE VALLEY TERRANES

The Esmond-Dedham and Hope Valley terranes were recognized on the basis of observations made on a regional scale. The rocks and relationships seen on this excursion can provide only a partial appreciation of the distinctive nature of the two terranes. A brief summary of some of the more important characteristics of the two terranes is provided below. A more complete account is given in O'Hara and Gromet (1985).

The Esmond-Dedham terrane underlies most of Rhode Island and that part of eastern Massachusetts lying east of the Bloody Bluff fault. Prominant late Precambrian intrusive members include the Esmond group, the Dedham and Milford granitic rocks, and the Ponaganset gneiss. These rocks are a lithologically diverse group of *ca* 620 Ma granitic rocks ranging in composition from diorite to granite. They intrude older rocks such as those of the Blackstone series and are locally overlain by latest Precambrian to early Paleozoic marine sediments containing trilobites of Acado-Baltic affinities (Skehan et al., 1978). Collectively, these rocks are intruded by numerous alakline (locally strongly peralkaline) and subalkaline granites of Orodovician to Devonian age. The 370 Ma Scituate granite in central Rhode Island is now known to be one of the largest members of this group (Hermes et al., 1981; Hermes and Zartman, 1985). Non-marine Pennsylvanian sediments fill the Narragansett and Norfork Basins, which developed as pull-apart basins (Mosher, 1983) within the Esmond-Dedham terrane.

The late Precambrian rocks of the Hope Valley terrane differ considerably from those of the Esmond-Dedham terrane. The Hope Valley alaskite, Potter Hill granite and Ten Rod granite gneisses are the principal units and they are composed almost exclusively of highly leucocratic granite gneisses. Mafic to intermediate compositions are rare, indicating these rocks are not simply metamorphosed equivalents of the Esmond-Dedham rocks. The granite gneisses intrude small bodies of mafic to intermediate schist and gneiss usually assigned to the Plainfield formation or Blackstone series (undifferentiated). Quartzite and calc-silicate rocks assigned to the Plainfield are also present. Cross-cutting and relatively undeformed pegmatitic to aplitic dikes related to the Permian Narragansett Pier and Westerly granites occur extensively.

Large variations in deformational features and metamorphic grade occur across the region. In central and northern Rhode Island and adjacent Massachusetts, the rocks of the Esmond-Dedham terrane are weakly to moderately deformed and display low-grade metamorphic assemblages. Primary igneous textures are partially to well preserved in the plutonic units outside of local zones of shearing. To the south and west toward the boundary with the Hope Valley rocks, Esmond-Dedham rocks of all ages become increasingly more deformed and recrystallized. Rocks near the boundary such as the Ponaganset and Scituate are ductilely deformed gneisses possessing a strong penetrative lineation and/or foliation. The Ponaganset gneiss in particular becomes an intensely lineated augen gneiss containing 5-20% feldspar porphyroclasts in a highly recrystallized matrix. A probable tectonic origin for the Ponaganset-Hope Valley contact was first recognized by O'Hara (1983). This contact constitutes the northern segment of the Hope Valley shear zone.

The late Precambrian Hope Valley rocks are everywhere highly deformed and have a strongly developed penetrative fabric. Extensive recrystallization has left little if any of

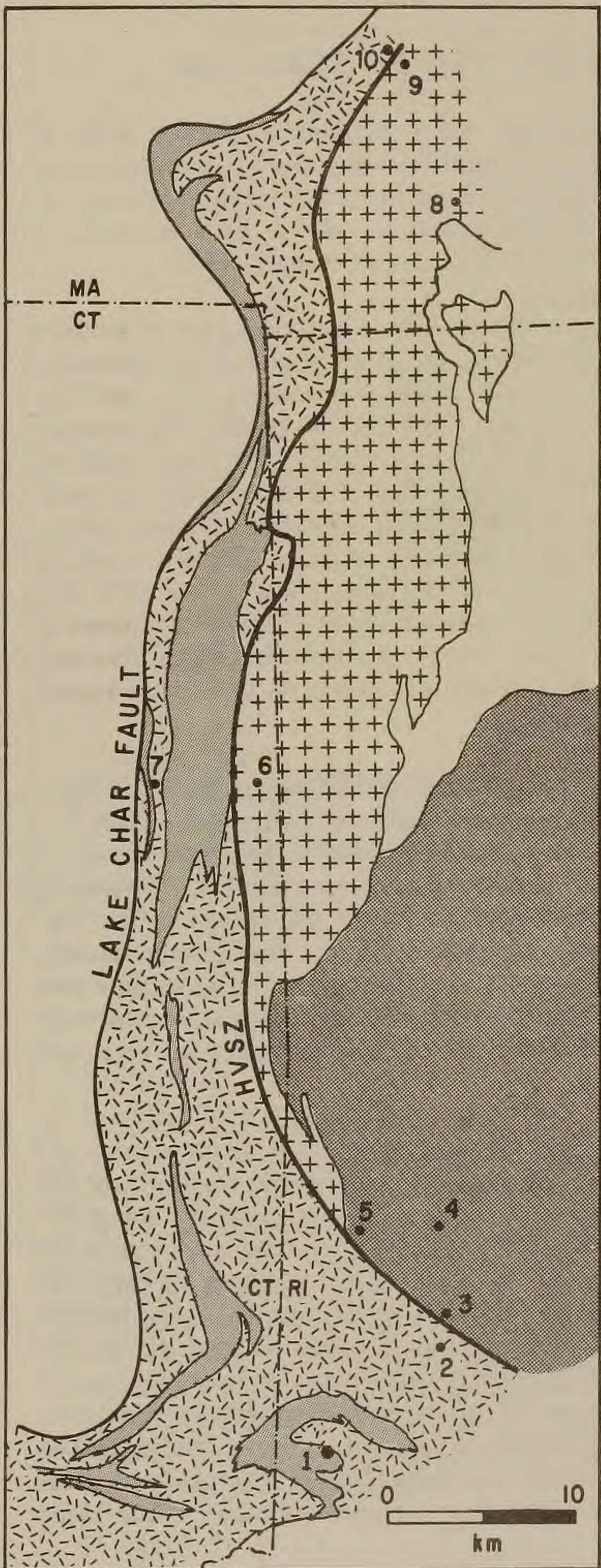


Figure 2. Locations of trip stops along the Hope Valley shear zone in western Rhode Island, eastern Connecticut and adjacent Massachusetts. Distribution of the larger masses of the Plainfield Formation within the Hope Valley terrane is shown.

the original igneous mineralogy. Many of these rocks closely resemble deformed Devonian Scituate granite. In our experience, these rocks cannot be confidently distinguished from one another on field or petrographic criteria. This led earlier workers (who had no way of knowing that the Scituate is Devonian in age) to consider the Hope Valley alaskite and the Scituate to be gradational. Consequently, small bodies of Scituate were mapped within the Hope Valley rocks, and small bodies of Hope Valley alaskite and Ten Rod granite were mapped within the Scituate.

