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MID-PALEOZOIC CALC-ALKALINE IGNEOUS ROCKS OF THE NASHOBA BLOCK AND MERRIMACK TROUGH

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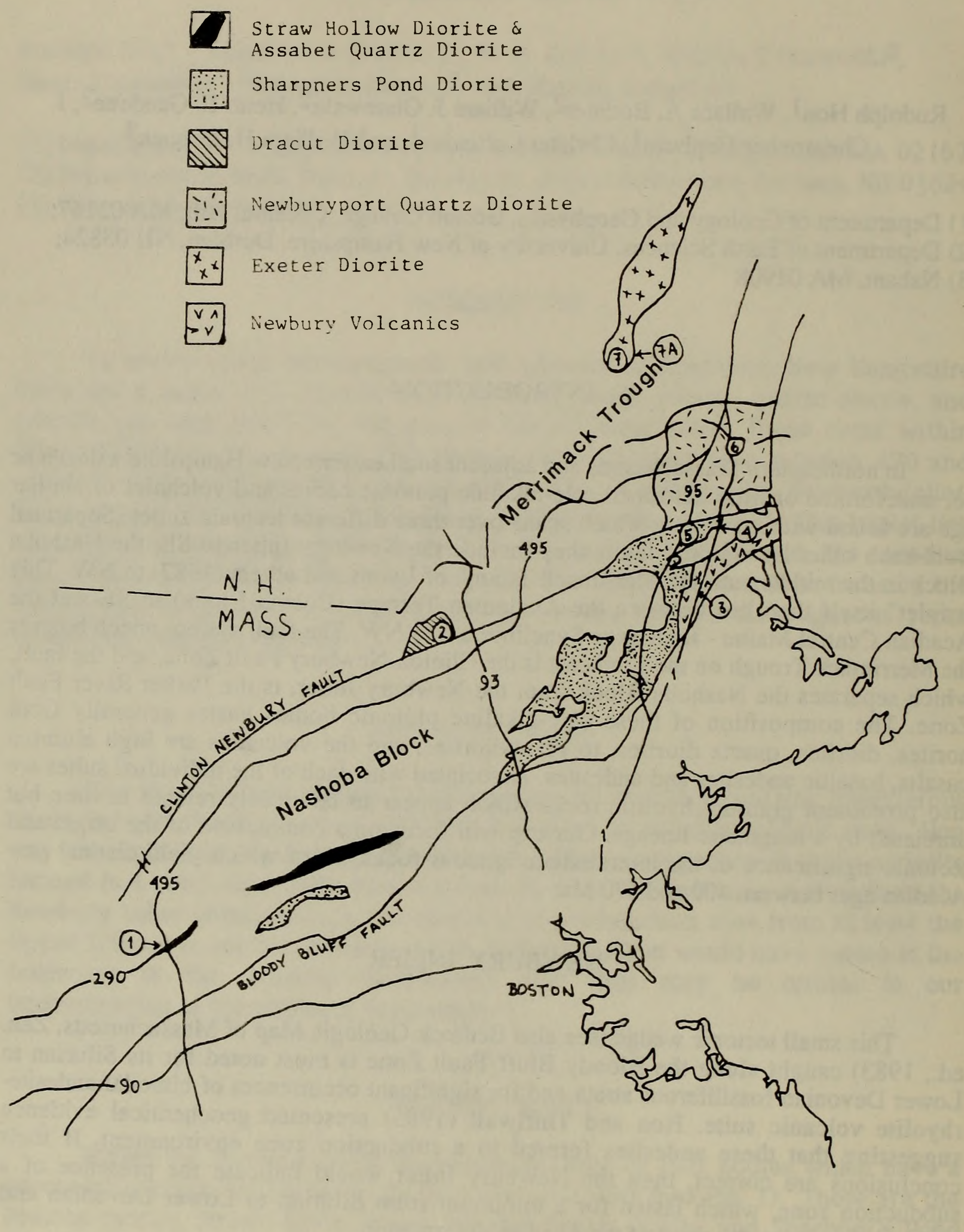
INTRODUCTION

In northeastern Massachusetts and adjacent southeastern New Hampshire a dozen or so, undeformed or little deformed calc-alkaline plutonic bodies and volcanics of similar age are found within a region which spans over three different tectonic zones. Separated from each other by regional faults they include the Newbury Inlier to SE, the Nashoba Block in the middle, and the Merrimack Trough of Lyons and others (1982) to NW. This "triplet" itself then lies between the Avalonian Terrane (Boston Block) to SE and the Acadian Central Maine - Kearsarge Synclinorium to NW. The fault system which bounds the Merrimack Trough on the southeast is the Clinton-Newbury Fault Zone, and the fault, which separates the Nashoba Block from the Newbury Inlier, is the Parker River Fault Zone. The composition of these calc-alkaline plutonic bodies varies generally from norites, diorites, quartz diorites, to granodiorites, and the volcanics are high alumina basalts, basaltic andesites and andesites. Associated with each of the individual suites are also prominent granitic/rhyolitic rocks which appear to be closely related in time but unrelated by a magmatic lineage. Our trip will focus on a comparison of the origin and tectonic significance of the intermediate igneous rocks, all of which yield distinct pre-Acadian ages between 400 and 470 Ma.

NEWBURY INLIER

This small tectonic wedge (see also Bedrock Geologic Map of Massachusetts, Zen, ed., 1983) caught along the Bloody Bluff Fault Zone is most noted for its Silurian to Lower Devonian fossiliferous strata and for significant occurrences of bimodal andesite-rhyolite volcanic suite. Hon and Thirlwall (1985) presented geochemical evidence suggesting that these andesites formed in a subduction zone environment. If their conclusions are correct, then the Newbury Inlier would indicate the presence of a subduction zone, which lasted for a minimum from Silurian to Lower Devonian and ceased just prior to the onset of the Acadian deformation.

FIGURE 1. Stop locations.



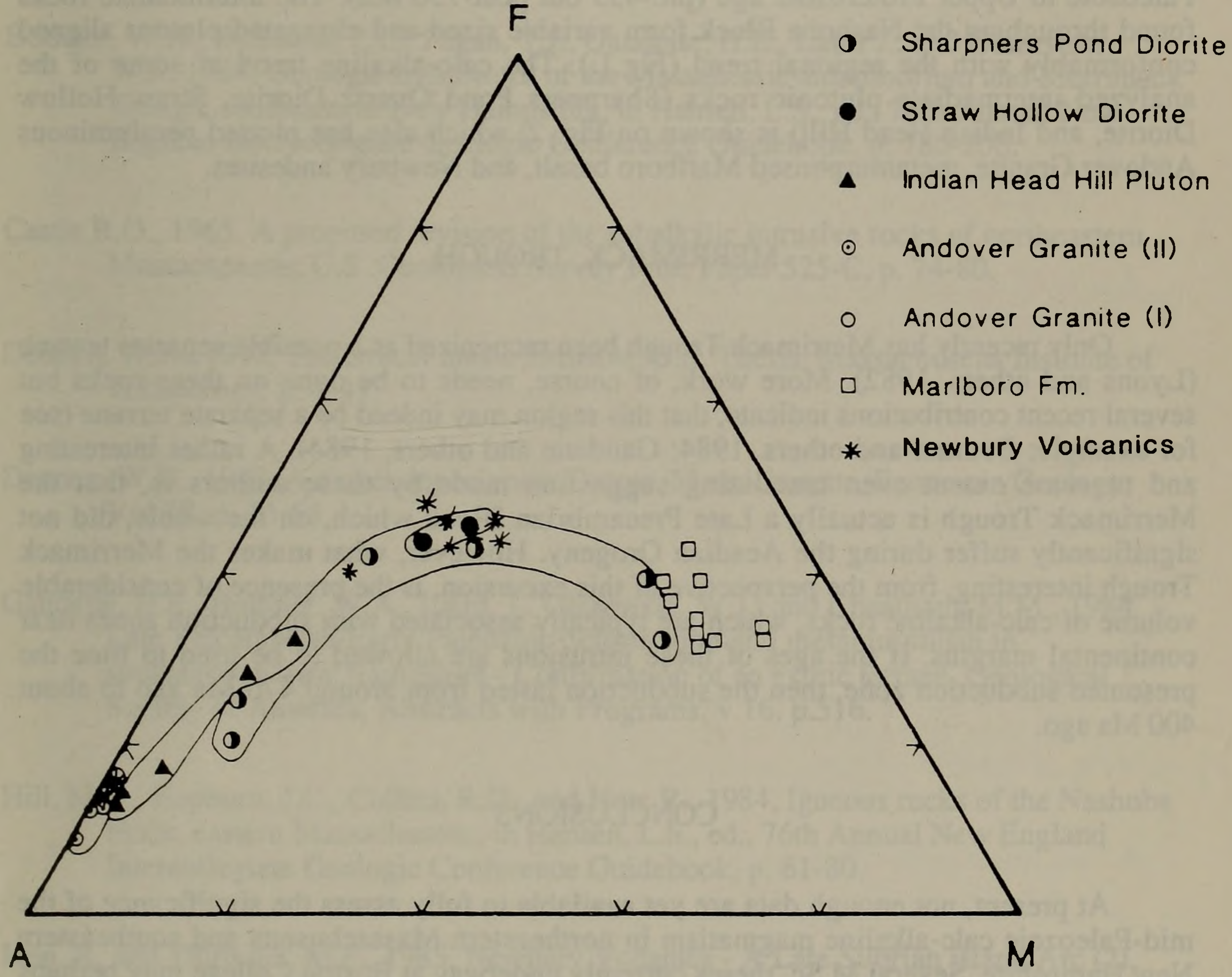


FIGURE 2 AFM Diagram Nashoba Block.

