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ZIRCON GEOCHRONOLOGY AND PETROLOGY OF PLUTONIC ROCKS IN RHODE ISLAND

O. Don Hermes,[1] L.P. Gromet,[2] R.E. Zartman[3]

INTRODUCTION

The geological evolution of the plutonic basement of Rhode Island and adjacent areas is complex and poorly understood. The basement, which is composite in nature, is dominated by late Precambrian calcalkaline plutonic rocks as well as by alkaline and calcalkaline rocks of mid-Paleozoic age. In addition, some of these rocks in southernmost Rhode Island are intruded by late Paleozoic calcalkaline plutonic rocks. Rocks that form the older basement have several features in common with the rocks underlying the Avalon Peninsula of Newfoundland and other areas along the eastern margin of the Appalachians. Recognition of this similarity has led to growing acceptance of the hypothesis that these areas constitute a distinctive belt within the Appalachian Orogen. Known as the Avalon Zone, this belt is characterized by a basement of late Precambrian plutons intruded into metasedimentary and metavolcanic rocks (Rast and others, 1976; Williams, 1978). These plutonic rocks probably represent the first major continental crust-forming event within the Appalachian orogenic cycle. An important aspect of occurences in southeastern New England is that a deeper level of erosion has created extensive exposures of the core of this part of the Avalon Zone; thus we are offered outstanding opportunities for study of intrusive rocks associated with the early developmental stage of the Appalachian Orogeny.

With the exception of the work by Day and others (1980a, b) on the Sterling Group, little petrographic or geochemical data are available for the older crystalline rocks of Rhode Island. Recognizing the potential significance of this terrain as it relates to the understanding of the Avalon Zone, we have initiated integrated geochronological, petrological, and geochemical studies of selected parts of the area. New petrographic and geochemical data, and zircon U-Th-Pb isotopic ages on a limited suite of these rocks are providing a needed framework for on-going studies. Outcrops visited on this trip will emphasize the diversity of lithologies, structures and relationships that must be studied in greater detail before a better understanding of the complex geologic history of the region can be developed.

PETROLOGY AND GEOCHRONOLOGY

Earlier studies summarized in Quinn (1971) and the Rhode Island state map outline and separate major lithologic units. In broad terms, Quinn defined three major groupings of igneous rocks: (1) "older" plutonic rocks thought to be of early or middle Paleozoic age (including the Ponaganset, Sterling, and Esmond Groups), (2) rocks of "Mississippian (?) or older" age (East Greenwich Group and Rhode Island "Quincy"), and (3) "Pennsylvanian or younger" rocks (Narragansett Pier and Westerly Granites). Few reliable radiometric ages have been determined on these rocks, and

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most age estimates have been based on crosscutting relationships and syn- or post-kinematic characteristics, such as, the degree of foliation. However, the degree of deformation is a poor indicator of age since, in general, all of these units are somewhat deformed, and it is common to observe rock units within a single outcrop grade from well-foliated to massive. Although several granitic rocks to the east have yielded Cambrian to late Precambrian radiometric ages (including the Bulgarmarsh Granite (Galloway, 1973), Newport Granite Porphyry (Smith, 1978), and Dedham Granodiorite (Kovach and others, 1977; Zartman and Naylor, in press)), these rocks are of unknown relationship to the rocks west of the Narragansett Basin.

Our preliminary petrologic and geochronologic work (see Fig. 1 for sample localities) indicates that some substantial revisions to Quinn's grouping of these rocks is required. In particular, the Scituate Granite Gneiss and perhaps other lithologies of the Sterling Group appear to be composed of compositionally and temporally diverse rocks which may not have a common origin. For the purpose of the presentation, we choose to discuss these rock units in terms of the following groupings: (1) Esmond Group, (2) mid-Paleozoic rocks, (3) Hope Valley and Ten Rod Granites, and (4) Narragansett Pier and Westerly Granites. This list is not in order of age, but does correspond to the NE to SW order that we will follow on this trip (Fig. 2).

ESMOND GROUP: These rocks range from quartz diorite to two-feldspar granite and are largely restricted to a north-south zone just west of the Narragansett Basin (Fig. 1). The Esmond Group also may include more mafic hypabyssal and volcanic rocks that are associated spatially with the Hunting Hill greenstone member of the Blackstone Series.

The Esmond Group rocks are massive to faintly foliated and generally exhibit prominent secondary development of chlorite, epidote, and muscovite. These minerals are concentrated along annealed brittle fractures and form a foliation in the rock. Minerals present include quartz, microcline, plagioclase, biotite, opaques and accessory sphene, apatite, monazite, zircon and calcite. Xenolithic inclusions and larger roof pendants of Blackstone Series-like rocks are common.

Age relationships within the Esmond Group show the Esmond Granite to be intrusive into quartz diorite, and both of these lithologies are cut by a fine-grained granite facies. Quinn (1971) described a porphyritic variety, the Grant Mills Granodiorite, as gradational into Esmond Granite.

Representative major element analyses of these rocks are given in Table 1, and selected oxides and trace elements are illustrated in Figures 3-5. These data and the petrography indicate that the Esmond Group is a calcalkaline rock series. Interestingly, rare earth patterns of some Esmond Group rocks are similar to those from other calcalkaline granitic suites known to have formed at a convergent plate boundary, such as the Peninsular Range batholith (Gromet, 1979; Gromet and Silver, 1979a, b) and the Sierra Nevada batholith (Frey and others, 1978).

The summary of zircon geochronology presented in Figure 6 shows that all sampled varieties of the Esmond Group have a late Precambrian primary age and can be interpreted to be comagmatic. This age is similar to a Rb-Sr isochron (Kovach and others, 1977) and to zircon ages (Zartman and Naylor, in press) for Dedham related rocks from nearby Massachusetts. The zircon fractions fall on a chord whose lower intercept trends toward zero, indicating no major isotopic disturbance

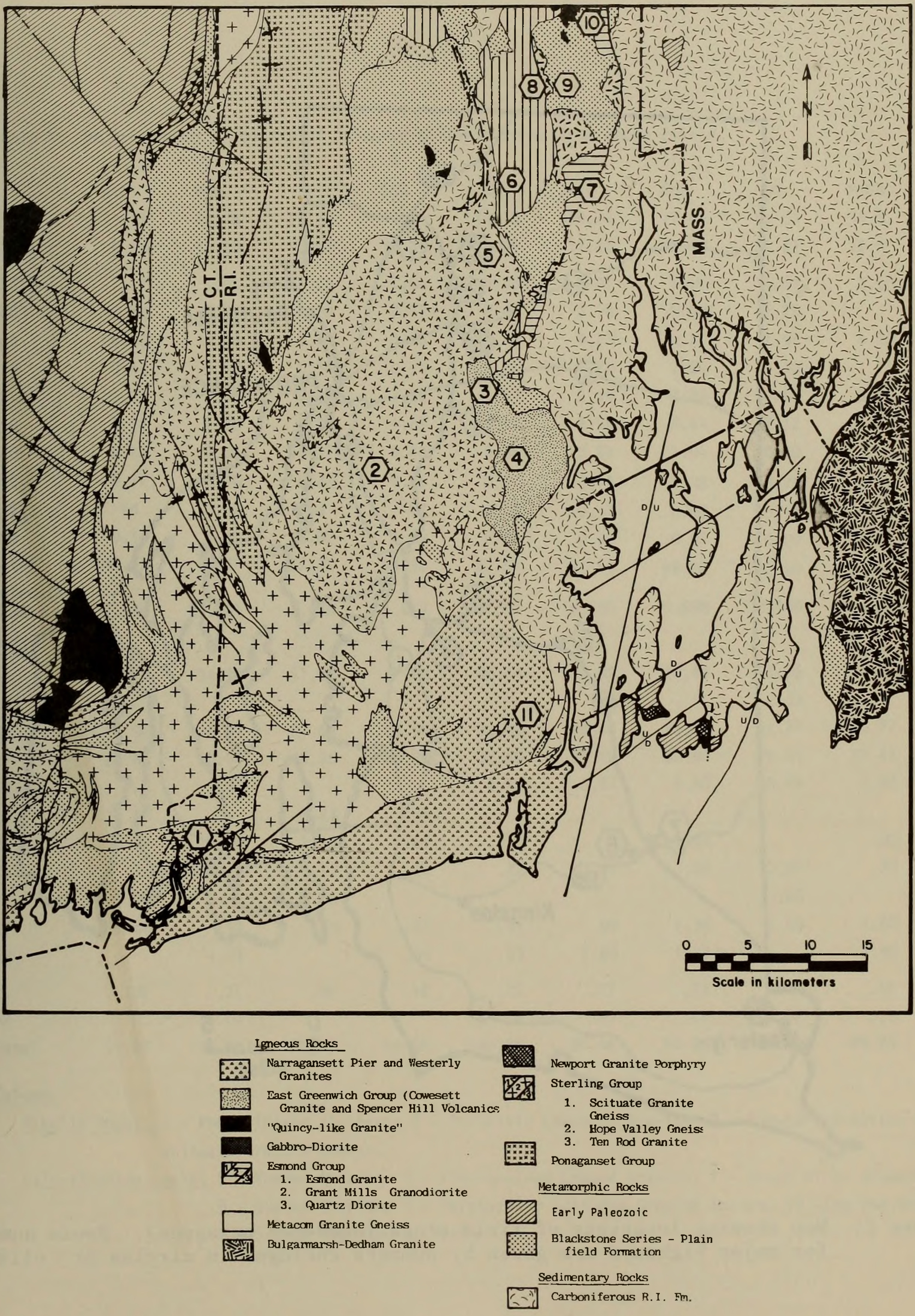


Figure 1: Generalized geologic map of Rhode Island and adjacent areas. Numbered hexagons indicate locations of samples collected for zircon analysis.