Recent geochronological and field studies (Gromet and O'Hara, 1984; O'Hara and Gromet, 1985) has clarified the extent of the Scituate granite, showing that it extends considerably further south in Rhode Island than previously mapped, and that the small bodies of "Scituate" mapped within the Hope Valley rocks of southwestern Rhode Island and eastern Connecticut are late Precambrian in age. The newly determined distribution is shown in Figs 1 and 2. It is now clear that the southwestern margin of the Devonian Scituate granite is a highly deformed granite gneiss, and that Ordovician to Devonian anorogenic plutons do not extend into the Hope Valley terrane. The SE-trending contact between Scituate granite and Hope Valley alaskite is tectonic contact and constitutes the southern segment of the Hope Valley shear zone.

THE HOPE VALLEY SHEAR ZONE (HVSZ)

The northern and southern segments of the Hope Valley shear zone have been identified in somewhat different ways. The northern segment is a contact between the Hope Valley and Ponaganset gneisses located principally by field relations and deformational features (O'Hara, 1983). The southern segment is a lithologically cryptic contact between Scituate granite and Hope Valley gneisses located largely on the basis of geochronological methods (Gromet and O'Hara, 1984). However, the two segments together define a smooth and continuous boundary (Figs 1 and 2) that share a coherent set of structural characteristics.

Lineations and foliations associated with the Ponaganset-Hope Valley contact are seen to pass smoothly and continuously along strike into the Scituate and Hope Valley gneisses along the southern segment of the HVSZ. The attitudes and relative intensities of the structural features vary in a systematic manner along the HVSZ. Along most of the Ponaganset-Hope Valley segment, a strongly developed lineation (approximately N-trend, 0-30^{o}N plunge) is accompanied by a weak to moderate west-dipping foliation (10-40^{o}) (e.g., Stops 6,7 and 8). As the HVSZ is followed south, the foliation steepens and intensifies (Stop 5) into a transition region where the boundary deflects to the southeast. Continuing along the SE-striking southern segment, the foliation in the Scituate and Hope Valley gneisses overturns and dips northeast (Stops 2 and 3) and the gneisses are more highly foliated than lineated.

These variations in structural features provide some important insights into the formation of the HVSZ. The dominant structural feature of the Ponaganset-Hope Valley segment is the strongly developed north-trending lineation. Three lines of evidence occurring on a range of scales indicate that the lineation developed as a stretching lineation within a north-trending right-lateral shear zone. On a regional scale, the lineations display an overall NW-trending pattern away from the HVSZ, but are deflected into parallelism with the HVSZ on approach from either side (Fig. 3). Similar patterns are observed in ductile shear zones on a variety of scales (Ramsay and Graham, 1970), where the elongation direction (represented here by the lineation) is deflected toward the shear plane (the Ponaganset-Hope Valley contact) at high shear strains. The sense of deflection in Figure 3 indicates a right-lateral shear sense on the shear plane.

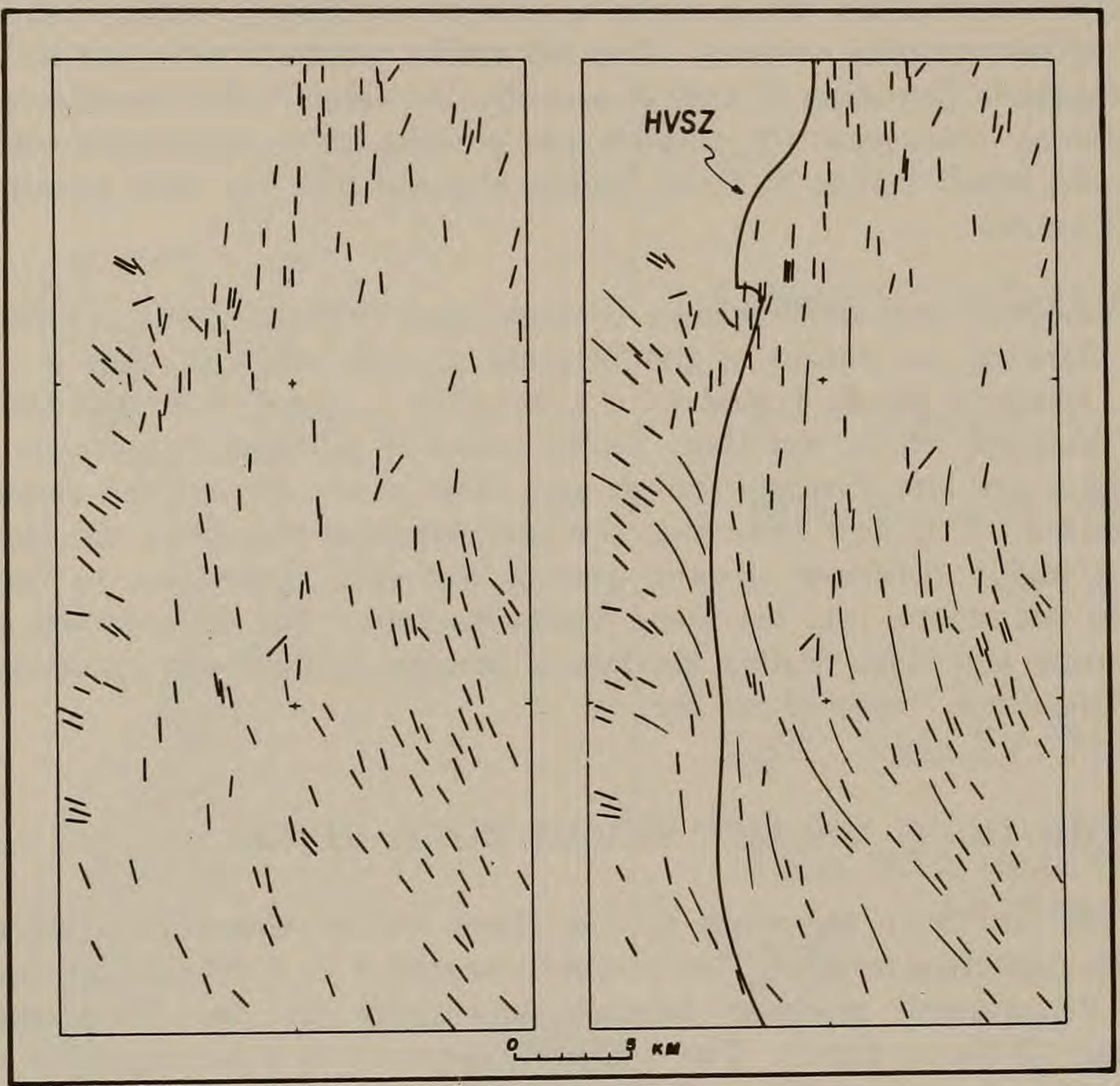
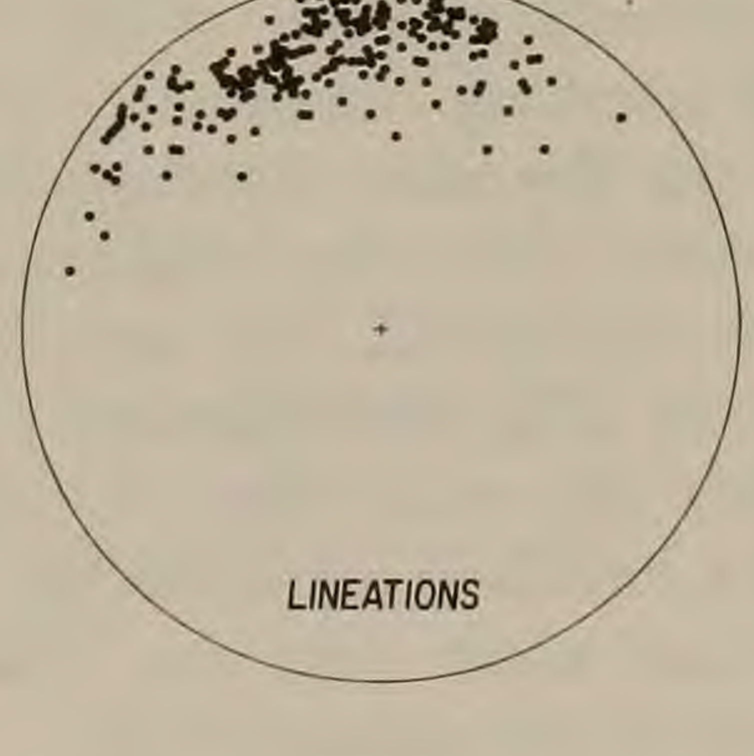