NASHOBA BLOCK

About half the block is underlain by little deformed or undeformed calc-alkaline plutonic rocks and by contemporaneous peraluminous and metaluminous granites yielding radiometric ages of 402 to 455 Ma. The rest of the Nashoba block consists of stratified rocks which are mostly metamorphosed volcanics and volcanogenic sediments of Lower Paleozoic to Upper Proterozoic age (pre-455 but post-730 Ma). The intermediate rocks found throughout the Nashoba Block form variable sized and elongated plutons aligned conformably with the regional trend (Fig.1.). The calc-alkaline trend of some of the analyzed intermediate plutonic rocks (Sharpners Pond Quartz Diorite, Straw Hollow Diorite, and Indian Head Hill) is shown on Fig. 2. which also has plotted peraluminous Andover Granite, metamorphosed Marlboro basalt, and Newbury andesites.

MERRIMACK TROUGH

Only recently has Merrimack Trough been recognized as a possible separate terrane (Lyons and others, 1982). More work, of course, needs to be done on these rocks but several recent contributions indicate, that this region may indeed be a separate terrane (see for example: Bothner and others, 1984; Gaudette and others, 1984). A rather interesting and to some extent even tantalizing suggestion made by these authors is, that the Merrimack Trough is actually a Late Precambrian Block which, on the whole, did not significantly suffer during the Acadian Orogeny. However, what makes the Merrimack Trough interesting, from the perspective of this excursion, is the presence of considerable volume of calc-alkaline rocks, which are typically associated with subduction zones near continental margins. If the ages of these intrusions are allowed to be used to time the presumed subduction zone, then the subduction lasted from around 470 Ma ago to about 400 Ma ago.

CONCLUSIONS

At present, not enough data are yet available to fully assess the significance of the mid-Paleozoic calc-alkaline magmatism in northeastern Massachusetts and southeastern New Hampshire. Several M.Sc. theses currently underway at Boston College may perhaps provide some of the key data in the near future.

In conclusion, we would like to suggest that the mid-Paleozoic calc-alkaline suite may be indicative of a long lasting (appr. 70 Ma) subduction zone which preceeded and might have ultimately led to a continental collision - the Acadian Orogeny. The position of the arc axis probably was not at the same place all the time but most likely migrated from place to place leaving behind plutonic bodies of discrete ages. It would be premature at this time to argue for the exact position or the polarity of this subduction zone, but the essence provided by the mid-Paleozoic calk-alkaline suite is, that such a subduction zone might have existed and that it was most likely responsible for the high temperature regime causing the widespread crustal anatexis.

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ROADLOG FOR MID-PALEOZOIC CALC-ALKALINE IGNEOUS ROCKS OF THE NASHOBA BLOCK AND MERRIMACK TROUGH.

ITINERARY

Mileage: Part I.

0.0 Assembly point and Stop #1. Meet at junction of Interstates I-290 and I-495 just north of Marlborough, Mass. at 10 a.m. Meet on S.E. side of this large interchange. If coming north on I-495, take exit 25A "to 85, Marlborough", park on shoulder of ramp just before it merges with I-290 by silver colored electric box. If coming east on I-290, continue over I-495 and park just east of where the ramp from I-495N, joins I-290 extension "to 85, Marlborough". We will leave this exposure at 11 a.m.

STOP #1: STRAW HOLLOW DIORITE or ASSABET QUARTZ DIORITE
The large exposures at this cloverleaf are complex and show a wide variety of features. Our principal purpose in stopping here is to examine the Straw Hollow Diorite or Assabet Quartz Diorite along the north side of the interchange. The diorite here is characteristic of the smaller bodies of Silurian calc-alkaline plutonic rocks in the Nashoba Block. Foliated and nonfoliated, or more weakly foliated varieties of hornblende-quartz diorite are present here. They have been intruded by garnet-bearing pegmatites associated with the younger phase of the Andover Granite (approximately 415 m.y., Hill et al., 1984). Sillimanite schists of the Nashoba Fm. are exposed along the south side of the cut. Blastomylonites believed to be associated with the Assabet River fault zone are also exposed here and will be briefly examined as an example of the type of deformation common along some of the larger shear zones in the Nashoba Block. If time permits, a relatively late brittle shear zone cutting the Straw Hollow, with carbonate mineralization, will be visited to provide contrast with the earlier ductile deformation.

To proceed to Stop 2 we will need to turn around and head north on I-495. Continue straight ahead on "to 85" east.

1.0 At traffic light, Fitchburg Street, exit to the right.

1.1 By entrance to Assabet Valley Regional Vocational High School, turn around and retrace route to traffic light.

1.2 Turn left (west) on "to 495-290".

2.2 Take Exit 26B, I-495 north toward Lowell.

2.8 Merge with I-495 north.

3.0 Cross Assabet River.

3.8	Excellent exposures of Nashoba Fm. gneisses and migmatites for next several miles, continue north toward Lowell.
25.8	Rest area on right. Odometer check.
26.7	Leave I-495 at Exit #36, "Lowell Connector". Exit to right.
27.4	Turn right, follow Exit 36, Lowell Connector.
28.1	Continue straight on Lowell Connector.
28.8	Continue toward Lowell Center.
29.9	Road ends, turn left toward Lowell Center.
30.1	Continue straight past Courthouse on right.
30.2	Bear right, follow one way.
30.4	Bear left, continue on one way.
30.45	At light, continue straight, now on Central St.
30.6	At light, Y intersection, bear right on Prescott St.
30.7	At light, turn right on E. Merrimack St.
30.8	Federal Building on left.
31.0	Continue straight.
31.1	At light, turn left on Routes 38 and 110.
31.3	Cross Merrimack River and bear right on Route 110 east, you are entering the Merrimack Trough.
	NOTE: If you should for any reason deviate from the Roadlog, find your way to Route 110 east on the northern side of Merrimack River and proceed 4.0 miles toward the turn-off to George Brox, Inc. quarry.
31.4	Continue on Route 110 east toward Lawrence.
32.2	Dracut town line.
34.9	Cross under power lines.
35.3	Turn left onto side road at sign for George Brox, Inc., proceed up hill. WATCH FOR TRUCKS!