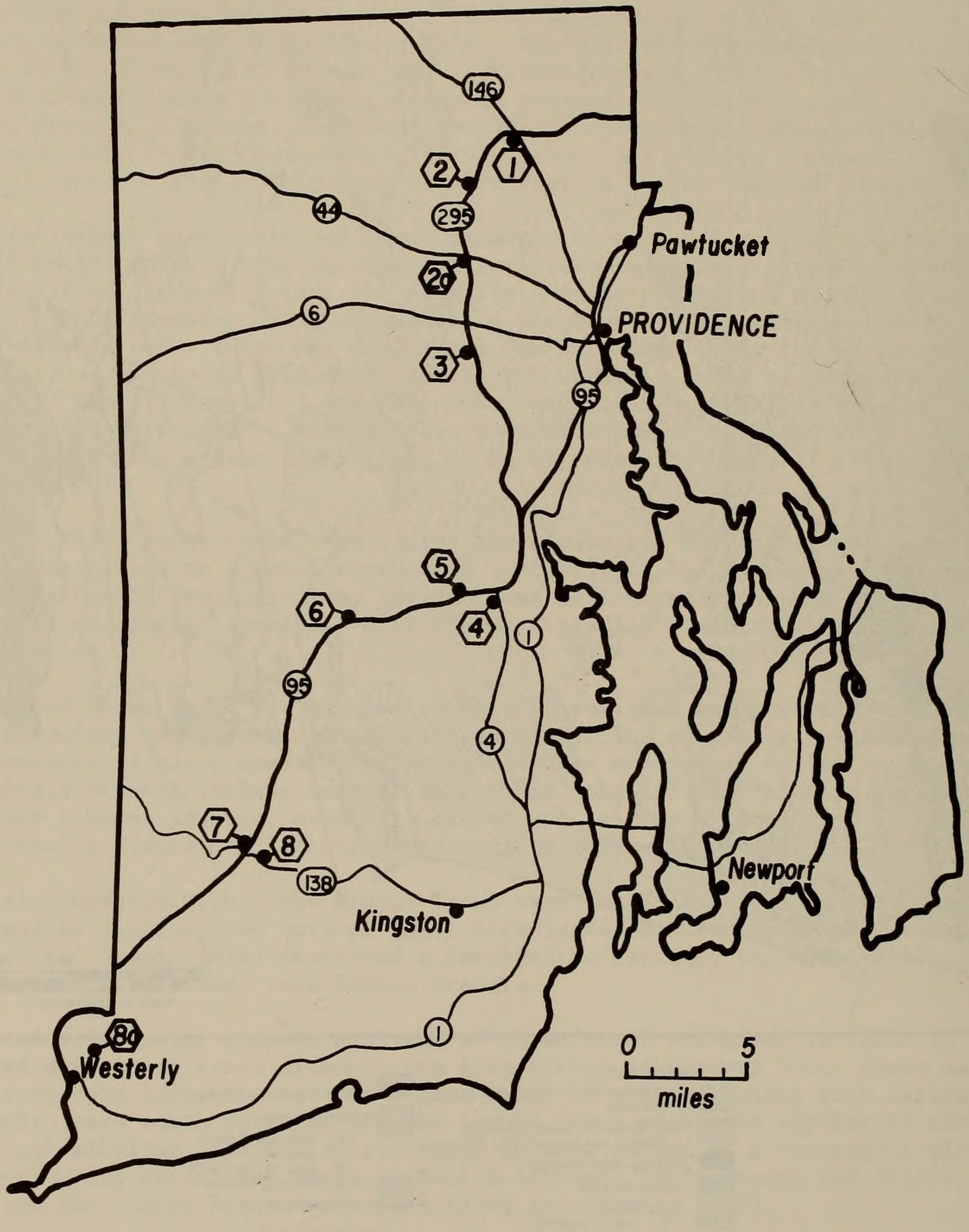


Figure 2: Map showing locations of field stops (numbered hexagons). Route numbers for major highways are given by numbers enclosed in circles or ellipses.

Table 1: Major element chemistry of selected plutonic rocks from Rhode Island.