Figure 3. Left: lineation trends in gneisses from eastern Connecticut and western Rhode Island based on six quadrangle reports (Dixon, 1974; Frost, 1950; Harwood and Goldsmith, 1971; Moore, 1963, 1983; Quinn, 1967). The plunge of the lineations is shallow to the north (See below). Right: same as left with the Ponaganset-Hope Valley segment of the HVSZ indicated. Flow lines have been added to emphasize the regional lineation pattern. Note the deflection of the lineation towards the boundary from either side. Below: equal area projections of lineations from the area, showing shallow northerly plunge. From O'Hara and Gromet (1985).



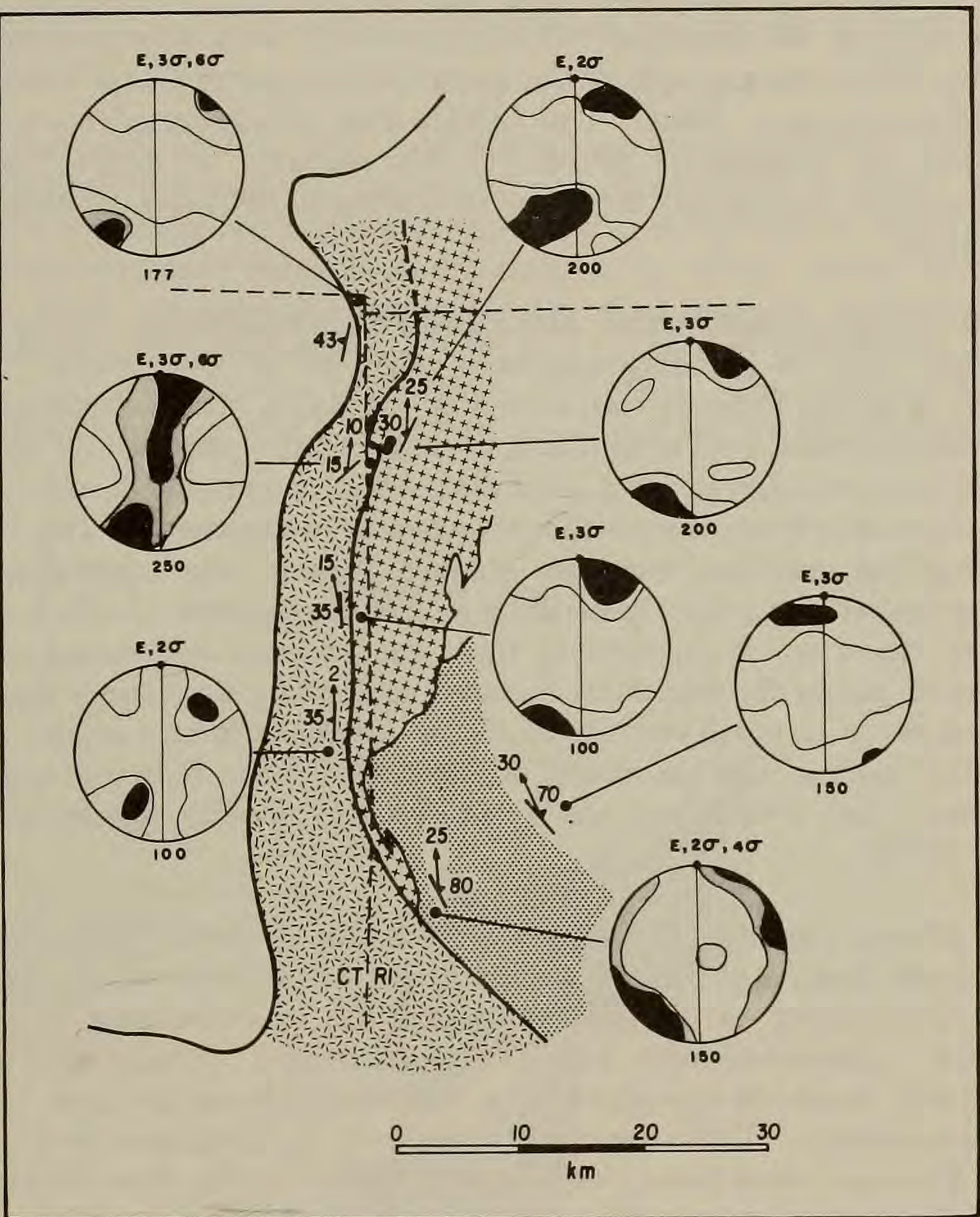


Figure 4. Equal-area projections (lower hemisphere) of quartz c-axis preferred orientations for samples of Ponaganset gneiss, Hope Valley alaskite and Devonian Scituate granite close to the boundary between the Esmond-Dedham and Hope Valley terranes. The patterns are plotted so that the foliation (line) is oriented vertically and the lineation (dot) occurs at the top of the pattern. Their geographical orientation can be obtained by reference to structure symbols at the sample localities. Note the similar asymmetry of the patterns along the length of the boundary. One sample, away from the boundary, indicates the opposite sense of shear. Contour intervals are indicated at the top of each pattern where E is the expected number of points within the counting circle for a randomly distributed population and sigma is the first standard deviation from E. The number of grains measured is indicated for each pattern. From O'Hara and Gromet (1985).

On the outcrop scale, feldspar augen with asymmetric deformation tails are commonly developed in the Ponaganset gneiss (e.g., Stop 6). Asymmetric tails are best developed parallel to rather than normal to the lineation. The tails are reasonably inferred to have formed during shear parallel to the lineation. The asymmetric tails give predominantly right-lateral shear senses. On a microscopic scale, asymmetric quartz c-axis fabrics (Fig. 4) also are indicative of non-coaxial shear. The fabrics can be explained by a process involving dislocation creep on dominantly prism [c] slip systems in quartz, with the asymmetry about the lineation (extension) direction indicating a right-lateral shear sense (O'Hara and Gromet, 1985).

A major component of right-lateral shear along the Ponaganset-Hope Valley contact implies compression along the SE-trending southern segment of the HVSZ. Several observations on a variety of scales support this inference, including attitude changes along the boundary, foliation development, and orientation of lineations relative to the boundary. The attitude of the HVSZ can be inferred from the foliations in the gneisses, which change considerably along the transition from the northern to southern segments. The HVSZ is inferred to dip west along the northern segment, steepen through the transition region, then overturn and dip northeast along the SE-striking southern segment. A block diagram (Fig. 5) illustrates these changes. It is notable that the gneisses associated with the southern segment are more highly foliated than lineated, indicating a stronger component of flattening, and that the north to northwest trend of the lineations is at a higher angle to the southeast strike of this part of the boundary. Collectively, these features argue that the Scituate granite gneiss has overthrust the Hope Valley alaskite gneiss along the southern segment of the HVSZ.