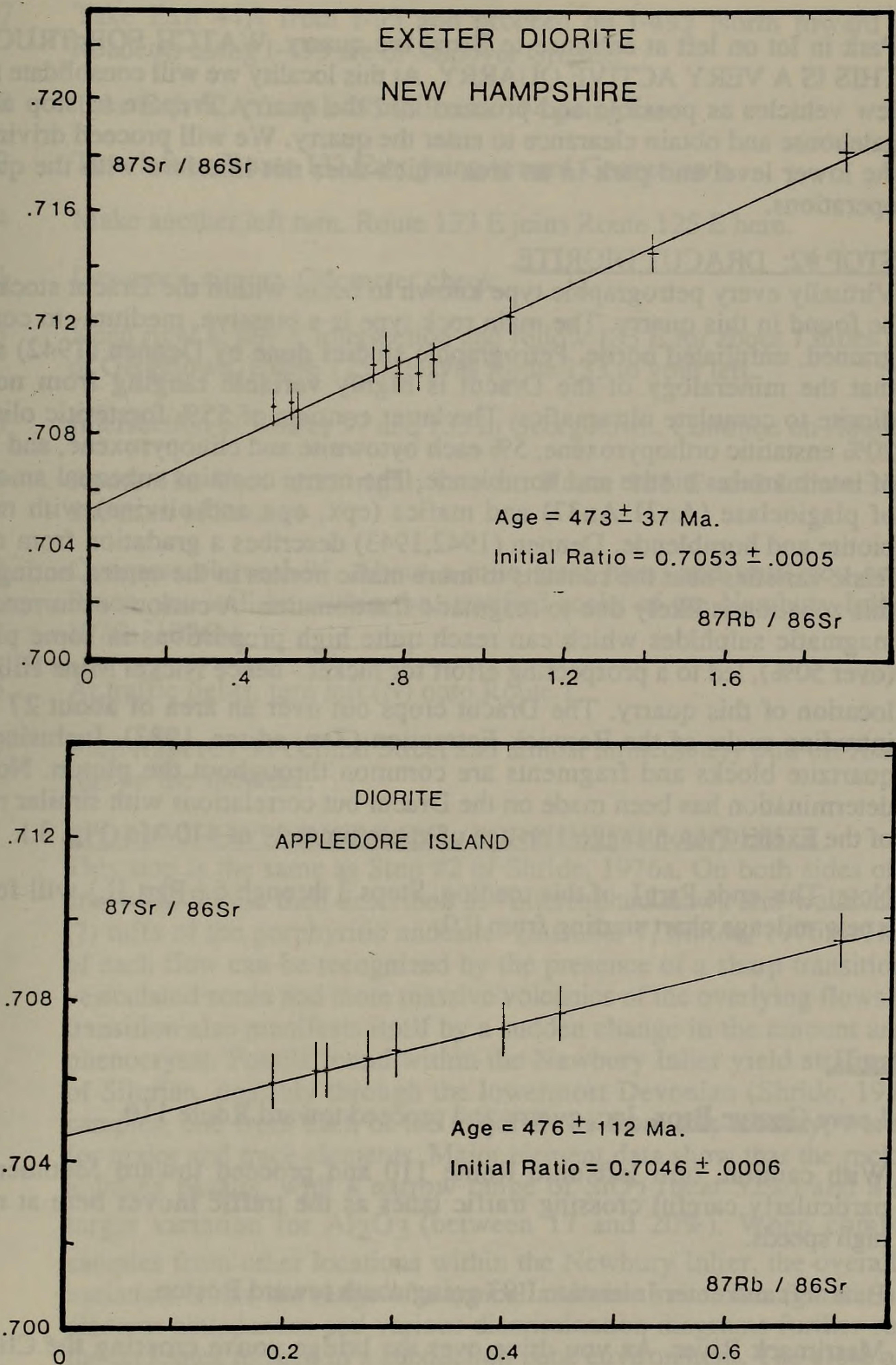


FIGURE 3 Rb/Sr Isochrons for Exeter and Appledore Island Plutons

Rb Decay Constant = 1.42×10^{-11} Years.

35.7 Park in lot on left at entrance to Brox, Inc quarry. WATCH FOR TRUCKS- THIS IS A VERY ACTIVE QUARRY. At this locality we will consolidate to as few vehicles as possible and proceed into the quarry. Prepare to stop at the gatehouse and obtain clearance to enter the quarry. We will proceed driving to the lower level and park in an area which does not interfere with the quarry operations.

STOP #2: DRACUT DIORITE.
Virtually every petrographic type known to occur within the Dracut stock can be found in this quarry. The main rock type is a massive, medium- to coarse-grained, unfoliated norite. Petrographic studies done by Dennen (1942) show that the mineralogy of the Dracut is highly variable ranging from noritic diorite to cumulate ultramafics. The latter consists of 55% forsteritic olivine, 20% enstatitic orthopyroxene, 5% each bytownite and clinopyroxene, and 15% of intercumulus biotite and hornblende. The norite contains subequal amounts of plagioclase (An71-An37) and mafics (cpx, opx and olivine) with minor biotite and hornblende. Dennen (1942,1943) describes a gradation from more felsic varieties near the contacts to more mafic norites in the center, noting that this zonation is likely due to magmatic fractionation. A curious occurrence of magmatic sulphides which can reach quite high proportions in some places (over 50%), led to a prospecting effort for nickel - hence Nickel Mine Hill, the location of this quarry. The Dracut crops out over an area of about 27 mi^2, intruding rocks of the Berwick Formation (Zen, editor, 1983). Inclusions of quartzite blocks and fragments are common throughout the pluton. No age determination has been made on the Dracut but correlations with similar rocks of the Exeter Pluton suggest an age of approximately of 470 Ma (Fig. 3.).

Note: This ends Part I. of this roadlog. Stops 3 through 6 (Part II.) will follow a new mileage chart starting from 0.0.

Mileage: Part II.

0.0 Leave George Brox, Inc. quarry and proceed toward Route 110.

0.3 With caution, turn left onto Route 110 and proceed toward Methuen. Be particularly careful crossing traffic lanes as the traffic moves here at rather high speeds.

3.2 Bear left and enter Interstate I-93 going south toward Boston.

3.7 Merrimack River. As you drive over the bridge you're crossing the Clinton-Newbury Fault again. Leaving behind the Merrimack Trough, you will re-enter the Nashoba Block, here underlain by Andover Granite.

6.7 Take Exit 44A from I-93 and proceed on I-495 North toward Lawrence. Roadcuts along I-495 are of Andover Granite.

9.8 Take Exit 42A from I-495 to Route 114 going east.

11.2 Turn left on Route 133 East going toward Georgetown.

11.4 Make another left turn. Route 133 E joins Route 125 E here.

14.1 Lawrence airport. Odometer check.

14.3 Keep right at this Y intersection and follow 133 E for about 7 miles in direction of Gergetown. Route 125 E leaves Route 133 to your left.

21.3 Intersection of Routes 97 and 133 in Georgetown. Continue on Route 133 East.

21.5 Route 133 East turns right; stay on Route 133 E and follow signs in the direction of Route 1.

23.2 Overpass above I-95. About a mile from here, and until you cross Parker River, you will be within the stratified rocks of the Newbury Inlier (Shride, 1976a, 1976b)

26.5 At traffic lights, turn left (N) onto Route 1.

28.9 Turn right (E) on Central Street and almost immediately pull off road and park cars on the shoulder.

STOP #3: NEWBURY INLIER - PORPHYRITIC ANDESITE.

This stop is the same as Stop #2 of Shride, 1976a. On both sides of the street are, what Shride then described as "intercalated flows and water-laid ash-fall (?) tuffs of the porphyritic andesite" (member 7, Shride, 1976a). Here the top of each flow can be recognized by the presence of a sharp transition between vesiculated zones and more massive volcanics of the overlying flows. The same transition also manifests itself by a sudden change in the amount and types of phenocrysts. Fossils found within the Newbury Inlier yield stratigraphic ages of Silurian, possibly through the lowermost Devonian (Shride, 1976b). Four samples, one from each of the major flows from this locality, were analyzed for major and trace elements. Major element data show that the rocks are high alumina basalts, with a narrow range of SiO_2 (near 52%) and a somewhat larger variation for Al_2O_3 (between 17 and 20%). When combined with samples from other locations within the Newbury Inlier, the overall observed variation is like the range of a typical andesitic suite of magmatic arcs. Trace element abundances and various discrimination diagrams further support that the andesites formed in a subduction zone environment. The close association of the basaltic andesites with rhyolites and microgranites within the Newbury Inlier suggests two separate, but contemporaneous, magma systems. Magma mixing between these two respective end-members may have produced a large array of intermediate rocks such as the Sharpners Pond Quartz Diorite, which will be seen at the next stop.

Turn around, please use EXTREME CAUTION, and prepare to enter Route 1 going north.

29.1 Turn right (N) onto Route 1.

29.4 Newbury town line.

30.5 Parker River bridge. Parker River here follows the Parker River Fault, which separates the Newbury Inlier from the Sharpners Pond Quartz Diorite of the Nashoba Block. Exposures north of the bridge are of pink granite (Sgr of Zen, editor, 1983), and quartz diorite of the Sharpners Pond.

32.8 Turn left on Middle Road, following the sign indicating direction toward Byfield. Stop almost immediately near outcrops on both sides of the road.

STOP #4: SHARPNERS POND QUARTZ DIORITE.
Exposures of the Sharpners Pond Quartz Diorite along both sides of Middle Road show extreme variability in mineralogy, texture, and structure, quite typical for rocks of this general area. Note the complex brecciation and "pillowing" of the more mafic types within the granitic matrix. Our geochemical study shows that the granitic rocks and the mafic to intermediate rocks are genetically unrelated and, in addition, there is some evidence that this granitic component is virtually identical to the granitic masses mapped as pinkish biotite granite near Byfield (Sgr of Zen, editor, 1983). It seems likely that the granitic rocks represent an anatectic melt which formed in response to higher temperatures caused by the intrusions of the more mafic magmas. Such a contemporaneous two-magma system might have interacted in a variety of ways resulting in structures similar to the ones shown by these exposures.

The Sharpners Pond Pluton is a body about 60 mi^2 large, found largely between the towns of Wilmington and Newbury. Castle (1965) identified within the pluton three basic petrographic phases: hornblende diorite, hornblende-biotite tonalite, and biotite tonalite which tend to predominate in a given region, but which show gradational transition from one type to another. Hornblende diorite is almost certainly a cumulate rock consisting of approx. equal amounts of plagioclase (andesine to sodic labradorite) and hornblende (with occasional clinopyroxene cores), and minor amounts (0 to 10%) of biotite. Sphene is a characteristic accessory seen in almost all hand specimens. All other phases of the Sharpners Pond have the same mineralogy (with the exception of minor alkali feldspar) but in varied proportions.