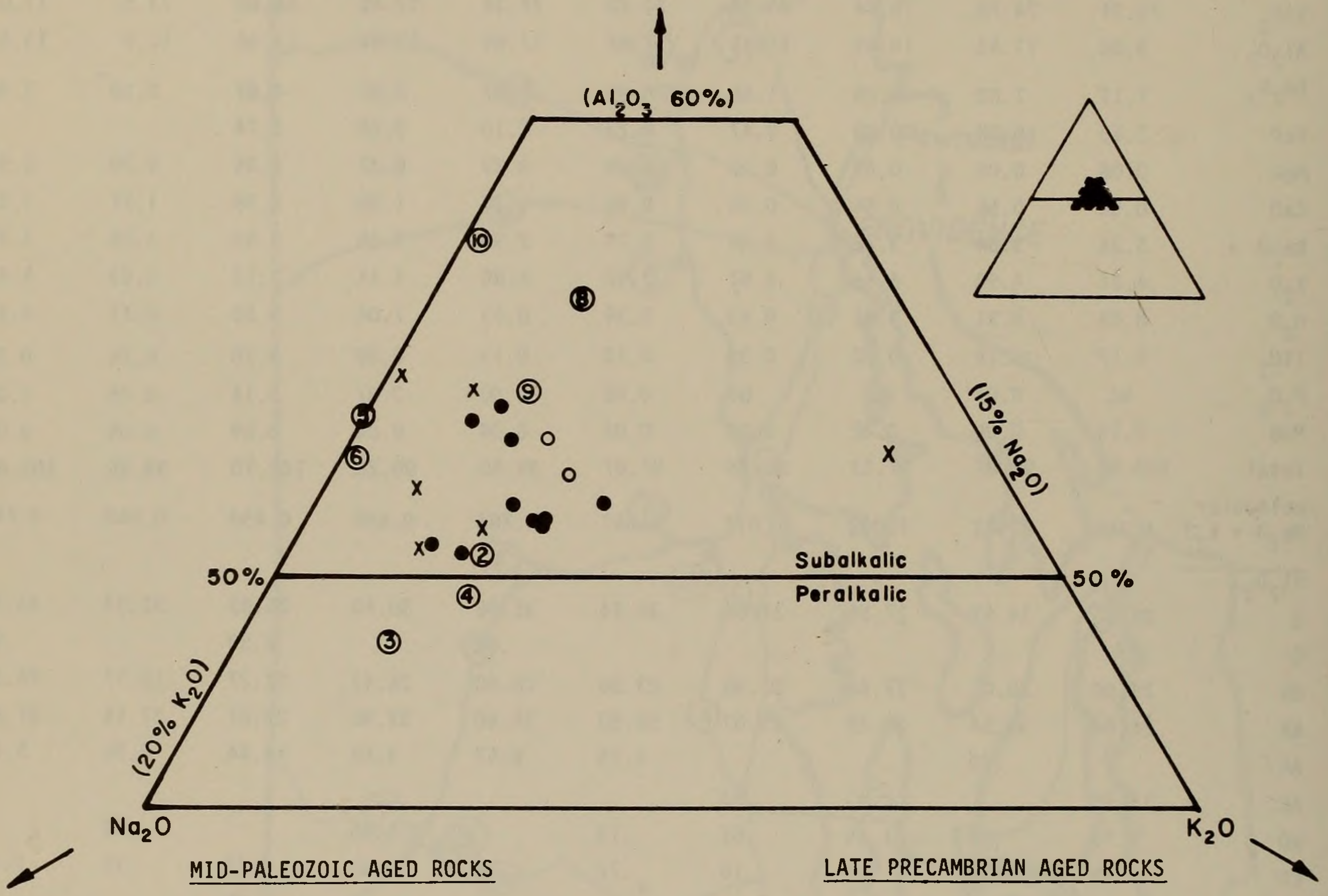
	1	2	3	4	5	6	7	8	9	10
	RIQ	PCG	CG	SGG	EG	FEG	GMG	Qd	PSGG	TRG
SiO_2	70.24	74.78	75.64	73.84	74.48	74.34	72.46	65.02	73.5	73.0
Al_2O_3	9.80	11.43	10.49	10.44	11.98	12.86	12.42	17.54	12.9	13.6
Fe_2O_3	7.17	1.80	1.28	1.60	0.95	1.07	2.02	4.67	2.50*	2.98*
FeO	2.50	0.38	0.20	0.47	0.23	0.10	0.69	2.74		
MgO	0.06	0.08	0.05	0.06	0.28	0.29	0.27	1.34	0.30	0.56
CaO	0.58	0.56	0.54	0.30	0.96	1.33	1.58	3.98	1.21	1.51
Na_2O	5.26	3.54	3.72	3.38	3.74	2.98	3.86	3.50	3.28	3.21
K_2O	4.24	4.98	4.56	4.67	3.92	4.80	4.44	2.12	5.03	4.47
H_2O	0.46	0.31	0.81	0.43	0.34	0.53	1.04	0.18	0.77	0.29
TiO_2	0.17	0.16	0.02	0.06	0.13	0.14	0.38	0.78	0.26	0.31
P_2O_5	bd	0.01	bd	bd	0.02	0.02	.0.07	0.14	0.05	0.08
MnO	0.14	0.04	0.02	0.03	0.04	0.04	0.05	0.09	0.05	0.07
Total	100.62	98.07	97.33	95.28	97.07	98.50	99.28	102.10	99.85	100.08
molecular $\frac{Na_2O + K_2O}{Al_2O_3}$	1.348	0.981	1.053	1.017	0.867	0.786	0.898	0.459	0.840	0.744
Q	25.20	34.97	37.55	37.89	36.44	35.95	30.49	25.85	32.33	33.35
C						.42		2.53		.93
OR	24.90	30.01	27.68	28.96	23.86	28.80	26.43	12.27	29.77	26.39
AB	26.64	30.54	29.35	29.07	32.60	25.60	32.90	29.01	27.14	27.80
AN		.60			4.45	6.57	3.48	18.44	6.96	5.63
AC	15.50		2.63	.83						
WO	1.19	.90	1.15	.65	.13		1.65		.02	
EN	.15	.20	.13	.16	.72	.73	.68	3.27	.75	1.39
FS	3.08		.05					.05		
MT	2.56	.91	.59	1.51	.51	.05	1.30	6.63	1.02	.94
HM		1.21		.35	.63	1.05	1.14		1.30	1.83
IL	.32	.31	.04	.12	.25	.27	.73	1.45	.50	.59
AP		.02			.05	.05	.17	.32	.12	.19
Total	99.54	99.68	99.17	99.55	99.65	99.46	98.96	99.83	99.23	99.72

Column:

Alkalic Rocks: 1 - Rhode Island "Quincy"; 2 - Perthitic Cowesett Granite; 3 - Coewsett Granite; 4 - "type" Scituate Granite Gneiss.

Calc-alkaline rocks: 5 - Esmond Granite; 6 - Fine-grained Esmond Granite; 7 - Grant Mills Granodiorite; 8 - Quartz diorite; 9 - Porphyritic Scituate Granite Gneiss; 10 -Ten Rod Granite.

* All iron reported as Fe_2O_3



MID-PALEOZOIC AGED ROCKS

2. Perthitic Cowesett Granite
3. Cowesett Granite
4. "Type" Scituate Granite Gneiss
9. Porphyritic Scituate Granite Gneiss

LATE PRECAMBRIAN AGED ROCKS

Esmond Group Rocks

5. Esmond Granite
6. Grant Mills Granodiroite
8. Fine-grained Esmond Granite

Sterling Group

10. Ten Rod Granite Gneiss

Figure 3: Plot of molecular Al_2O_3-Na_2O-K_2O for some granitic rocks from Rhode Island. Numbers correspond to analyses on Table 1 (analyses 1 and 7 plot out of this diagram). Data from Day and others (1980a) as follows: x = Hope Valley Alaskite Gneiss, o = Ten Rod Granite Gneiss, ● = Scituate Granite Gneiss.

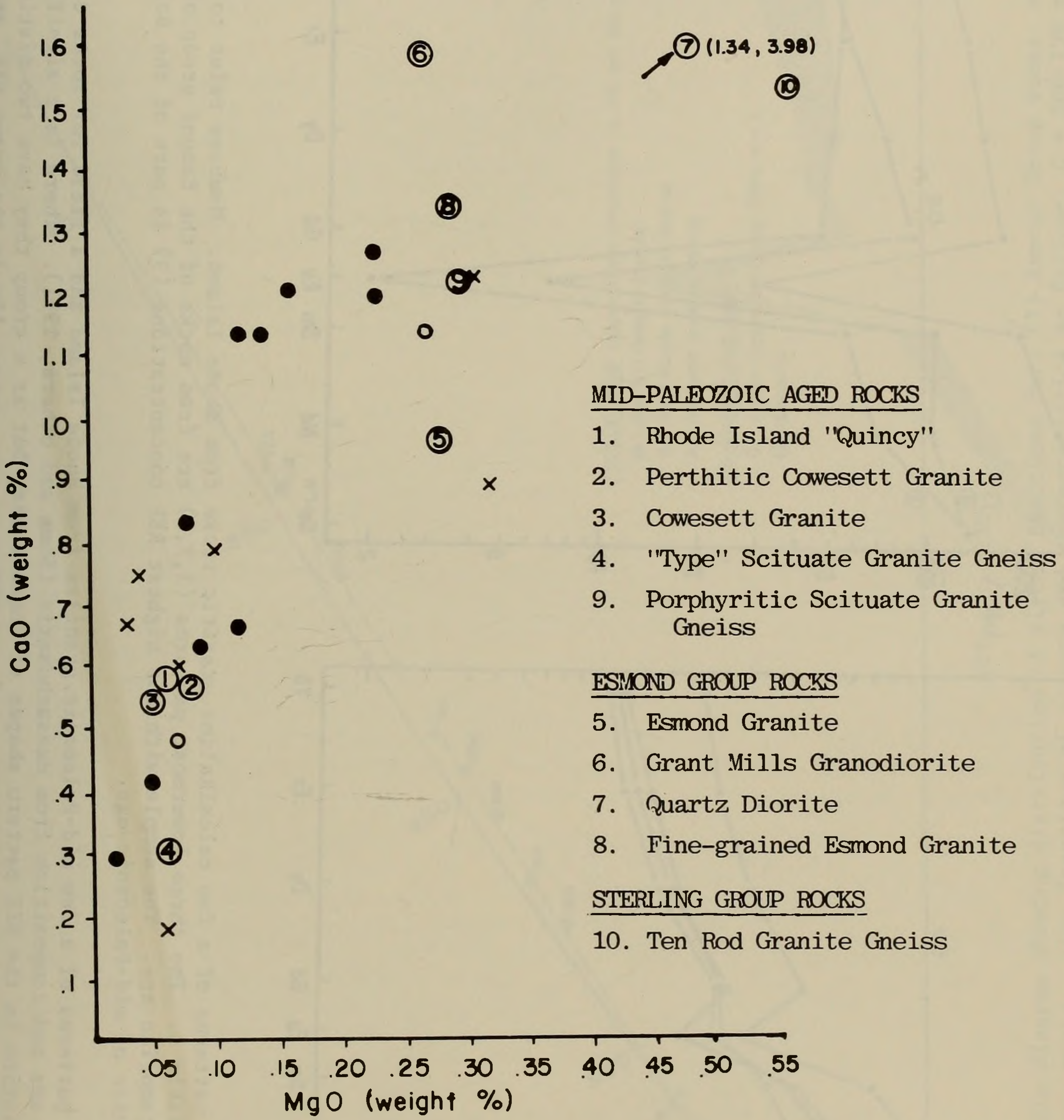


Figure 4: CaO vs. MgO for some granitic rocks from Rhode Island. Numbers correspond to analyses on Table 1. Symbols same as in Figure 3.