To summarize, the different structural features of rocks along the HVSZ indicate that it originated as a high-grade ductile shear zone with major components of dextral shear along the Rhode Island-Connecticut border and south-directed overthrusting in southern Rhode Island. Deformation associated with the HVSZ produced a thick rind of gneissic rocks along the western and southern margins of the Esmond-Dedham terrane, leaving a less deformed, lower grade interior. Differences in the deformational character of plutonic rocks in southern New England were recognized by Goldsmith (1978), who identified an eastern brittely deformed terrane and a western ductilely deformed terrane in this region. Goldsmith's deformation terranes correspond to the core of the Esmond-Dedham terrane (brittle), and the outer margins of the Esmond-Dedham terrane and the Hope Valley terrane (ductile).

The age of the Hope Valley shear zone appears to be Alleghanian. An upper age limit is given by the 370 Ma Scituate granite, which has been truncated and deformed by the HVSZ. A lower limit is provided by the Permian Narragansett Pier granite and its asociated pegmatites (Stops 1, 2 and 3), which intrude rocks of both terranes and are largely undeformed. An Alleghanian age for the HVSZ is implied by an overall parallelsim of metamorphic isograds in the Pennsylvanian sediments of the Narragansett basin (e.g., Murray and Skehan, 1979; Mosher, 1983) to the southern segment of the HVSZ. The highest metamorphic grades are found in the extreme southwest corner of the basin, where it most closely approaches the HVSZ.

The relationship of the HVSZ to other major fault zones in southeastern New England is the subject of further study. The Bloody Bluff fault and the HVSZ are similar in that together they constitute a western tectonic boundary to Esmond-Dedham rocks. The HVSZ continues northward toward the Bloody Bluff, although the details of how they join remain to be worked out. It seems likely, however, that the HVSZ and the Bloody Bluff are a single structure, with the along-strike variaiton in deformational characteristics (from brittle along the northern Bloody Bluff to increasingly more ductile southward on the

HVSZ) being indicative of progressively deeper structural levels exposed to the south. This feature appears to be the result of overthrusting and thickening along the southern segment of the HVSZ as it changed from predominantly strike-slip to south-directed thrust motion.

The Lake Char and Honey Hill fault zones are fundamentally different from the HVSZ and Bloody Bluff and probably have no direct relationship to them. The Lake Char and Honey Hill are generally low angle structures separating quartzo-feldspathic basement gneisses from metamorphosed volcanic and sedimentary rocks. Rocks on both the upper and lower plates share an extended strain history that appears to include Alleghanian, Acadian and possibly older deformations (Dixon and Lundgren, 1968; O'Hara and Gromet, 1983). In the Permian, the Lake Char-Honey Hill fault zone appears to have been a basement-cover boundary that was warped and truncated by the HVSZ-Bloody Bluff fault.