Continue (W) on Middle Road.

33.2 Take sharp turn (N) on unmarked road (Highfield Road).

33.9 Turn left (W) on Scotland Road. More exposures of Sharpners Pond.

35.9 Pass under I-95.

36.2 Make right turn on the side road, and immediately park alongside the road. Walk back few hundred feet toward the roadcuts along the ramp to I-95 South. NOTE: A similar set of outcrops can also be seen along the ramp to I-95 going north.

STOP #5: SHARPNERS POND QUARTZ DIORITE.

These exposures further accentuate the features observed at the previous stop. Well developed magmatic "pillowing", magmatic brecciation and cementing, several stages of subsequent mafic magma intrusions of different types, and magma mixing can all be seen here. Such complex features are not necessarily developed everywhere. As a matter of fact, a short distance west of here and further toward the SW, the rocks are much more uniform in their appearance and more homogeneous in their mineralogy. Age determination on two samples from localities nearby, by $^{206}Pb/^{207}Pb$ on zircons, gave concordant ages of 430+/-5 Ma (Zartman and Naylor, 1984). This age is nearly identical to stratigraphic ages of Upper Silurian obtained for the Newbury Inlier. Considering the additional fact that the Newbury volcanics are also a bimodal suite consisting of rhyolites and andesites, it is then possible to correlate the Newbury inlier as a down faulted block carrying with it the volcanic equivalents of the Sharpners Pond Pluton.

Turn around, drive back under I-95, turn left and enter I-95 going north toward Amesbury.

37.4 Crossing the Clinton-Newbury Fault once again. You are back in the Merrimack Trough. Rock exposures along the highway are of Newburyport Quartz Diorite.

40.4 Merrimack River.

41.1 Take exit from I-95 onto Route 110 (E) in the direction of Salisbury.

43.5 Turn left onto Route 1 (N).

43.6 Set of blinking traffic lights. Bear left on Route 1, and proceed carefully through the intersection.

44.3 Turn right (E) on Gerrish Road, just ahead of railroad overpass.

44.6 Make sharp left turn (N) onto unmarked Seabrook Road.

45.0 Small abandoned quarry on your left. Park in the quarry.

STOP #6: NEWBURYPORT COMPLEX.

This stop is in the same place as STOP #2. of Shride (1971). The Newburyport complex forms a composite pluton which consists of somewhat older tonalites and granodiorites to the SE and of younger porphyritic granites to the NW.

Samples taken from this quarry, which lies within the nonporphyritic tonalites and granodiorites, yielded a $^{207}Pb/^{206}Pb$ zircon age of 466 Ma (Zartman and Naylor, 1984). The porphyritic granite by the same technique gave an age of 437 Ma. The 466 Ma age is remarkably similar to ages obtained for the Exeter and Appledore diorites (Fig. 3) suggesting the presence of a Middle Ordovician magmatic province within the Merrimack Trough. Rocks exposed at this locality are medium grained and are, according to Shride (1971), in the middle of a compositional range defined by mineralogical variations of mafics, feldspars, and quartz. The mafic minerals (near 20%) include biotite and hornblende; sphene is a dominant accessory. A characteristic feature of the Newburyport observed by Shride (1971) is a positive correlation between the frequency of ovoid dioritic inclusions and the more mafic appearance of the host rock. This correlation may be interpreted as evidence for a two-magma system within the Newburyport magma chamber and an incomplete magma mixing between the silicic and more mafic magma type.

After a U-turn, retrace the directions back to Route 1.

45.4 Turn right (W) on Gerrish Road.

45.8 Turn right (N) on Route 1 (Lafayette Road) and proceed under the railroad bridge.

46.6 Traffic lights. Bear left and follow signs in the direction of I-95 going to New Hampshire.

47.5 Continue straight, rejoin I-95 North, and proceed toward Hampton - Exeter Toll Booth exit from I-95 in New Hampshire.

Note: This ends Part II. of this field trip. The upcomming Part III. presents road log to Stops 7 and 7A with fresh start from 0.0 beginning at Hampton - Exeter Toll Both exit off I-95.

Mileage: Part III.

0.0 Tollgate ($0.25 toll). Follow exit ramp to Route 51/101W.

3.6 Traffic lights.

4.0 Pass exit to Route 108 (to Exeter and Newmarket, N.H.)

5.4 Pass exit to Route 85 (to Newfields). Large road cut along Route 101 on your left (S) just beyond the undepass beneath Route 85 exposes contact metamorphosed Kittery Formation. Possible stop (Stop 7A) on the return to I-95.

6.2 Pull off the highway and park near the top of this small hill. 0Exposures of the Exeter Diorite occur on both sides of the highway over the next half mile either as 50 to 100 m long glacially-smoothed pavements or blasted joint surfaces several meters high. The safest crops are on the north (right) side of the highway.

STOP #7: EXETER PLUTON.

The diorite here is fairly typical of the types seen within the Exeter Pluton over its entire 32 by 7 km northeast trending body. It extends from the southernmost exposures, seen here near the town of Exeter, toward Rollingsford, NH. Farther west are exposures of gabbro, that contain plagioclase, orthopyroxene, biotite, minor olivine, and secondary uralitic amphibole. To the northeast, rocks of the Exeter Pluton become gradually more felsic, but never granitic. Over much of its extent, it is typically "salt and pepper", medium gray, medium- to coarse-grained, unfoliated diorite and quartz diorite. Frequent aplite dikes, some pegmatitic, parallel joints, and are sometimes offset by minor faults. Xenoliths of the surrounding Kittery and Eliot Formations are common, particularly near the margins and in areas interpreted to represent the original roof zone (better illustrated in the center of the pluton in Durham). The xenoliths commonly show variable degrees of digestion and often emphasize the carbonate content by the development of epidote, diopside, and occasional grossularite as elongate pods (concretions?). More pelitic inclusions commonly contain coarse, anhedral, poikiloblastic biotite, and small hypersthene granules.

The diorite here contains subequal amounts of plagioclase (3-5 mm subhedra, An35-50), biotite, pyroxenes, amphiboles, quartz (10-15%), and minor magnetite. Comagmatic mafic clots usually 15 - 20 cm long contain abundant biotite, pyroxenes, amphibole, and minor plagioclase. In most thin sections of the Exeter, plagioclase subhedra are normally zoned, very strongly near the contacts with the Merrimack Group. Hornblende is largely altered to chlorite, pyroxene (both clinopyroxene and orthopyroxene occur) remains unaltered, and biotite is slightly chloritized and commonly displays sagenitic rutile. Quartz is invariably interstitial; microcline is occasionally present. Little chemical work has been published on the Exeter Pluton. Preliminary work indicates that the varied body averages 56% silica. Gaudette and others (1984) reported a Rb/Sr whole rock age of 473+/-37 Ma (0.7053+/-0.0005) for the Exeter (Fig.3.), which is consistent with the nearby Newburyport Quartz Diorite, and smaller diorite bodies near Portsmouth and on the Isles of Shoals (Appledore Island data on Fig.3.). The age of these bodies constrains the age of the Merrimack Group in coastal New Hampshire as pre-Middle Ordovician. Other evidence suggests a Late Proterozoic age (Bothner and others, 1984).

Proceed in the same direction toward the next intersection.

7.0 Traffic lights, turn left towards Exeter (a U-turn if possible) and retrace route to I-95.

8.2 STOP 7A: CONTACT METAMORPHOSED KITTERY FORMATION. (Optional stop). If time and interest remains, we can make a short stop at the large outcrop of the contact metamorphosed Ordovician to Precambrian(?) Kittery Formation exposed on the west side of the Route 85 bridge. The outcrop contains brittle, purplish-brown quartzite and pelitic hornfels, and is less than 1 km from the contact with the Exeter Pluton. The actual contact is not exposed here. The quartzite occurs in beds 30 to 50 cm thick intercalated with 5 - 10 cm pelitic hornfels (originally phyllite) layers. Occasional calc-silicate bands occur within the quartzite. The surface facing the highway is strongly slickensided. On the top of the outcrop, porphyroblasts of probable cordierite (now retrograded to white mica), form noticeable knots 1-10 mm across in some pelitic layers. Elsewhere at the contact, hypersthene is developed within the pelitic portions of the Kittery. They likewise show retrograde alteration. It is therefore likely that the Kittery, regionally metamorphosed before the emplacement of the Exeter, was contact metamorphosed some 473 Ma ago, and then mildly metamorphosed during the Acadian or Alleghanian events.