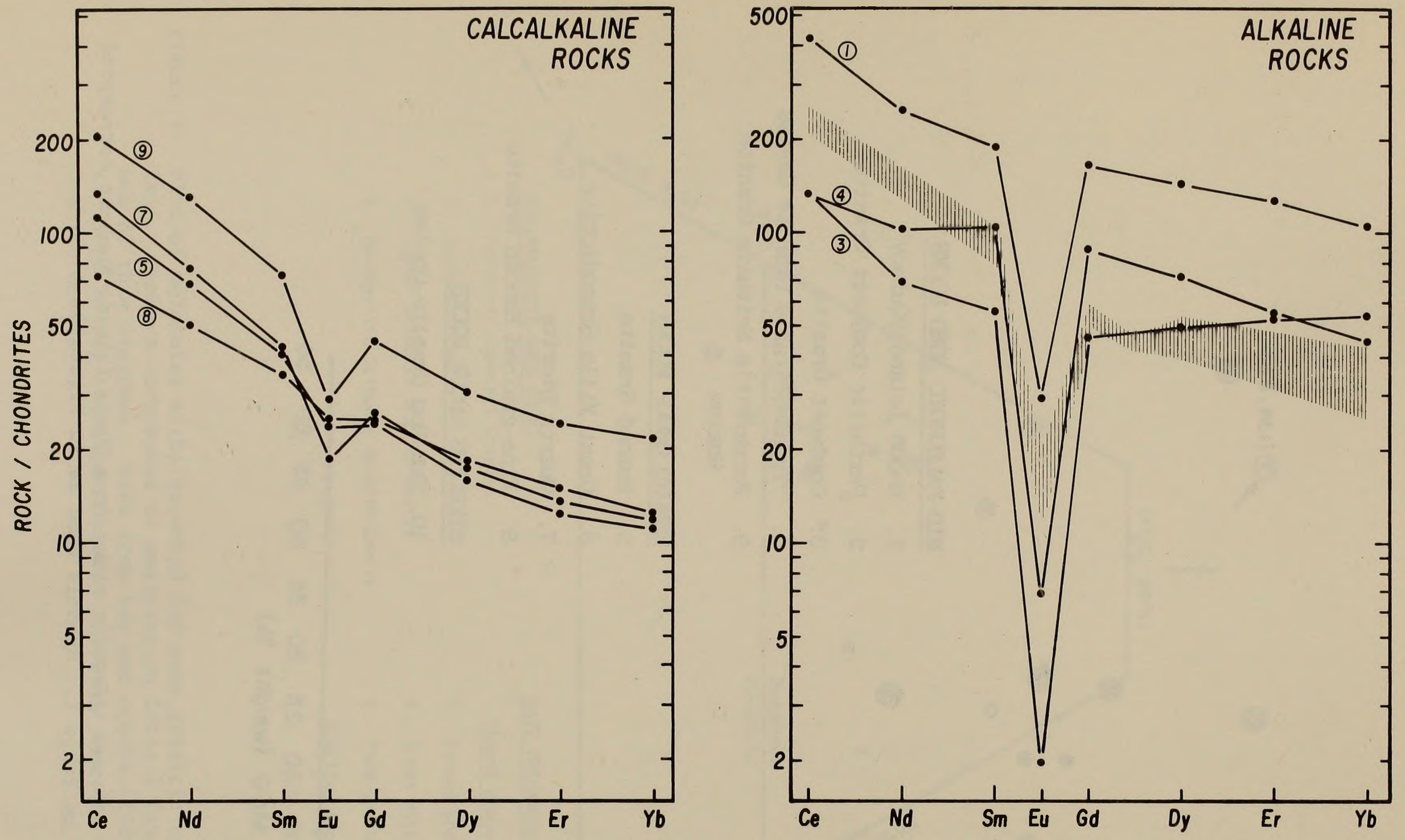


Figure 5: A. REE patterns of a few calcalkaline granitic rocks from Rhode Island. Numbers refer to samples in Table 1. The three lowermost patterns (5,7,8) are from rocks of the Esmond group of late Precambrian age. The sample with the highest REE concentrations (9) is part of the Scituate granite of mid-Paleozoic age.

B. REE patterns of a few mid-Paleozoic granites from Rhode Island and a field for rocks of similar age and composition from Massachusetts (Buma and others, 1971). There is a significant variation in the REE pattern shapes of these rocks, but as a group they have two distinguishing characteristics: (1) highly enriched REE contents, especially in the heavy REE, and (2) exceptionally large negative Eu anomalies.

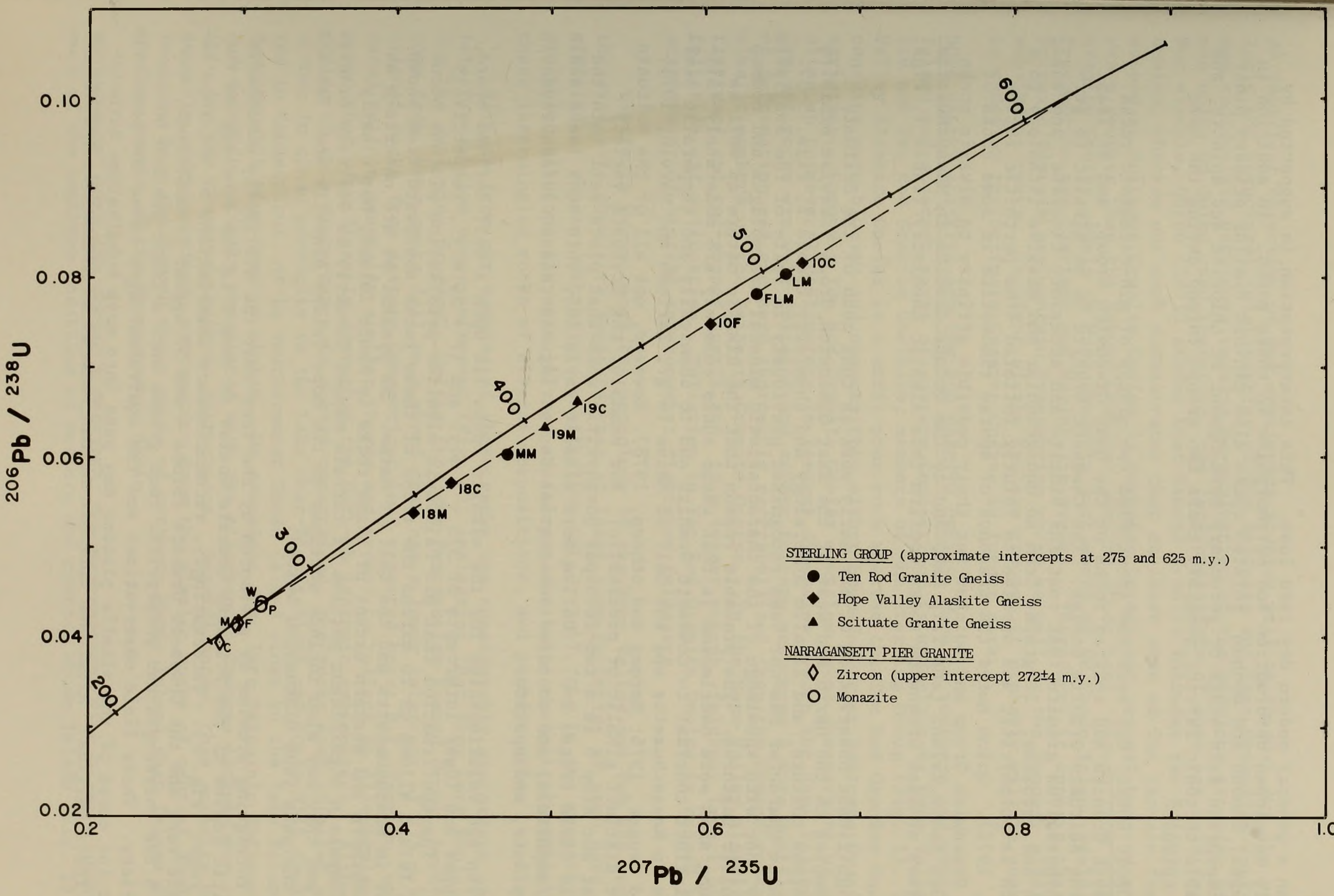


Figure 6: Concordia diagram showing distribution of zircon fractions for: (1) Esmond Group rocks, and (2) mid-Paleozoic rocks. Size fractions of zircons and characteristics as follows: C = 100-150 mesh, M = 200-250 mesh, F = 325-400 mesh, LM = least magnetic, MM = most magnetic, DB = dark brown, LT = light color.

other than a general modern day lead loss. This interpretation is supported by the feebly developed deformation and metamorphism in these rocks. In addition to similar ages, Esmond and Dedham related rocks also exhibit similar primary mineralogy, widespread late-stage or secondary development of chlorite and epidote, and a comparable tectonic fabric; possibly these two groups formed during the same magmatic episode.