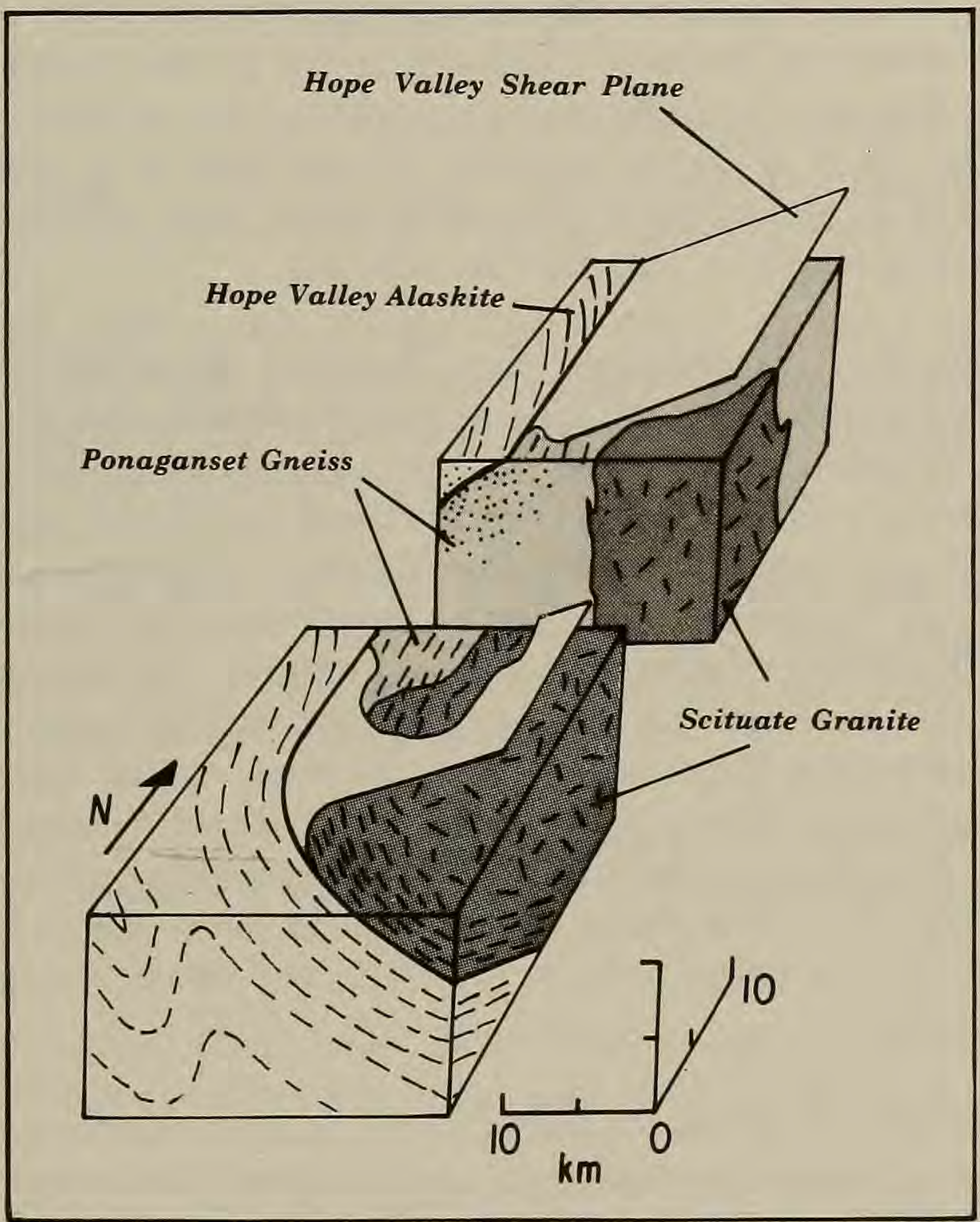


Figure 5. Schematic block diagram illustrating the inferred geometry of the HVSZ (white plane) in west-central Rhode Island and adjacent Connecticut. The boundary is inferred to dip west along the north-trending segment. Further south it steepens, passes through vertical then dips to the northeast along the southeast-trending segment. From O'Hara and Gromet (1985).

REGIONAL SIGNIFICANCE

The HVSZ represents both a major regional geologic break and a locus of deformation within the plutonic "basement" rocks of southeastern New England. The distinctive character of the Esmond-Dedham terrane -- its diverse assemblage of late Precambrian plutonic rock types, latest Precambrian to early Paleozoic cover sequence with Acado-Baltic fauna, Odovician to Devonian anorogenic magmatism, and Pennsylvanian non-marine basins -- indicates an evolutionary history quite distinct from that of the Hope Valley terrane. The absence of Ordovician to Devonian anorogenic granites in the Hope Valley terranes implies the Esmond-Dedham rocks were remote from Hope Valley rocks through this time period. On this basis, it appears unlikely that these two groups of rocks acquired their present relative positions prior to the Late Palezoic.

It is significant that high-grade metamorphism within the Esmond-Dedham terrane is restricted to its southern and western margins and is Alleghanian in age. The Alleghanian orogeny appears to be the only major Paleozoic deformational event to have affected these rocks. Evidence for the involvement of Esmond-Dedham rocks in the major Taconic and Acadian orogenies in the New England Appalachians is lacking. In contrast, rocks of the Hope Valley terrane occupy the cores of domes located further west (e.g., the Willimantic and possibly Pelham domes in Connecticut and Massachusetts) and, along with rocks of the Merrimack synclinorum, are involved in Acadian structures.

The above observations on the southeastern New England segment of the "Avalon zone" or eastern basement rocks of the Appalachians strongly point to the existence of two different terranes (in the tectonostratigraphic sense) that were accreted to the North American continent in two discrete episodes. The first involved the Hope Valley terrane in or prior to the Devonian. Initial accretion during the Taconic orogeny is possible, with subsequent Acadian consolidation to the ancient North American continental margin. In either case, it appears that the Hope Valley terrane constituted the eastern basement block of the Acadian orogeny, and perhaps the motive force for Acadian convergence. The second accretionary event involved the Esmond-Dedham terrane, which collided obliquely with the Hope Valley terrane along the Hope Valley shear zone in Alleghanian time. This event appears to be one of the principal causes of the Alleghanian orogeny in southeastern New England. Kinematic features of the Hope Valley shear zone and the absence of oceanic rocks along it suggest it was principally a transcurrent fault transporting rocks along the axis of the Appalachians.

Recognition of the bipartite nature of the "Avalon zone" in southeastern New England allows for both the involvement of Avalonian rocks in early and mid-Paleozoic orogenies as well as the late Paleozoic accretion of an "exotic" Avalonian terrane. This appears to resolve some of the fundamental discrepancies among tectonic models of the New England Appalachians (Osberg, 1978; Robinson and Hall, 1980; Rodgers, 1981; Hall and Robinson, 1982; Zartman and Naylor, 1984).

ACKNOWLEDGEMENT

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ROAD LOG

Mileage Cum.	Int.	
		Begin at park and ride lot at Exit 1, I-95 Hopkinton, RI (8:30 AM 10/5/85).
0.0	0.0	Turn left onto Route 3 South
0.3	0.3	Turn left onto entrance ramp, I-95
2.2	1.9	**STOP 1 BIOTITE GNEISS AND PEGMATITE DIKES**

The grey porphyroclastic biotite gneiss exposed here is fairly typical of biotitic gneisses mapped by previous workers as part of the Plainfield Formation. They occur as scattered masses in this part of the Hope Valley terrane. In nearby exposures, the gneiss is intruded by Hope Valley alaskite. Here, the gneiss is intruded by dikes of the Narragansett Pier granite (a massive, equigranular, medium-grained granite) and related pegmatites.