Continue back to I-95. Proceed north to Lewiston, Maine

End of Part III. and end of field trip.

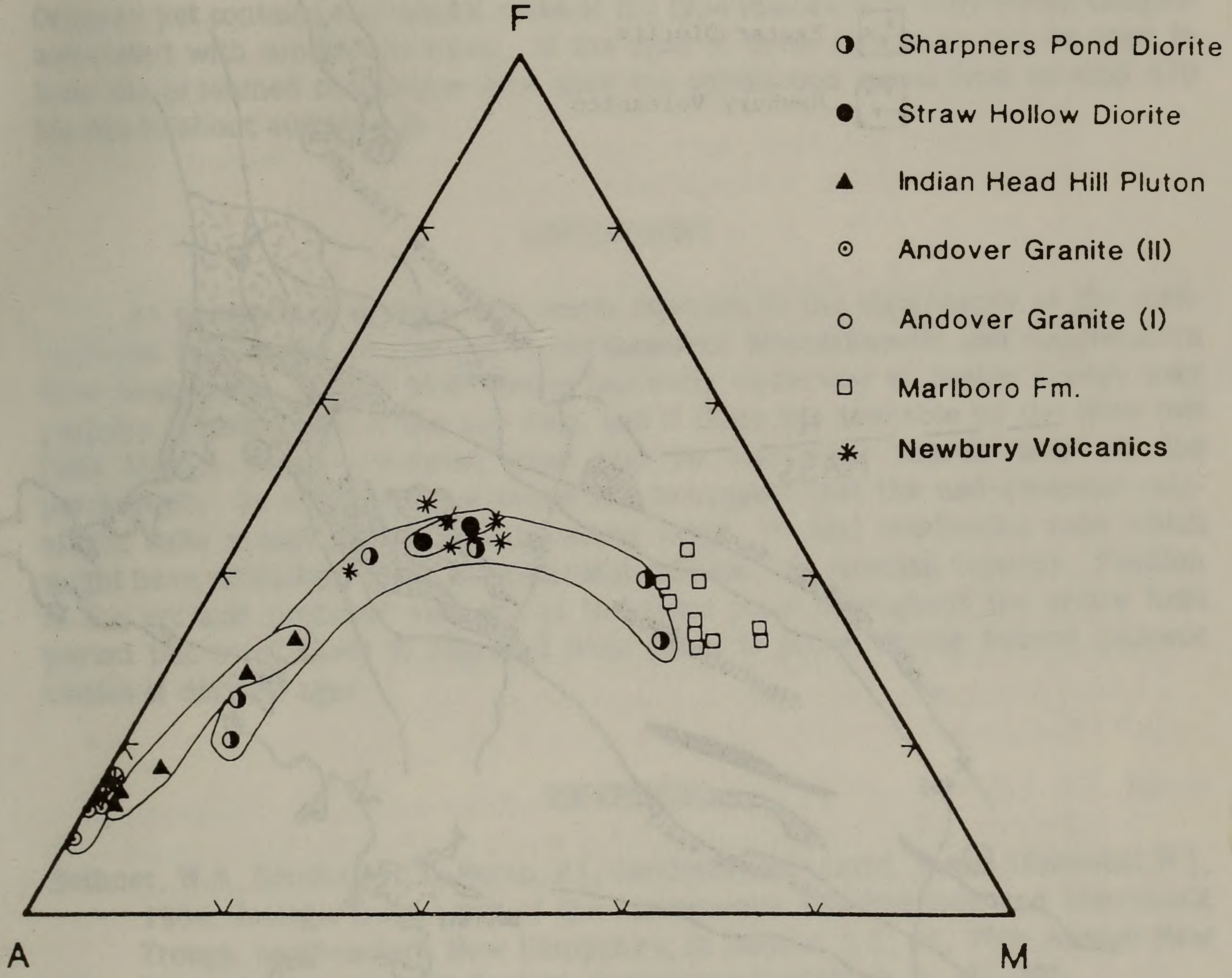
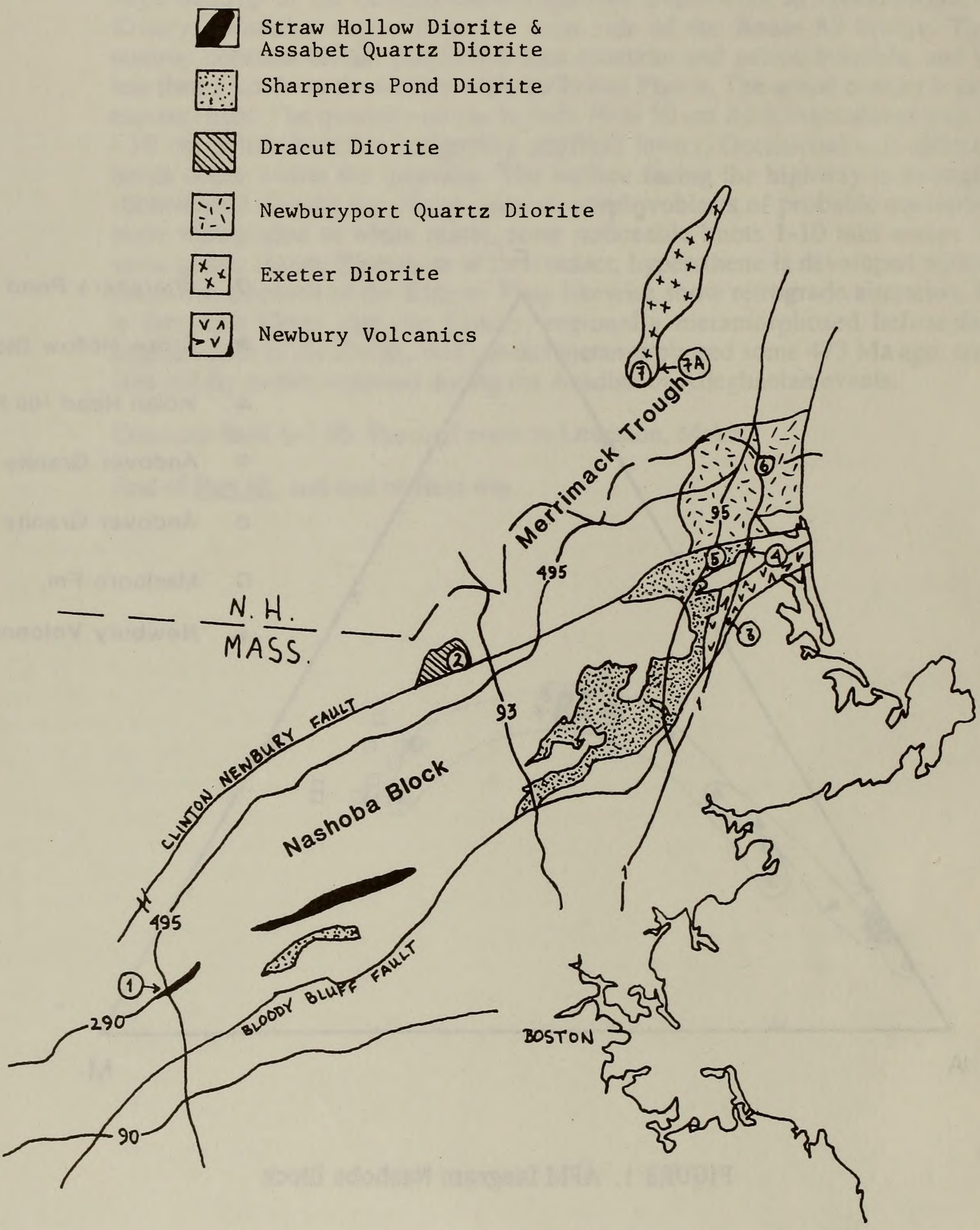


FIGURE 1. AFM Diagram Nashoba Block

FIGURE 2. Stop Locations



MERRIMACK TROUGH

Merrimack Trough has only recently been recognized as a seperate terrane (Lyons and others, 1982). More work needs to be done but many recent contributions indicate that this region is indeed a separate terrane (see for example: Bothner and others, 1984; Gaudette and others, 1984). One of the rather interesting and tantalizing suggestions is that the Merrimack Trough is in fact an old Precambrian Block which suffered insignificant deformation during the Acadian Orogeny yet contains calc-alkalic rocks of the type indicative of continental margins associated with subduction zones. If the ages of these intrusions can be used to time the presumed subduction zone then the subduction lasted from around 470 Ma ago to about 400 Ma ago.

CONCLUSIONS

At present not enough data exists relevant to the significance of the mid-Paleozoic calc-alkalic magmatism in northeastern Massachusetts and southeastern New Hampshire. Several M.Sc. theses currently underway at Boston College may perhaps provide some of the key data, and if these are available by the time this field trip is being conducted, they will be informally shared with all the participants. In conclusion, we would like to suggest that the mid-Paleozoic calc-alkalic suite is indicative of a long lasting (appr. 70 Ma) subduction zone which might have ultimately led to a continental collision, the Acadian Orogeny. Position of the arc axis probably was not at the same place throughout the entire time period but most likely it migrated from place to place leaving behind plutonic bodies of discrete ages.