MID-PALEOZOIC ROCKS: Our work has identified two groups of mid-Paleozoic rocks: the Cowesett Granite and related rocks of the East Greenwich Group, and at least part of the Scituate Granite Gneiss. The Cowesett Granite is an alkalic to peralkalic hypersolvus granite that contains biotite and accessory fluorite, and sodic amphibole and pyroxene. It grades from an equigranular and massive lithology to a rock which is porphyritic and massive to faintly foliated (the perthitic facies of Quinn, 1971). Quinn noted the presence of sparse riebeckite in some rocks of the East Greenwich Group and pointed out their possible affinity to alkalic rocks in northern Rhode Island (see Trip B-4) and to the Quincy Granite in Massachusetts. New analyses of East Greenwich rocks confirm this alkalic chemistry (Table 1, Figs. 3-5).

A significant observation of our early work is that much of the Scituate Granite Gneiss to the north and west of the East Greenwich Group likewise exhibits a hypersolvus texture, and alkalic mineralogy and chemistry (Table 1, Figs. 3-5). This alkalic character has not been recognized previously in spite of the available chemistry, nor with knowledge of the characteristic mineral assemblages and common mesoperthitic textures. The probable reason that the alkalic nature as well as their young ages were overlooked is that these rocks commonly are moderately foliated in distinct contrast to Cowesett Granite and to chemically and temporally similar rocks in Massachusetts and the Gulf of Maine (e.g., Zartman and Marvin, 1971; Lyons and Kruger, 1976; Hermes and others, 1978). However, not all of the Scituate rocks are distinct alkalic or peralkalic. For example, the Scituate variety exposed at our Stop 6 is a two-feldspar porphyritic rock that plots well into the subalkalic field (Figs. 2-3). Unlike more alkalic varieties, this rock lacks sodic pyroxene/amphibole, and contains substantial Ca-bearing minerals including plagioclase, epidote, and apatite.

Zircon age relationships for the alkalic rocks lie upon a well defined chord having upper and lower intercepts of 373 ± 7 m.y. and 17 ± 30 m.y., respectively (Fig. 6). The confirmation that mid-Paleozoic alkaline-peralkaline plutons occur in Rhode Island allows us to extend the trend of these rocks southward from known exposures in Massachusetts and the Gulf of Maine. At present we are uncertain as to the southern and western extent of these rocks in Rhode Island, but clearly they encompass a significant portion of terrain mapped formerly as Scituate Granite Gneiss, and they may also include portions of the Hope Valley Alaskite and Ten Rod Granite Gneisses (see discussion below).

An intriguing problem is presented by the fact that the distinctly subalkalic porphyritic facies of the Scituate Granite Gneiss at Stop 6 is the same age as the alkalic rocks (Fig. 6). Interestingly, reconnaissance observations of outcrops between this rock and the Cowesett Granite (Stops 4 and 5) appear transitional, and at Stop 6 the coarse-grained porphyritic rock grades into a finer-grained border zone variety. These field observations and the equivalent ages raise the possibility that the cores of the alkalic plutons may pass into more subalkaline lithologies at their margins. Alternate interpretations have to be evaluated, however.

An important objective of our continuing studies will be to sort out the petrologic and structural relationships of the Scituate and East Greenwich rocks. The new radiometric data does require re-evaluation of the previous grouping of some map units by Quinn, and therefore, the interpretations of some age relationships. For example, Quinn (1971) states that Esmond Granite intrudes the Scituate Granite Gneiss, whereas our work demonstrates that at least some of the terrain formerly mapped as Scituate Granite Gneiss is Devonian in age and several hundred million years younger than the Esmond Granite. On the other hand, zircon from a Scituate Granite Gneiss sample in Massachusetts just north of NW Rhode Island yields a late Precambrian age (Zartman and Naylor, in press). Therefore, it appears that the Scituate terrain may contain Precambrian rocks as well as the younger alkalic and subalkalic rocks. In light of the two age groups, it probably will be necessary to redefine the Scituate Granite Gneiss in future work.

HOPE VALLEY ALASKITE AND TEN ROD GRANITE GNEISS: Much of southern and western Rhode Island and adjacent parts of eastern Connecticut is underlain by Hope Valley Alaskite and Ten Rod Granite Gneisses, members of the Sterling Group (Fig. 1). The Hope Valley Alaskite Gneiss is a mafic-poor rock whereas the Ten Rod Granite Gneiss contains more biotite and opaques than either Hope Valley or Scituate Granite varieties. Commonly Ten Rod Granite Gneiss contains large phenocrysts of microcline up to several centimeters in longest dimension. Both the Hope Valley and Ten Rod rocks are well-foliated and appear to have undergone a more ductile style of deformation and are more thoroughly recrystallized than the Esmond rocks on the alkalic members of the Scituate Granite Gneiss. In the Hope Valley Alaskite Gneiss, flattened and rod-shaped quartz and, to a lesser extent, feldspar impart both a foliation and a lineation. Foliation in Ten Rod Granite Gneiss is caused by planar arrangement of biotite and somewhat flattened feldspars.

Little is known about the petrology of the Hope Valley and Ten Rod rocks, but the available chemistry suggests that at least some varieties of each have alkalic affinities, whereas others are subalkaline (Figs. 3-4). As in the case of the Situate Granite Gneiss, it will be necessary to evaluate the relationships among these intermingled rocks of diverse compositions, and perhaps ages.

Zircons from our samples of these rocks are considerably discordant and yield a late Precambrian upper intercept (Fig. 7), indicating that they were emplaced during the Avalonian Orogeny. Unlike the late Precambrian Esmond Group, however, zircons from these rocks fall on a chord that has a lower intercept of 275 m.y. Additional rocks from eastern Connecticut (not reported here; R.E. Zartman, unpub. data) fall on generally similar chords and appear to reflect an Alleghenian aged event that significantly disturbed the U-Th-Pb isotopic systematics. Although the region of this disturbance is poorly constrained, the rocks most affected are either in close proximity to the Lake Char-Bloody Bluff and Honey Hill fault system in Connecticut, or in southernmost Rhode Island close to the late Paleozoic Narragansett Pier Granite pluton. We speculate that late Paleozoic deformation and magmatic activity associated with the Alleghenian Orogeny largely was responsible for the observed isotopic disturbance. Significantly, this activity has not severely affected zircon systematics from the alkalic rocks of central Rhode Island, or from the Esmond Group rocks of northern Rhode Island that fringe the western margin of the Narragansett Basin.

NARRAGANSETT PIER AND WESTERLY GRANITES: The Narragansett Pier Granite underlies much of the southern coastline of western and central Rhode Island (Fig. 1). It truncates many of the structures in the older rocks, and generally exhibits a lit-par-lit intrusive style (see Trip B-5). The rock generally is massive except for local flow foliation, and is calcalkaline in composition. The Westerly Granite is a finer-grained aplitic facies that commonly forms E-W striking dikes that dip gently to the south. These dikes, up to several tens of meters thick, especially are common in the western part of the Narragansett Pier Granite pluton near Westerly.

Rocks of this pluton cut a variety of country rocks, including Hope Valley Alaskite Gneiss, rocks of the Blackstone Series, and the Carboniferous Rhode Island Formation. Monazite, from both a white border facies and an interior pink facies from the eastern part of the pluton, have been dated by U-Pb techniques (Kocis, 1981). These data yield generally concordant ages of 276 m.y., which is compatible with the field relationships. We have dated zircon from a sample of Narragansett Pier Granite from the western part of the pluton. The zircon is mildly discordant, and yields an upper intercept of 272 ± 4 m.y., in agreement with the monazite data (Fig. 7). Generally, Westerly Granite is considered to be a comagmatic aplitic facies of the NPG. Our attempts to date zircon from Westerly Granite are not yet definitive, but suggest that it may be part of the Narragansett Pier Granite magmatic episode. Interestingly, zircon from the Westerly Granite exhibits a marked inheritance that we presently are evaluating in greater detail.