The biotite gneiss has a fairly strong linear fabric (ESE trend, shallow E plunge) and a weaker foliation (ESE strike, steep SW dip). Narrow, small-scale shear zones and incipient shears occur approximately parallel to and normal to the lineation. The latter shears warp or fold the lineation, a feature not commonly observed in lineated gneisses to the north and east.

Larger granitic to pegmatitic dikes were emplaced along variously oriented surfaces, and some develop a somewhat anastamosing form parallel to foliation planes in the gneiss. Thinner, generally sharp-walled dikes occur along shear planes in the gneiss. Incipient shears commonly have thin (<2 cm) and discontinuous pegmatoid veins along the shear plane, and some shears displace or warp earlier pegmatite veins. It appears that the shears were actively forming during pegmatite emplacement and that some of the pegmatites took advantage of the shears during injection. The late but not always post-tectonic emplacement of dikes related to the Narragansett Pier granite seen here is consistent with observations made further to the east in the Narragansett Basin (e.g., Murray and Skehan, 1979; Mosher, 1983).

7.6 5.4 **STOP 2 HOPE VALLEY ALASKITE AND BIOTITE GNEISS, CROSS-CUT BY PEGMATITE DIKES**

This road cut was previously described by Hermes et al. (1981 a,b). The Hope Valley alaskite is a coarse to medium-grained pink leucocratic gneiss containing no more than a few percent biotite, magnetite and a few other accessory phases. Flattened and elongated aggregates of quartz and feldspar define a strong foliation ($135^{o}/30^{o}$NE) and a weak to moderate lineation (approximately 165^{o} trend and 10-15^{o}NW plunge). The alaskite intrudes a foliated grey biotite gneiss locally containing conspicuous magnetite octahedra (intrusive relationships are more convincingly displayed in other nearby exposures). The biotite gneiss here was originally mapped as part of the Blackstone series (Moore, 1958). However, it is quite similar to the biotite gneiss observed at Stop 1 and perhaps both are better grouped with the Plainfield Formation. Undeformed pegmatites cross-cut the Hope Valley alaskite and the biotite gneiss.

In thin section, the alaskite and biotite gneiss display a highly equilibrated equigranular texture typical of rocks of the Hope Valley terrane. Quartz, microcline and lesser plagioclase share straight grain boundaries that meet at 120^0 junctions. There is little intragranular strain in these rocks despite the large strains associated with mesoscopic structures, indicating extensive recovery during or after ductile deformation.

The attitude and trend of foliation and lineation fabrics indicate that they are related to right lateral shear and south-directed overthrusting on the Hope Valley shear zone, which passes immediately to the north. The next outcrops seen on I-95 extending up the grade to the northeast are strongly deformed Devonian Scituate granite gneiss of the Esmond-Dedham terrane.

8.5 0.9 Take exit for Route 3.
Road cuts in highly deformed Devonian Scituate granite, previously mapped as Hope Valley alaskite

8.9 0.4 Turn left onto Route 3 south

9.5 0.6 **STOP 3 DEFORMED SCITUATE GRANITE GNEISSES AND ASSOCIATED AMPHIBOLITE GNEISS**

The outcrop on the east side of the road contains a foliated, medium to coarse-grained augen gneiss (microcline, quartz, plagioclase, biotite, sphene and iron oxide) interlayered with dark amphibolite gneiss. Both the augen gneiss and the amphibolite gneiss were mapped as part of the Blackstone Series (Moore, 1958). However, the augen gneiss closely resembles porphyroclastic Scituate granite gneiss (see next stop) and the amphibolite gneiss has a much different composition and texture than the "Blackstone" of the previous stop.

The outcrop on the west side of the road is a leucocratic, medium-grained equigranular gneiss originally mapped as Hope Valley alaskite. It is indeed petrographically indistinguishable from common Hope Valley rocks, but two samples of identical rocks from adjacent road cuts on I-95 (immediately to the northeast) have given Devonian ages (O'Hara and Gromet, 1985). The observations here and in nearby areas underscore the difficulty in distinguishing Devonian Scituate rocks and late Precambrian Hope Valley alaskite. Mediumgrained, equigranular leucocratic gneisses are common to both.

The augen gneiss and equigranular gneiss are interpreted to be two different textural types of the Devonian Scituate granite that have suffered considerable post-emplacement deformation. Feldspar porphyroclasts in the augen gneiss have well developed deformation tails. Biotite streaks and feldspar deformation tails define a strong foliation ($125^0/25^0$NE) and a weaker lineation ($140^0/10^0$N). Near the amphibolite gneiss, the augen gneiss becomes finer grained and laminated. Layers of the amphibolite gneiss have been somewhat disrupted by shearing. Pegmatite dikes cut the older rocks, and aplitic dikes (some with discontinuous pegmatoid cores) cut the pegmatites and the older rocks.

10.1 0.6 Turn right onto K G ranch road

13.9 3.8 Junction Route 165. Park before intersection, walk west on Route 165 to roadcut on north side of road.

STOP 4 DEVONIAN SCITUATE GRANITE GNEISS

This road cut contains a stronly lineated coarse to medium-grained pink augen gneiss and finer grained leucocratic equigranular gneiss. Local contacts between these types range from sharp to gradational. Some of the finer grained gneiss with sharp-walled contacts have the appearance of aplitic dikes that intruded the augen gneiss and were deformed along with it.

A striking feature of these rocks is a strongly developed lineation (010^{0}/20-30^{0}N) defined by streaks of biotite and rods of quartz and feldspar. There is only a weak foliation. The lineation is approximately normal to the face of the road cut and is best observed on undersides and side faces. Deformation is poorly expressed on surfaces normal to the lineation.

In thin section, the augen gneiss consists of quartz, microcline, plagioclase and biotite, with minor hornblende, epidote and sphene. Relict igneous textures are not observed. Feldspar augen are comprised of anhedral, generally equant recrystallized grains which show little intracrystalline strain. Coarse quartz grains make up linear aggregates and are highly undulose with good subgrain development. Finer quartz (<0.1 mm) in the matrix are typically clear unstrained grains. Biotite (with associated granular sphene) and lesser hornblende are aligned parallel to the linear quartz aggregates. The overall mineral textures indicate deformation was ductile and occurred under amphibolite or higher grade conditions.