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ITINERARY

<u>Mileage: Part I.</u>

0.0 Assembly point and Stop #1. Meet at junction of Interstates I-290 and I-495 just north of Marlborough, Mass. at 10 a.m. Meet on S.E. side of this large interchange. If coming north on I-495, take exit 25A "to 85, Marlborough", park on shoulder of ramp just before it merges with I-290 by silver colored electric box. If coming east on I-290, continue over I-495 and park just east of where the ramp from I-495N, joins I-290 extension "to 85, Marlborough". We will leave this exposure at 11 a.m.

STOP #1: STRAW HOLLOW DIORITE or ASSABET QUARTZ DIORITE

The large exposures at this cloverleaf are complex and show a wide variety of features. Our principal purpose in stopping here is to examine the Straw Hollow Diorite or Assabet Quartz Diorite along the north side of the interchange. The diorite here is characteristic of the smaller bodies of Silurian calc-alkaline plutonic rocks in the Nashoba Block. Both foliated and non-or more weakly foliated varieties of hornblende-quartz diorite are present here. They have been intruded by garnet bearing pegmatites associated with the younger phase of the Andover Granite (approximately 415 m.y., Hill et al., 1984). Sillimanite schists of the Nashoba Fm. are exposed along the south side of the cut.

Blastomylonites believed to be associated with the Assabet River fault zone are also exposed here and will be briefly examined as an example of the type of deformation common along some of the larger shear zones in the Nashoba Block. If time permits, a relatively late brittle shear zone cutting the Straw Hollow, with carbonate mineralization, will be visited to provide contrast with the earlier ductile deformation.

To proceed to Stop 2 we will need to turn around and head north on I-495.Continue straight ahead on "to 85" east.

1.0 At traffic light, Fitchburg Street, exit to the right.

1.1 By entrance to Assabet Valley Regional Vocational High School, turn around and retrace route to traffic light.

1.2 Turn left (west) on "to 495-290".

2.2 Take Exit 26B, I-495 north toward Lowell.

2.8 Merge with I-495 north.

3.0 Cross Assabet River.

3.6 Excellent exposures of Nashoba Fm. gneisses and migiratites for next several miles, continue north toward Lowell.

25.8 Rest area on right.

26.7 Leave I-495 at Exit #36, "Lowell Connector". Exit to right.

27.4 Turn right, follow Exit 36, Lowell Connector.

27.5 Bear left, follow Exit 36, Lowell Connector.

28.1 Continue straight on Lowell Connector.

28.8 Continue toward Lowell Center.

29.9 Road ends, turn left toward Lowell Center.

30.1 Continue straight past Courthouse on right.

30.2 Bear right, follow one way.

30.4 Bear left, continue on one way.

30.45 At light, continue straight, now on Central St.

30.6 At light, Y intersection, bear right on Prescott St.

30.7 At light, turn right on E. Merrimack St.

30.8 Federal Building on left.

31.0 Continue straight.

31.1 At light, turn left on routes 38 and 110.

31.3 Cross Merrimack River and bear right on Rte. 110 east.

31.4 Continue on Rte. 110 east toward Lawrence.

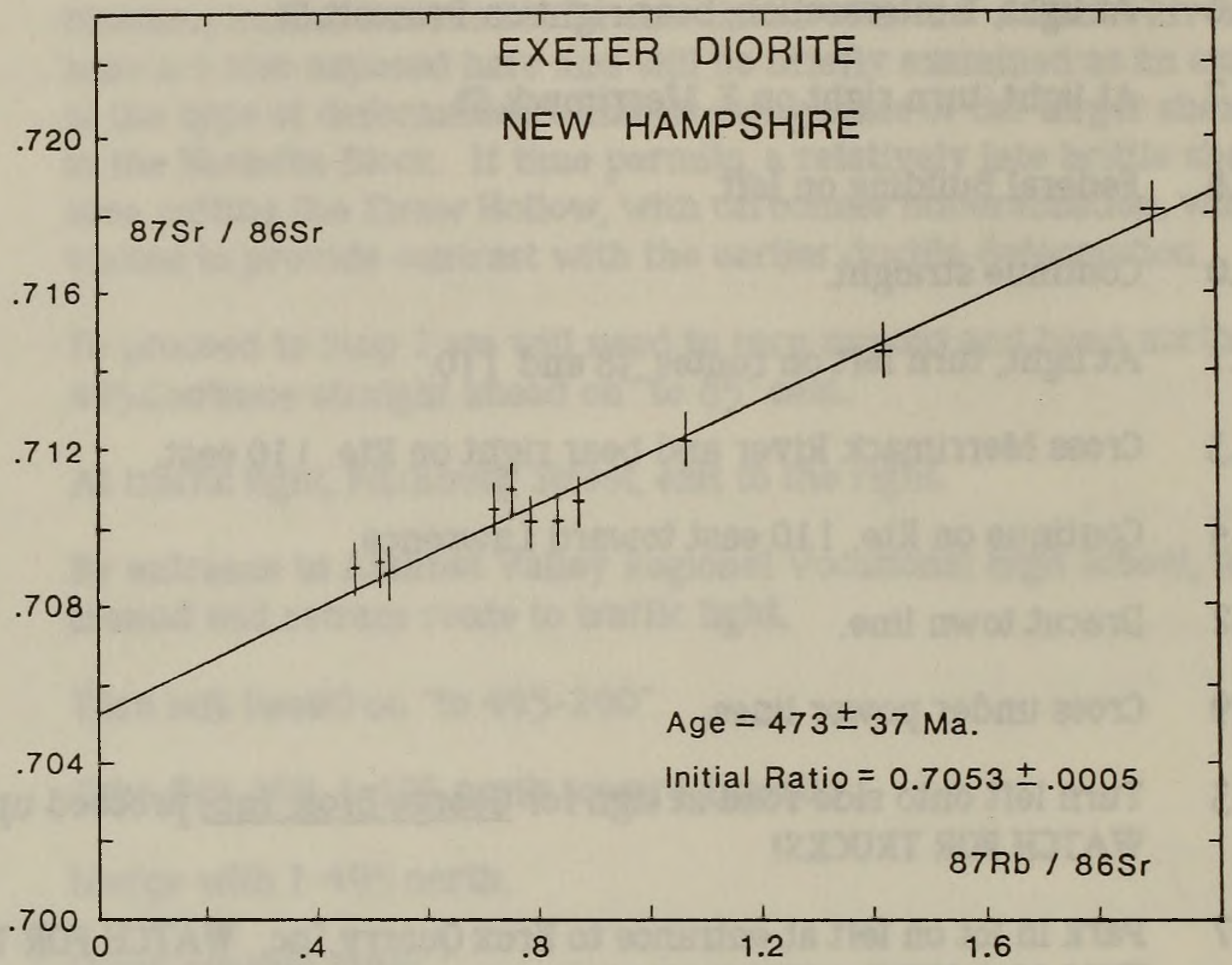
32.2 Dracut town line.

34.9 Cross under power lines.

35.3 Turn left onto side road at sign for <u>George Brox, Inc.</u>, proceed up hill. WATCH FOR TRUCKS!

35.7 Park in lot on left at entrance to Brox Quarry,Inc. WATCH FOR TRUCKS- THIS IS A VERY ACTIVE QUARRY. At this locality we will consolidate to as a few vehicles as possible and proceed driving into the quarry. Prepare to stop at the gatehouse and obtain a clearance or permition to enter the quarry. For this trip we are promissed an entrance for all participants. We will proceed driving to the lower level and park near an area which does not interfere with the quarry operation.