ACKNOWLEDGMENTS

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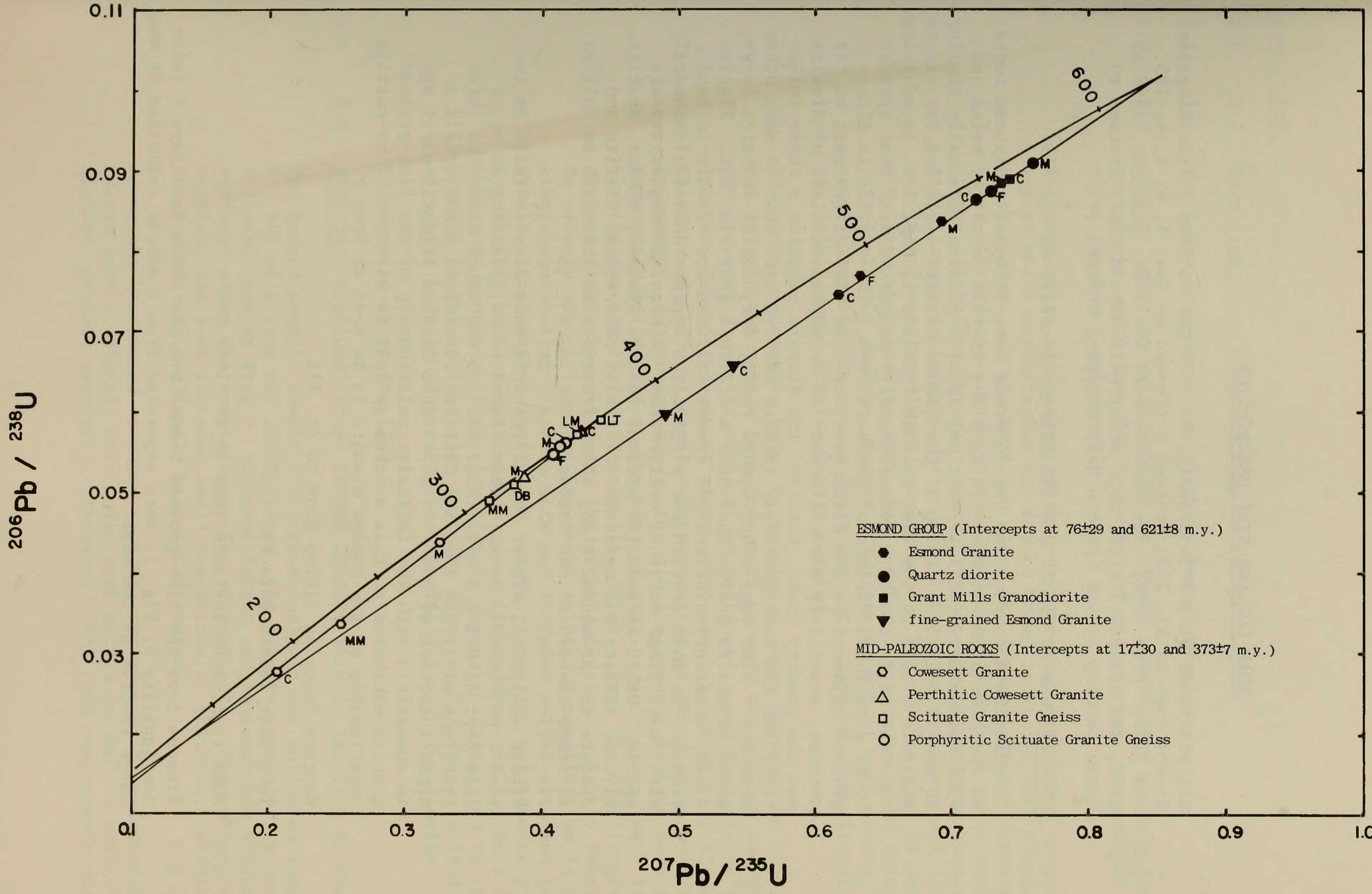

Figure 7: Concordia diagram showing distribution of: (1) zircon fractions for some Sterling Group rocks, and (2) zircon and monazite fractions from Narragansett Pier Granite. Monazite data from Kocis (1981) W = "white" facies, P = "pink" facies, other letters same as in Figure 6.

ROAD LOG AND STOP DESCRIPTION

Miles cum.	int.	
0	-	Log starts at Stop 1 in Lincoln, RI. To get to Stop 1 from Kingston, travel east on Rt. 138; proceed northward on Rts. 1, 4, 2, 4, I95, and I295. From I295, take exit 9A onto Rt. 146S. Take Rt. 116W at exit, and after 0.7 mile, turn right onto Albion Road. Proceed to large outcrop behind Lincoln Mall Shopping Center.

STOP 1: ESMOND QUARTZ DIORITE (Zircon locality 8, Fig. 1)

The diorite member of the Esmond Group here intrudes schistose rocks of the Blackstone Series. In turn the diorite is cut by veins and dikes of subhorizontal to vertical aplitic granite, generally similar to the fine-grained facies of the Esmond Granite collected for zircon analysis ¼ mile to the east (zircon locality 9, Fig. 1). In addition, the diorite is cut by a compositionally composite dike that appears to be a textural variant of the host rock. The diorite is finer-grained adjacent to the Blackstone rocks at the eastern part of the outcrop, especially where lit-par-lit or webbed veinlets of diorite cut the country rock. Locally, the diorite exhibits a shear foliation, but the rock generally is more massive here than at most other outcrops. Like many other Esmond rocks, the diorite contains large anhedral quartz grains that have a distinct gray-blue hue. Plagioclase, accessory biotite, and sparse sulfides are visible in hand sample. In thin section the plagioclase appears subhedral-anhedral with thin, clear marginal overgrowths. Microcline megacrysts are sparse. Other accessories present include opaques, sphene, apatite, zircon, calcite and epidote. Partially chloritized biotite and epidote are prominent along shear fractures in this rock as well as in other members of the Esmond Group.

Within analytical error, the zircon from this diorite falls on the same U-Pb discordia as the other Esmond rocks, yielding an upper intercept of 621 ± 8 m.y. (Fig. 6). On the other hand, the three fractions of zircon from the diorite, considered alone, yield an upper intercept of 648 ± 27 m.y. This implied slightly older age is compatible with the intrusive relationship of the fine-grained granite exhibited at this outcrop as well as with the cross-cutting relationship of the Esmond Granite to be seen at Stop 2.

Retrace route on Albion Road to Rt. 116.

0.5	0.5	Turn left (east) onto Rt. 116
1.6	1.1	Bear right onto entrance ramp to Rt. 146N.
1.9	0.3	Zircons from the fine-grained Esmond Granite shown in Figure 6 (zircon locality 9, Fig. 1) were separated from a sample collected at the large roadcut to the east.

cum. int.

2.6 0.7 Bear right onto entrance ramp to I295S.

3.8 1.2 The large roadcut to the north is Esmond Granite

5.8 2.0 STOP 2: CONTACT RELATIONSHIPS OF ESMOND GRANITE AND DIORITE (Walk toward the south from the north end of the outcrop, and proceed along the Rt. 7 exit ramp).

The complexity and variety of intrusive relationships and intrusive styles which characterize the Esmond Group rocks are well displayed at this stop. In the road cut along the freeway, Esmond Granite and a dioritic rock both intrude schistose to massive mafic rocks of the Blackstone Series. In most instances the contacts between the Blackstone Series rocks and the intrusives are sharp and local stoping of angular blocks has occurred. The granite also is intrusive into the dioritic rock, but complex interfingering of these two lithologies is common. Toward the northern end of the outcrop, the granite and diorite are in fault contact. Both of these lithologies are foliated and locally highly sheared.

Additional outcrop is found by walking a short distance to the south and up the exit ramp. Here, contacts between the granite and the diorite vary from near vertical to horizontal, and from planar to lobate. Some displacement along subhorizontal, undulating planes is evident. As before, complex intermingling of the granite and diorite is common. In several areas, the diorite appears to have been incompletely solidified at the time of granite intrusion. Both lithologies are cut by felsic pegmatite dikes. Near the diorite-granite contact along the exit ramp, the granite displays a hackly fabric due to closely spaced intersecting shear joints. Mineralization is common along intersecting fracture sets and includes molybdenite and lesser pyrite, along with sericite and quartz. Locally, molybdenite platlets are sharply bent as the orientation switches from one fracture orientation to another. Mineralization is generally restricted to the granite in the contact zone near the diorite, but sparse sulfides also have been found parallel to the foliation in the diorite.

Continue south on Rt. I295.