The rocks exposed here were originally mapped as Scituate granite gneiss (Moore, 1958). Recent Rb-Sr whole rock (O'Hara and Gromet, 1985) and U-Pb zircon (Hermes and Zartman, 1985) dates on the augen gneiss of this outcrop give Devonian ages (370 Ma), indicating emplacement along with the much less deformed Scituate rocks to the north and east.

13.9 0.0 Turn left onto Route 165 west.

16.8 2.9 **STOP 5 DEVONIAN SCITUATE GRANITE GNEISS AND LATE PRECAMBRIAN PONAGANSET GNEISS**

The Scituate granite gneiss exposed here is variable in texture. Two principal types are present: a medium-grained pink leucocratic gneiss and a coarser pink biotite gneiss. Moore (1958) mapped the leucocratic gneiss as Hope Valley alaskite and the coarse biotite gneiss as Scituate granite gneiss, and both assignments are reasonable on a petrographic basis. However, Rb-Sr analysis of both lithologies lie on a Devonian isochron (370 Ma), indicating both are varieties of Scituate granite.

Also present here is a grey porphyroclastic biotite gneiss interspersed with amphibolite layers. The grey porphyroclastic gneiss is similar to the Ponaganset gneiss known extensively in the region to the north, and we group this gneiss with the Ponaganset. The Ponaganset gneiss here appears to be intruded by the medium-grained Scituate gneiss, although the highly deformed nature of the rocks makes confident identification of contact relations difficult.

All the rocks here are strongly lineated ($355^0/10\text{-}15^0$N) and moderately foliated with a steep dip ($350^0/70^0$E). In thin section, the lineation in the coarse Scituate gneiss is defined by alternating elongate aggregates of recrystallized quartz and biotite. The biotite aggregates are thin and discontinuous, and have associated granular sphene and magnetite. Feldspars vary from equant, anhedral grains to somewhat elongate or tabular; microcline is somewhat undulose. The finer grained leucocratic gneiss has a highly equilibrated texture with equant quartz and feldspar grains with smooth, anhedral grain boundaries. Quartz c-axes show a strong preferred orientation pattern that is characteristic of gneisses in western Rhode Island and eastern Connecticut (Fig. 4).

The pervasive N-trending, shallowly plunging lineation seen here and at the previous stop is a dominant feature of the gneisses along the Rhode Island-Connecticut border (Fig. 3). The strong lineation is characteristic of the north-trending segment of the Hope Valley shear zone and appears to have formed as a stretching lineation related to a major component of right lateral shear on the shear zone (O'Hara and Gromet, 1985).

19.4	2.6	Beach Pond. Lunch stop. Resume trip eastbound on Route 165
26.4	7.0	Junction Route 3. Turn left onto Route 3 North
27.7	1.3	Junction Route 102. Turn left onto Route 102 North
35.3	7.6	Junction Route 117. Proceed straight on Route 102
38.7	3.4	Junction Route 114. Proceed straight on Route 102
41.7	3.0	Junction Route 94. Turn sharp left onto Route 94 North
45.7	4.0	Junction Route 6. Turn left onto Route 6 West

49.7 4.0

STOP 6 LINEATED PONAGANSET GNEISS

The Ponaganset gneiss is a large elongate late Precambrian plutonic body forming the western margin of the Esmond-Dedham terrane. The Ponaganset varies from a coarsely porphyroclastic biotite gneiss to fine grained leucocratic gneiss, both of which are represented in this outcrop. The coarse augen gneiss is highly lineated (N-trend, $10\text{-}15^0$N plunge) but weakly foliated. It is locally intruded by a leucocratic gneiss. Sharp contacts are observed, and the leucocratic gneiss shares the same strong lineation. Vein quartz and related pegmatoid bodies are present. A mullion-like structure appears to be weakly developed in the outcrop.

The large feldspar augen (up to 40 mm) commonly have asymmetric deformation tails when viewed on surfaces parallel to the lineation. The augen are circular, ovoid or tabular on surfaces normal to the lineation. Most asymmetric augen indicate right-lateral shear sense, although some with a opposite shear sense are present.

In addition to quartz, alkali feldspar, plagioclase and biotite, minor minerals in the coarse augen gneiss include hornblende, epidote, sphene, and rarer secondary muscovite. In thin section the lineation is defined by elongate aggregates of quartz and feldspar, and by trains of biotite and hornblende. Tails on feldspar augen are composed of finer recrystallized grains. Myrmekite is commonly developed around the margins of the augen. The leucocratic gneiss contains locally abundant secondary muscovite.

This locality is approximately 2 km from the surface trace of the HVSZ, and the rocks here are among the most highly deformed found along this segment of the boundary. More moderately deformed, coarse porphyritic granitic rocks occur further to the east and represent a reasonable protolith for the gneiss here.

53.2 0.5 **STOP 7 "SCITUATE" GRANITE GNEISS**

This is a medium-grained, pink biotite gneiss that is remarkably similar in appearance to the Devonian Scituate granite of central Rhode Island. Moore (1983) appropriately mapped this and other nearby granite gneisses as Scituate. Rb-Sr whole rock analysis, however, indicates a late Precambrian age. The similarity of this rock to typical Devonian Scituate granite again underscores the difficulty in distinguishing and separating late Precambrian and Devonian leucocratic gneisses in this region. We tentatively assign the rock here to the Hope Valley terrane on the basis of its occurrence to the west of quartzitic rocks of the Plainfield Formation, which we group with the Hope Valley terrane. On a lithologic basis, the rock could be equally well considered a somewhat leucocratic and non-porphyroclastic phase of the Ponaganset.

The gneiss has a strong, shallow-dipping foliation (NNW strike, 15^{o}W dip) and a subhorizonal NNW-trending lineation. Streaks of biotite help define the lineation and can be seen on foliation planes. A finer grained and more leucocratic gneiss is present low in the road cut on the south side of the road. It is slabby in appearence and grades upward into the coarse gneiss typical of the rest of the outcrops here. Greater shearing appears to have occurred in the finer grained gneiss, although it is unclear whether its fine grain size is the cause or the effect.

In thin section, quartz, perthitic alkali feldspar, plagioclase and biotite are accompanied by minor hornblende, allanite, and epidote. In contrast to other gneisses along the HVSZ, minerals in this gneiss have retained large amounts of intracrystalline strain. Quartz grains (0.1-2 mm) have high aspect ratios (5:1), sutured grain boundaries and intense undulose extinction. Recovery is very limited. Perthites have irregular shapes and only minor recrystallization about their margins. Tabular plagioclase have bent and microfaulted lamellae. These features all suggest lower grade conditions during deformation than at the other localities visited. It might be significant that this locality is somewhat west of the HVSZ (surface trace 4.5 km to the east) and quite close to the Lake Char fault (1 km to the west).