<u>STOP #2: DRACUT DIORITE</u>.
In this quarry virtually every petrographic type known to occur within the Dracut stock can be found. Main rock type is, however, a massive, medium to coarse grained unfoliated norite. This body crops out over an area of about 27 mi^2, intruding quartzites of the Berwick Formation (Zen, editor, 1983). Inclusions of quartzite blocks and fragments are common throughout the pluton. There is no age determination but correlations with similar rocks of the Exeter Pluton suggests a date in the vicinity of 470 Ma (Fig.3). Petrographic studies done by Dennen (1942) show that the mineralogy is highly variable from noritic diorite to cumulate ultramafics consisting of 55% forsteritic olivine, 20% enstatitic orthopyroxene, 5% each bytownite and clinopyroxene, and 15% of intercumulus biotite and hornblende. Predominant rock type is norite with subequal amounts of plagioclase (An71-An37) and mafics (cpx, opx and olivine) with minor biotite and hornblende. Dennen (1942,1943) describes a gradation from more felsic varieties near the



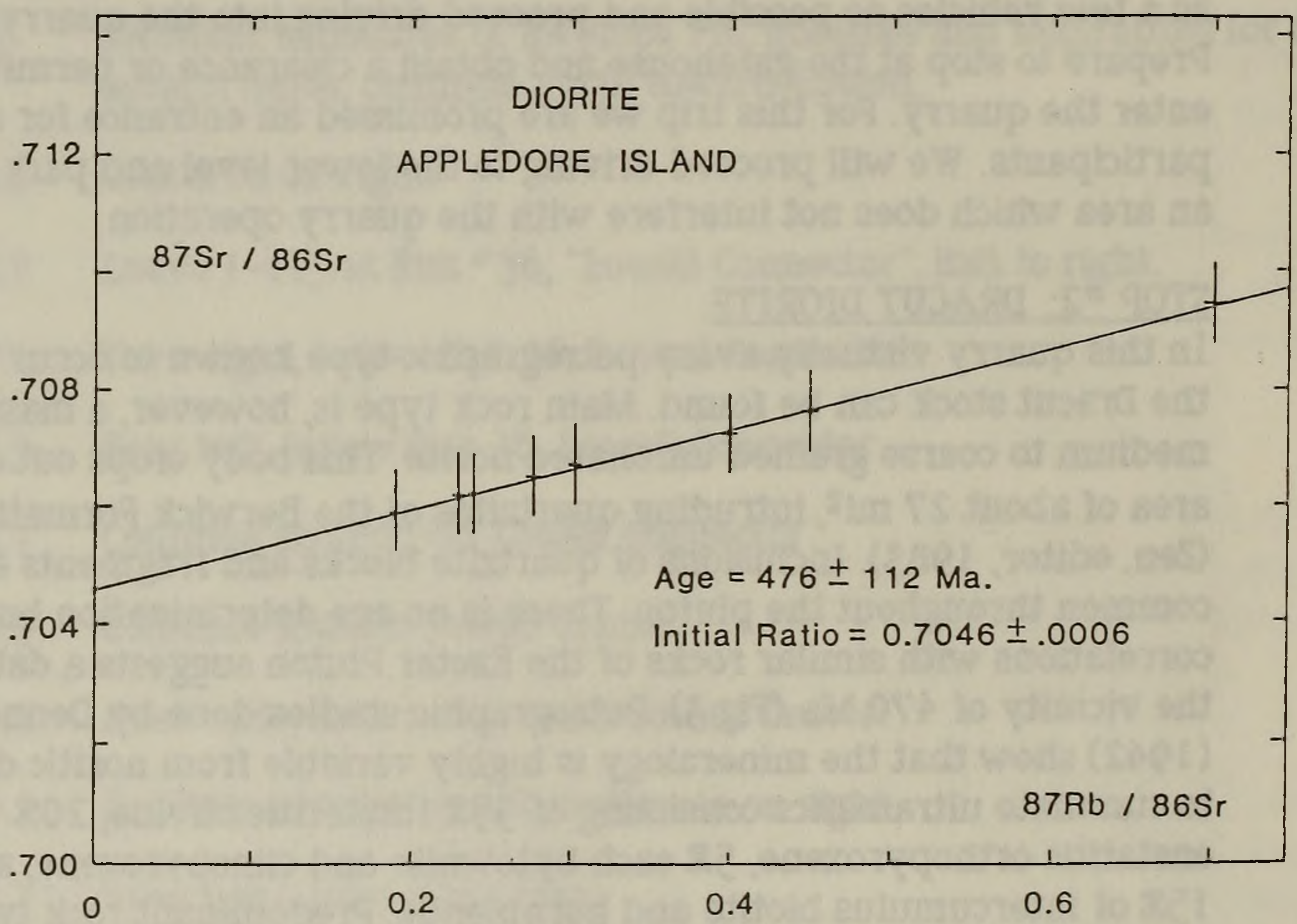


FIGURE 3 Rb/Sr Isochrons for Exeter and Appledore Island Plutons

Rb Decay Constant = 1.42×10^{-11} Years.

contacts to more mafic norites in the center noting that this zonation is likely due to magmatic fractionation. A curious occurrence of magmatic sulphides which can reach locally quite high proportions (over 50%), led to a prospecting effort for nickel - hence Nickel Mine Hill, the location of this quarry.

Note: This ends Part I. of this roadlog. Stops 3 through 6 (Part II.) will follow a new mileage chart starting from 0.0.

Mileage: Part II.

0.0 Leave George Brox, Inc. quarry and proceed toward Route 110.

0.3 With caution, turn left onto Route 110 and proceed toward Methuen. Be particularly careful crossing traffic lanes as the traffic moves here at rather high speeds.

3.2 Bear left and enter Interstate I-95 going south toward Boston.

3.7 Merrimack River. As you drive over the bridge you're crossing the Clinton-Newbury Fault again. Leaving behind the Merrimack Trough, you will re-enter the Nashoba Block, here underlain by Andover Granite.

6.7 Take Exit 44A and proceed on I-495 North toward Lawrence. Roadcuts along I-495 are of Andover Granite.

9.8 Take Exit 42A from I-495 to Route 114 going east.

11.2 Turn left on Route 133 East going toward Georgetown.

11.4 Make another left turn. Route 133 E joins Route 125 E here.

14.1 Lawrence airport.

14.3 Keep right at this Y fork and follow 133 E for about 7 miles in direction of Gergetown. Route 125 E leaves Route 133 to your left.

21.3 Intersection of Routes 97 and 133 in Georgetown. Continue on Route 133 East.

21.5 Route 133 East turns right; stay on Route 133 E and follow signs in the direction of Route 1.

23.2 Overpass above I-95. About a mile from here, and until you cross Parker River, you will be within the stratified rocks of the Newbury Inlier (Shride, 1976a,1976b)

26.5 At traffic lights, turn left (N) onto Route 1.

28.9 Turn right (E) on Central Street and almost immediately pull off road and park cars on the shoulder.

<u>STOP #3: NEWBURY INLIER - PORPHYRITIC ANDESITE:</u> This stop is the same as Stop #2 of Shride, 1976a. On both side of the street are exposures of "intercalated flows and water-laid ash-fall (?) tuffs of the porphyritic andesite (member 7)" (Shride,1976a). Fossils from a locality near here and other places within the Inlier yield stratigraphic ages of uppermost Silurian, possibly through the lowermost Devonian (Shride, 1976b). Four samples, one from each of the flows, were analyzed for major and trace elements. Major element data show that these are high alumina basalts: SiO_2 near 52% and Al_2O_3 between 17 and 20%. Trace elements and various discrimination diagrams suggest a subduction zone related magmatism. Other analyzed samples from the Newbury Inlier, however, are more like the typical andesites of magmatic arcs. Top of each flow is here readily recognizable by the presence of a vesicular band. Also note the differences in the phenocrystic content between the flows.

Close association of the basaltic andesites with rhyolites, and microgranites within the Newbury Inlier, is suggestive of two separate, but contemporaneous magma systems. Magma mixing between the two respective end-members could produce a large array of intermediate rocks such as the one of Sharpners Pond Quartz Diorite, which will be seen at the next stop.

Turn around, please use EXTREME CAUTION, and prepare to enter Route 1 going north.

29.1 Turn right (N) onto Route 1.

29.4 Newbury town line.

30.5 Parker River bridge. Parker River follows here the Parker River Fault, which separates the Newbury Inlier from Sharpners Pond Quartz Diorite of the Nashoba Block. Exposures north of the bridge are of pink granite (Sgr of Zen, editor, 1983), and quartz diorite of Sharpners Pond.

32.8 Turn left on Middle Road by following the sign indicating direction toward Byfield. Stop almost immediately after the turn alongside the road.

STOP *4: SHARPNERS POND QUARTZ DIORITE.

Examine exposures of Sharpners Pond Quartz Diorite along both sides of Middle Road just as it approaches Route 1, and observe the extreme variability in mineralogy, texture, and structure. These exposures are rather typical of rocks in this general area. Note the complex brecciation and "pillowing" of more mafic types within a granitic matrix. There is some evidence that the granitic component is virtually the same as the granitic masses mapped as pinkish biotite granite near Byfield (Zen, editor, 1983). Geochemical study shows that the granite and the mafic to intermediate rocks are genetically unrelated. Perhaps the granitic rocks represent anatectic melts which formed in response to raised temperatures due to intrusions of more mafic magmas. Such two magma system would interact in a variety of ways resulting in structures shown on these exposures.