8.9 3.1 STOP 2A: (Optional Stop) ESMOND GRANITE (Zircon locality 6, Fig. 1).

The Esmond Granite sample for zircon analysis was collected from the Rt. 44E exit ramp off I295S. Here, the granite generally is less foliated than at Stop 2, although fabric and textures are slightly variable along the extensive series of road cuts. Even where most massive, the rock contains small quantities of chlorite, epidote, and sericite in a slightly granulated texture.

Along the southbound entrance to I295, the typical Esmond Granite passes into a slightly more mafic rock with a medium- to coarse-grained seriate porphyritic texture. This rock corresponds quite cum. int. closely in lithology and texture to the Grant Mills Granodiorite which Quinn (1971) has described elsewhere as being gradational into Esmond Granite. We will not be stopping within areas mapped as Grant Mills Granodiorite, but the characteristic features of the rock can be observed at this outcrop where it does appear to be a gradational facies of the Esmond Granite.

Several tens of meters farther south along the entrance ramp, Esmond Granite can be seen to encompass and invade masses of mafic and schistose rocks, which according to convention generally are assigned to the Blackstone Series. Mostly sharp contacts between the granite and the inclusions suggests that little reaction has occurred between them, although the granite does display more compositional variation adjacent to the inclusions compared to granite far from them. In most instances, however, no simple correlation between immediate proximity and composition is evident, and the variation include more felsic as well as more mafic compositions. Locally, however, the granite has a more mafic appearance due to the presence of small and rather well disseminated mafic inclusions.. A variety of intrusive styles are exhibited, including locally abundant angular inclusions that form an intrusive breccia. As at the previous stop, the complexity and diversity of textural and contact relationships displayed in this outcrop are the result of igneous processes.

Continue south on I295.

12.6 3.7 The large outcrops at the intersection of I295 and 195 consist of Scituate Granite Gneiss (with locally abundant xenoliths and roof pendants of Blackstone Series rocks).

13.5 0.9 <u>STOP 3</u>: SCITUATE GRANITE GNEISS (Zircon locality 5, Fig. 1).

This stop will allow examination of two texturally distinct lithologies which have been mapped as part of the Scituate Granite Gneiss. In the section of the outcrop that we will be visiting, the lithologies are in fault contact. In other exposures these rocks may be in intrusive contact.

To the north of the fault, the rock is a medium-grained, moderately to strongly foliated and lineated quartz-feldspar rock with usually no more than several percent biotite. Smaller quantities of minute muscovite flakes present in much of this rock are particularly evident where the rock displays closely spaced shears. The presence of some schistose inclusions indicate that this is a magmatic rock. In thin section, the only likely relict grains are scattered ragged-edged mesoperthite. The persistence of this exsolved phase suggests that the recrystallization to which this rock had been subjected was not pervasive enough to obliterate all of its primary texture.

The lithology south of the fault is a hypersolvus alkalic granite (see analysis 4, Table 1). It is distinguished from the previous lithology by its considerably coarser grain size, the common presence of sodic pyroxene, riebeckite, and tabular Carlsbad-twinned cum. int.

mesoperthite, a much less foliated and lineated character, and a general lack of closely spaced shears. The mafic minerals are dominated by biotite which are largely grouped into thin, ovoid clots typically a centimeter or so in longest dimension. The clot-like texture, which is characteristic of type Scituate Granite Gneiss (Quinn, 1971), is recognizeable even where the rock is highly foliated. This texture stands in contrast to the finer grained and more evenly disseminated mafics in the granite gneiss north of the fault. In thin section, the rock displays mortar texture with relict igneous mesoperthite, quartz, and pyroxene-riebeckite-biotite clots set in a fine-grained matrix of quartz and feldspar. Zircon and fluorite are common accessory phases.

Zircons separated from this lithology (mildly foliated material located several tens of meters south of the fault) yield a Devonian upper intercept on concordia (Fig. 6). Although this rock is more foliated than the Cowesett Granite (Stop 4), the strong compositional, temporal, and inferred primary textural similarites between these rocks suggests that they were formed by closely related processes. The more foliated character of the lithology here, presumably, was the reason Quinn assigned it to the Scituate Granite Gneiss, but the zircon age data are in gross conflict with his field interpretations for the Scituate Granite Gneiss *as a whole*. As it now appears that the Scituate Granite Gneiss probably includes rocks of diverse ages and origins, a redefinition of this unit may be necessary.

The time of juxtaposition of the lithologies exposed in this outcrop is unknown, but the distinct differences in the textures and structures of these rocks suggests that the faulting postdates the development of these features. The age of the lithology north of the fault has not been determined, but there is little to suggest that it is part of the magmatic episode which generated the late Precambrian Esmond Group and related rocks. The rock here lacks the Ca-bearing phases such as non-albitic plagioclase, hornblende or epidote which are so characteristic of the late Precambrian rocks. Rather, this rock is likely to be a more recrystallized and slightly subalkaline variant (see range of chemistries for alkaline rocks, Table 1, Fig. 2-3) of the lithology south of the fault. Future work will need to address this possibility.

Continue south on I295.

16.5 3.0 Roadcut consisting of dark colored rocks of the Blackstone Series that are cut by dikes, sills, veins and pods of Esmond Granite.

18.7 2.2 Merge into southbound I95

21.9 3.2 Merge left, take exit 9 (Rt. 4S); then quickly merge right in preparation for an exit to the right.

22.4 0.5 Exit right onto Rt. 401

22.6 0.2 Continue straight through stop sign towards resturant; take sharp left and park vehicles adjacent to Narragansett Electric property. Walk cum. int. east to Rt. 4 overpass and climb down embankment to roadcut. Walk southward along Rt. 401 exit ramp, returning to parked vehicles.

STOP 4: COWESETT GRANITE (zircon locality 4, Fig. 1).

With the exception of the relatively young Narragansett Pier Granite, the massive Cowesett Granite in this area is the least deformed plutonic rock that we have found in Rhode Island. Flow and shear foliations are absent, and the only structural features of significance are two highly sheared mafic dikes (N75W, 80N) that contain biotite and garnet and are strongly foliated parallel to the strike direction. The rock is coarse grained and contains perthitic feldspar, quartz, and irregular and sparsely dispersed mafic clots of intergrown biotite, lesser sodic pyroxene, sodic amphibole, and ragged opaques. Fluorite is common in the rock matrix as well as in localized vugs and veinlets. The colorless to milky quartz is quite distinct from the bluish quartz associated with Esmond Group rocks. The perthite is euhedral-subhedral and exhibits thin exsolution bands oblique to Carlsbad twin planes that give many grains a herringbone appearance. This texture is quite common in other alkalic plutons of SE New England (Hermes and others, 1978).

Major and trace element patterns for Cowesett Granite, as well as for the other alkalic rocks, are quite distinct from the more calcalkaline Esmond Group (Figs. 3-5). Zircon geochronology demonstrates that the Cowesett Granite is of the same age as the more foliated and deformed alkalic rocks to the north and west (e.g., stop 3 and 5). Interestingly, the Cowesett rocks are overlain unconformably to the east by younger but metamorphosed and deformed Carboniferous sediments of the Narragansett Basin. It is unclear whether this localized area somehow was shielded from the effects of the Alleghenian Orogeny, or perhaps represents an allochthons block formed in a stress-free environment.

Proceed west on Rt. 401.

22.9 0.3 Turn right (north) onto Rt. 2.

23.2 0.3 Bear right onto entrance ramp to I95S.

24.8 0.3 STOP 5: PORPHYRITIC COWESETT GRANITE

The rock exposed here was mapped by Quinn (1971) as a perthitic facies gradational into Cowesett Granite to the east. Since the Cowesett itself is a perthitic one-feldspar granite, it seems inappropriate to use this criterion to distinguish the two rocks. At this outcrop the rock is a seriate subporphyritic rock that contains perthitic feldspar phenocrysts up to 1 cm. Other nearby outcrops of this facies are more distinctly porphyritic. Generally biotite is more abundant than in the Cowesett of the previous stop. The outcrop is cut by numerous closely spaced subhorizontal shear joints that locally impart a prominent foliation. Gash veins filled with quartz cut this foliation. In thin section the margins of many feldspar and quartz grains have been granulated to form mortar texture. Accessory cum. int. minerals include zircon, fluorite, sparse pyroxene and/or amphibole, and calcite that appears secondary.