53.4	0.2	Take entrance ramp to I-395 North (old Route 52)
71.3	17.9	Lake Char on right
72.7	1.4	Take Exit 2 to Route 16 East
79.5	6.8	Town of Douglas, Massachusetts. Make left at intersection to stay on Route 16 East
81.5	2.0	Town of East Douglas. Continue East on Route 16
84.9	3.4	Junction Route 146. Enter Route 146 North.

85.6 0.7 **STOP 8 LINEATED PONAGANSET GNEISS**

This strongly lineated porphyroclastic biotite gneiss has a well developed rod or pencil structure. The lineation (NNE trend, 25-30^{o}N plunge) is defined by rods of quartz and feldspar and streaks of biotite. A foliation (110^{o}/30^{o}N) is also present.

The linear fabric seen here is a regionally extensive characteristic of the N-striking segment of the HVSZ. This outcrop is 32 km north of Stop 6, and 55 km north of Stops 4 and 5 where we first observed strongly lineated Ponaganset and Scituate gneisses.

90.8 5.2 **STOP 9 GREY AND PINK PONAGANSET (?) GNEISSES SEPARATED BY AMPHIBOLITE LAYERS**

Two texturally distinct gneisses are present here: a fine grained (<2 mm) grey gneiss with coarse white to pink feldspar augen and a medium grained (1-10 mm) pale pink leucocratic gneiss. The grey gneiss consists of alkali feldspar, quartz, biotite, chlorite, hornblende, granular epidote and sphene, opaque and minor secondary muscovite. The pink gneiss has a similar mineralogy but lacks hornblende. The gneisses occur separately as large slabs several meters thick that are bounded above and below by highly stretched amphibolite layers. All these rocks have a strong foliation (95^{o}/20^{o}N) and a weak lineation (N/20^{o}N). The gneisses typically become very fine grained and laminated within 10 to 20 cm of the amphibolite layers. The fine grained margins of the slabs are seen in thin section to be totally recrystallized into a fine grained (.05-.1 mm) equigranular mylonite that has the same mineral assemblage as the slab interiors. That is, the fine grained margins are more highly sheared equivalents of the interiors.

The outcrop relationships observed here provide convincing evidence for the tectonic juxtaposition of two texturally different gneisses. The juxtaposition appears to be lithologically controlled by the amphibolite layers, which are more competent than the quartzofeldspathic gneisses they separate. It is important to note that the strike of the foliation and the sheared amphibolite layers are approximately perpendicular to the NNE strike of the HVSZ. We suspect that the N-dipping sheared amphibolite layers mark zones of south-directed thrusting within the Esmond-Dedham terrane. Asymmetric deformation tails on the feldspar augen are consistent with this. The origin of the south-directed thrusts may be related to similar thrusts recognized along the southern segment of the HVSZ. That is, as the southern margin of the Esmond-Dedham terrane overrode the Hope Valley terrane, the Esmond-Dedham terrane came under approximately N-S oriented compression and developed internal thrusts sympathetic to the major thrust along the southern segment of the HVSZ. It is notable that other similarly oriented thrusts have been recognized within the Esmond-Dedham terrane (e.g., the thrust at Snake Hill, Rhode Island: R. Kemp and N. Rast, pers. comm.).

The two gneisses here are considered to be part of the Ponaganset gneiss. The grey porphyroclastic gneiss is quite similar to (although more sheared than) typical Ponaganset. In other outcrops nearby, the medium grained leucocratic gneiss is observed to grade without break into a porphyroclastic gneiss similar to typical Ponaganset. This feature and its sharp contrast with Hope Valley alaskite observed immediately to the north (Stop 10), lead us to group it with the Ponaganset.

A comparison to the new Massachusetts state map (Zen et al., 1983) indicates that the grey gneiss with feldspar augen was mapped as Ponaganset gneiss, but that the pink leucocratic gneiss has been mapped as "Scituate" gneiss (quotations added). Radiometric dates of "Scituate" gneiss in this area give late Precambrian ages (Zartman and Naylor, 1984). It appears appropriate to abandon the use of the name Scituate for these rocks as it is now known that the type Scituate granite is Devonian. Several problems arise when considering how the leucocratic "Scituate" gneisses relate to the other rocks of the region, and whether they should be assigned to the Esmond-Dedham or Hope Valley terranes. On the Massachusetts map, "Scituate" was considered gradational with Hope Valley alaskite, but "Scituate" also contained some rocks previously mapped with the Northbridge gneiss (usage now abandoned, with most of the Northbridge asigned to the Ponaganset gneiss). In our opinion, the leucocratic gneisses grouped as "Scituate" on the Massachusetts map include some rocks that should be considered as part of the Ponaganset gneiss (such as those here) and other rocks that probably are associated genetically with the Hope Valley alaskite. Unfortunately, as was made clear in our work further south, the assignment of leucocratic granite gneisses to specific units on the basis of field and petrographic characteristics can be subjective and inaccurate.

91.6 0.8 Take Exit ramp.

91.7 0.1 **STOP 10 HOPE VALLEY ALASKITE**

This outcrop of Hope Valley alaskite is a medium grained, leucocratic buff-colored gneiss. It has a uniform, almost bedded appearance over the extent of the exposure. The bedded appearance is due to parting planes that are parallel to a strong foliation in the gneiss ($080^{0}/24^{0}$N). Fine grained muscovite is common on the parting planes. In thin section, the gneiss consists of strain free quartz, microcline, lesser plagioclase, minor biotite, sphene, muscovite and opaques.

The distinctive planar parting seen in this exposure is not present in the metaplutonic rocks of the last stop, but well developed parting is seen in several other areas mapped as Hope Valley alaskite and related rocks (e.g., Hope Valley alaskite near Framingham and Westborough, Massachusetts, and the Potter Hill granite gneiss in the Ashaway quad (Feininger, 1965), Rhode Island and Connecticut). Other Hope Valley alaskite exposures have a more massive, unstratified appearance (e.g., those at Stop 2). This suggests that the planar parting reflects a primary feature, such as layering in an originally stratified unit. A reasonable protolith for the rocks with prominant parting would be for example, a sequence of rhyolite flow and/or pyroclastic to volcaniclastic layers, whereas more massive Hope Valley rocks probably had plutonic protoliths.