Sharpners Pond Pluton forms about 60 mi^2 large body found between Wilmington and Newbury. Castle (1965) identified within the pluton three basic petrographic phases: hornblende diorite, hornblende-biotite tonalite, and biotite tonalite which tend to predominate in a given region but which show graditional transition from one type to another. Hornblende diorite is almost certainly a cumulate rock consisting of subequal amounts of plagioclase (andesine to sodic labradorite) and hornblende with occasional clinopyroxene cores, and minor amounts (0 to 10%) of biotite. Sphene is a characteristic accessory seen in almost all hand specimen. All other phases of the Sharpners Pond have the same mineralogy (with the exception of minor alkali feldspar) but in varied proportions.

Continue (W) on Middle Road.

33.2 Take sharp turn (N) on unmarked road (Highfield Road).

33.9 Turn left (W) on Scotland Road. More exposures of Sharpners Pond.

35.9 Pass under I-95.

36.2 Make right turn on the side road, and immediately park alongside the road. Walk back few hundred feet toward the roadcuts along the ramp to I-95 South. NOTE: A similar set of outcrops can also be seen along the ramp to I-95 going north.

STOP *5: SHARPNERS POND QUARTZ DIORITE.

These exposures further accentuate the same and other similar features as observed at the previous stop. Well developed magmatic "pillowing", magmatic brecciation and cementing, several stages of subsequent mafic magma intrusions and of different types, and magma mixing. Not everywhere we see these complex features, as a matter of fact a short distance from here, and further toward SW the rocks are much more uniform in their appearance and more homogeneous in their mineralogy.

Age determination on two samples from nearby localities by $^{206}Pb/^{207}Pb$ on zircons gave concordant ages of 430+/-5 Ma. This age is nearly identical to stratigraphic ages of Upper Silurian obtained for the Newbury Inlier. Considering the additional fact that the Newbury volcanics are also a bimodal suite consisting of rhyolites and andesites, it is possible then to correlate the Newbury inlier as a down faulted block carrying with it volcanic equivalents of the plutonic rocks of the Sharpners Pond Pluton.

Turn around, drive back under I-95, and enter I-95 going north toward Amesbury.

37.4 Crossing the Clinton-Newbury Fault once again. You are back in the Merrimack Trough. Rock exposures along the highway are of Newburyport Quartz Diorite.

40.4 Merrimack River.

41.1 Take exit from I-95 onto Route 110 (E) in the direction of Salisbury.

43.5 Turn left onto Route 1 (N).

43.6 Set of blinking traffic lights. Bear left on Route 1, and proceed carefully through the intersection.

44.3 Turn right (E) on Gerrish Road, just ahead of railroad overpass.

44.6 Make sharp left turn (N) onto unmarked Seabrook Road.

45.0 Small abandoned quarry on your left. Park in the quarry.

STOP *6: NEWBURYPORT COMPLEX.

This stop is in the same place as STOP *2. of Shride (1971). Newburyport complex forms a composite pluton which consists of somewhat older tonalites and granodiorites to the SE and younger porphyritic granites to the NW. Samples taken from this quarry, which lies within the nonporphyritic tonalites and granodiorites, yielded $^{207}Pb/^{206}Pb$ zircon age of 466 Ma (Zartman and Naylor, 1984), whereas the porphyritic granite gave by the same technique an age of 437 Ma. The older age is remarkably similar to ages obtained for the Exeter and Appledore diorites (Fig. 3) suggesting a presence of Middle Ordovician magmatic province within the Merrimack trough.

Rocks exposed at this locality are medium grained and are, according to Shride (1971), in the middle of the range defined by mineralogical variations of mafics, feldspars and quartz. The mafic minerals (near 20%), include biotite and hornblende, sphene is a dominant accessory. Characteristic feature observed by Shride (1971) is a positive correlation between the frequency of ovoid dioritic inclusions and the more mafic appearance of the host rock which may be interpreted as an evidence for mixing between two types of magmas..

After a U-turn, retrace the directions back to Route 1.

45.4 Turn right (W) on Gerrish Road.

45.8 Turn right (N) on Route 1 (Lafayette Road) and proceed under the railroad bridge.

46.6 Traffic lights. Bear left and follow signs in the direction of I-95 going to New Hampshire.

47.5 Continue straight, rejoin I-95 North, and proceed toward Hampton - Exeter Toll Booth exit from I-95 in New Hampshire.

Note: This ends Part II. of this field trip. The upcomming Part III. presents road log to Stops 7 and 7A with fresh start from 0.0 beginning at Hampton - Exeter Toll Both exit off I-95.

Mileage: Part III.

0.0 Toolgate ($0.25 toll). Follow exit ramp to Route 51/101W.

3.6 Traffic lights.

4.0 Pass exit to Route 108 (to Exeter and Newmarket, N.H.)

5.4 Pass exit to Route 85 (to Newfields). Large road cut along Route 101 on your left (S) just beyond the undepass beneath Route 85 exposes contact metamorphosed Kittery Formation. Possible stop (Stop 7A) on the return to I-95.

6.2 Pull off the highway and park near the top of this small hill. 0Exposures of the Exeter Diorite occur on both sides of the highway over the next half mile either as 50 to 100 m long glacially-smoothed pavements or blasted joint surfaces several meters high. The safest crops are on the north (R) side of the highway.

STOP *7: EXETER PLUTON.

The diorite here is fairly typical of the types seen within the Exeter Pluton over its entire 32 by 7 km northeast - trending body. It extends from the southern exposures, seen here near the town of Exeter, toward Rollingsford, NH. Farther west are exposures of gabbro, that contain plagioclase, orthopyroxene, biotite, minor olivine, and secondary uralitic amphibole. To the northeast, rocks of the Exeter Pluton become gradually more felsic, but never granitic. Over much of its extent, it is typically "salt and pepper", medium gray, medium- to coarse-grained, and unfoliated diorite and quartz diorite. Frequent aplite dikes, some pegmatitic, parallel joints, and are sometimes offset by minor faults. Xenoliths of the surrounding Kittery and Eliot Formations are common, particularly near the margins and in areas interpreted to represent the original roof zone (better illustrated in the center of the pluton in Durham). The xenolith commonly show variable degrees of digestion and often emphasize the carbonate content by the development of epidote, diopside, and occasional grossularite as elongate pods (concretions?). More pelitic inclusions commonly contain coarse, anhedral, poikiloblastic biotite, and small hypersthene granules.
The diorite here contains subequal amounts of plagioclase (3-5 mm subhedra, An35-50), biotite, pyroxenes, amphiboles, quartz (10-15%), and minor magnetite. Comagmatic mafic clots usually 15 - 20 cm long contain abundant biotite, pyroxenes, amphibole, and minor plagioclase. In most thin sections of the Exeter, plagioclase subhedra are normally zoned, very strongly near the contacts with the Merrimack Group. Hornblende is largely altered to chlorite, pyroxene (both clinopyroxene and orthopyroxene occur) remains unaltered, and biotite is slightly chloritized and commonly displays sagenitic rutile. Quartz is invariably interstitial; microcline is occasionally present. Little chemical work has been published on the Exeter Pluton. Preliminary work indicates that the varied body averages 56% silica. Gaudette and others (1984), reported a Rb/Sr whole rock age of 473+/-37 Ma (0.7053+/-0.0005) for the Exeter (Fig.3.), which is consistent with the nearby Newburyport Quartz Diorite, and smaller diorite bodies near Portsmouth and on the Isles of Shoals (Appledore Island data on Fig.3.). The age of these bodies constrains the age of the Merrimack Group in coastal New Hampshire as

pre-Early Ordovician. Other evidence suggests a Late Proterozoic age (Bothner and others, 1984).

Proceed in the same direction toward the next intersection.

7.0 Traffic lights, turn left towards Exeter (a U-turn if possible) and retrace route to I-95.

8.2 STOP 7A: CONTACT METAMORPHOSED KITTERY FORMATION. (Optional stop). If time and interest remains, we can make short stop at the large outcrop of the contact matamorphosed Ordovician to Precambrian(?) Kittery Formation exposed on the west side of the Route 85 bridge. The outcrop of brittle, purplish-brown quartzite and pelitic hornfels within less than 1 km of the contact with the Exeter Pluton. The actual contact is not exposed here. The quartzite occurs in beds 30 to 50 cm thick intercalated with 5 - 10 cm pelitic hornfels (originally phyllite) layers. Occasional calc-silicate bands occur within the quartzite. The surface facing the highway is strongly slickesided. On the top of the outcrop, porphyroblasts of probable cordierite (now retrograded to white mica), which form noticeable knots 1-10 mm across, occur in some peliticlayers. Elsewhere at the contact, hypersthene is developed within the pelitic portions of the Kittery. They likewise show retrograde alteration. It is therefore likely that the Kittery, regionally metamorphosed before the emplacement of the Exeter, was contact metamorphosed some 473 Ma ago, and then mildly metamorphosed during the Acadian or Alleghanian events.

14.0 Hampton Toll Gate, I-95. Proceed north to Lewiston, Maine

End of Part III. and end of field trip.