Especially prominent in the south road cut are rounded xenoliths (autoliths?) of a fine-to medium-grained igneous rock. A one meter wide diabasic dike (N25W, 80SW), that exhibits chilled margins and contains locally stopped granite fragments, cuts the outcrop on both sides of the road. This is one of the unmetamorphosed dikes that has a more alkalic chemistry and mineralogy (Pierce and Hermes,1978) than Mesozoic dolerites associated with the Triassic-Jurassic Basins of the Appalachians (the eastern North American dolerites of Weigand and Ragland, 1970). Shear zones that cut the granite are truncated by the dike rock.

Our sample of the perthitic Cowesett facies collected for zircon dating (zircon locality 3, Fig. 1) is moderately alkalic (Figs. 3-5). Two zircon fractions lie on the same discordia chord as the Cowesett Granite which has a mid-Paleozoic upper intercept (Fig. 7).

Continue south on I95.

28.5 3.7 Take exit 6 to Rt. 3N, and turn right into unpaved commuter parking lot at end of exit ramp. On foot, cross Rt. 3 to the I295S entrance ramp.

STOP 6: BORDER ZONE OF PORPHYRITIC SCITUATE GRANITE (Zircon locality 2, Fig. 1).

The relationships observed along this road cut indicate that we are near the border zone of an intrusion, although our reconnaissance has not yet located any country rock. To best observe these features, walk along the top of the outcrop .

The northernmost part of the outcrop consists of dark gray rock that contains sparse phenocrysts of microcline in a fine-grained matrix of quartz, microcline, plagioclase, biotite, sphene, apatite, monazite, and calcite. Over a distance of 10-15 m, this apparent border facies grades into a rock which contains a greater abundance of phenocrysts and has a coarser matrix. Eventually, this facies grades into a coarse-grained porphyritic, pink rock that constitutes most of the outcrop. The pink rock contains abundant microcline phenocrysts and large strained quartz with lesser plagioclase, partly chloritized biotite, sphene, opaques, and calcite. Numerous autoliths of border facies rock occur in the pink facies, and locally the textures and lithologies are interfingered and complexly mixed (especially visible from the top of the outcrop). This mixed appearance gives the impression that the intrusion involved several pulses of emplacement.

Locally, the rock exhibits faint flow foliation of variable attitude (generally a NW strike and steep dip). Cutting this fabric are two sets of steeply dipping, closely spaced shears (N10W; N55E) that impart a deformational fabric, although locally the rock is rather massive. Several aplite and quartz veins exposed on top of the outcrop show small offsets along these shear directions.

cum. int. The textures and chemistry exhibited by the rocks at this stop are quite different from the alkalic rocks to the east (Fig. 3-5) yet zircon ages indicate that they are contemporaneous (Fig. 6). It is unclear whether this porphyritic Scituate facies represents a distinct calcalkaline magmatic episode, an allochthonous fault block, or a marginal compositional variety of the alkalic pluton. Reconnaissance examination of outcrops between stops 5 and 6 suggest that a gradational transition may exist. In future work, we intend to evaluate the hypothesis that this porphyritic facies of the Scituate Granite Gneiss exposed here might represent a more primitive calcalkaline border facies of an otherwise predominant alkalic-peralkalic pluton.

Continue south on I95.

37.8 9.3 Roadcut exposing Hope Valley Alaskite Gneiss.

38.8 1.0 STOP 7: HOPE VALLEY ALASKITE GNEISS

This stop is approximately one mile east of the Hope Valley Alaskite Gneiss type locality which was sampled for zircon geochronology. Here, the gneiss exhibits a lit-par-lit intrusion relationship into screens of more mafic-rich amphibole-bearing rock that may be a member of the Blackstone Series (see Fig. 11, Trip B-5). These relationships, as well as those farther to the south along I95, indicate that a least part of the Hope Valley Alaskite Gneiss truly is intrusive, and not a pile of volcaniclastics as speculated by Day and others (1980a).

The Hope Valley Alaskite exhibits a well developed foliation caused by planar arrangement of rodded and flattened quartz and feldspar. It is a two-feldspar rock of low color index with sparse biotite, opaques, muscovite, apatite, sphene, monazite, and zircon. This rock, as well as the Ten Rod Granite Gneiss of the next stop are significantly more foliated and have undergone much more ductile deformation than any of the other rocks observed at previous stops.

On a concordia diagram zircons from the Hope Valley Alaskite and Ten Rod Granite Gneisses define a chord with a late Precambrian upper intercept (Fig. 7). This upper intercept is similar to the Esmond Group rocks, and suggests that all of these rocks formed during a limited interval of time. A lower intercept of approximately 275 m.y. for the Hope Valley and Ten Rod rocks is in marked contrast, however, to the near zero age lower intercept for the Esmond Group and the Devonian-aged alkalic rocks. An important observation is that rocks containing zircons with late Paleozoic lower concordia intercepts appear to be restricted to southern Rhode Island-Connecticut, or to the region in close proximity to the Lake Char fault system of eastern Connecticut. Admittedly, this observation is based upon a limited sampling, but the rather prominent differences of textures and fabrics of Hope Valley Alaskite and Ten Rod Grnaite Gneisses, compared to the Devonian and late Precambrian rocks of central and northern Rhode Island, are rather profound. It seems reasonable to hypothesize that the Pb loss from the zircons of Ten Rod and Hope cum. int. Valley gneisses may be related to processes associated with the Alleghenian Orogeny. It has been known for some time that the K-Ar systematics of micas from much of Rhode Island and northward have undergone a rather pervasive Permian aged disturbance (Zartman and others, 1970). Likewise, ^{40}Ar/^{39}Ar release spectra from biotite and hornblende indicate that the effects of Alleghenian metamorphism extend across southwestern Rhode Island (Dallmeyer, 1981). In comparison, the area of disturbed zircons seems to be much more restricted.

continue south on I95.

39.4 0.6 Bear right at exit 3A (Rt. 138E); continue east on Rt. 138.

40.5 1.1 Park to the right along wide shoulder, across road from low outcrop.

STOP 8: TEN ROD GRANITE GNEISS

The Ten Rod Granite Gneiss contains distinctive microcline megacrysts up to 1 cm in size. Some megacrysts show crystal outlines suggesting that they may be igneous relicts, whereas others have crude augen shapes. The rock exhibits a distinct foliation (N60W, 35NE), and has layers parallel to the foliation characterized by slight differences in grain size and ratio of mafic/felsic minerals. Ten Rod Granite characteristically has a higher color index than Hope Valley Alaskite. In thin section, the Ten Rod Granite Gneiss consists of microcline, plagioclase, quartz, biotite, sphene, opaques, apatite, zircon, and monazite. The rock is completely recrystallized except possibly for some microcline phenocrysts, and owes its foliation to alignment of biotite, sphene, and flattened quartz and feldspar. The outcrop is cut by both concordant and discordant non-foliated granite and pegmatite that may be offshoots from the Narragansett Pier pluton.

Our sample of Ten Rod Granite Gneiss collected for zircon geochronology is from a locality about 15 miles east of this stop (zircon locality 11, Fig. 1); however, the texture, fabric and lithology there is quite similar. The zircon age was discussed in the previous stop description.

Make U-turn, retrace Rt. 138 westward to I95.

41.4 0.9 Enter ramp to I95S.

48.1 6.7 Take exit 1, and continue on Rt. 3S.

52.7 4.6 Turn left onto Rt. 78S

53.0 0.3 STOP 8A: (Optional Stop) RELATIONSHIPS OF NARRAGANSETT PIER AND WESTERLY GRANITES AND COUNTRY ROCK (Zircon locality 1, Fig. 1).

The road cut shows Narragansett Pier Granite intrusive into amphibolitic country rock, In turn the Narragansett Pier Granite is cut by Westerly Granite, and both granites are intruded by lamprophyric dikes that contain mantle-derived lherzolite nodules (see Fig. 13, Trip B-5). Here the pink Narragansett Pier Granite is a massive and coarse grained, equigranular two-feldspar granite. In hand sample, biotite, muscovite, pyrite, and magnetite can be recognized as prominent accessories. Sphene, monazite, allanite, apatite and zircon also are present. Westerly Granite ranges from gray to pink and contains mineralogy similar to Narragansett Pier Granite, but is a finer-grained aplitic facies.

Previous U-Pb data on monazite from Narragansett Pier Granite to the east in Narragansett yielded a concordant age of 276 m.y. (Kocis, 1981), which is in close agreement to our upper intercept zircon age of 272 ± 4 m.y. from rock at this outcrop (Fig. 7). Presently we are attempting to separate and determine a K-Ar age for phlogopite from the groundmass of the lamprophyre dike that cuts the outcrop.

END OF TRIP: To return to I95, take Rt. 78W, and follow signs to the interstate.

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