1-1-1981

Igneous Rocks of Northern Rhode Island

Rutherford, Malcolm J.

Carroll, Michael R.

Recommended Citation

Rutherford, Malcolm J. and Carroll, Michael R., "Igneous Rocks of Northern Rhode Island" (1981). *NEIGC Trips*. 295.
https://scholars.unh.edu/neigc_trips/295

IGNEOUS ROCKS OF NORTHERN RHODE ISLAND

Malcolm J. Rutherford and Michael R. Carroll
Department of Geological Sciences
Brown University
Providence, Rhode Island 02912

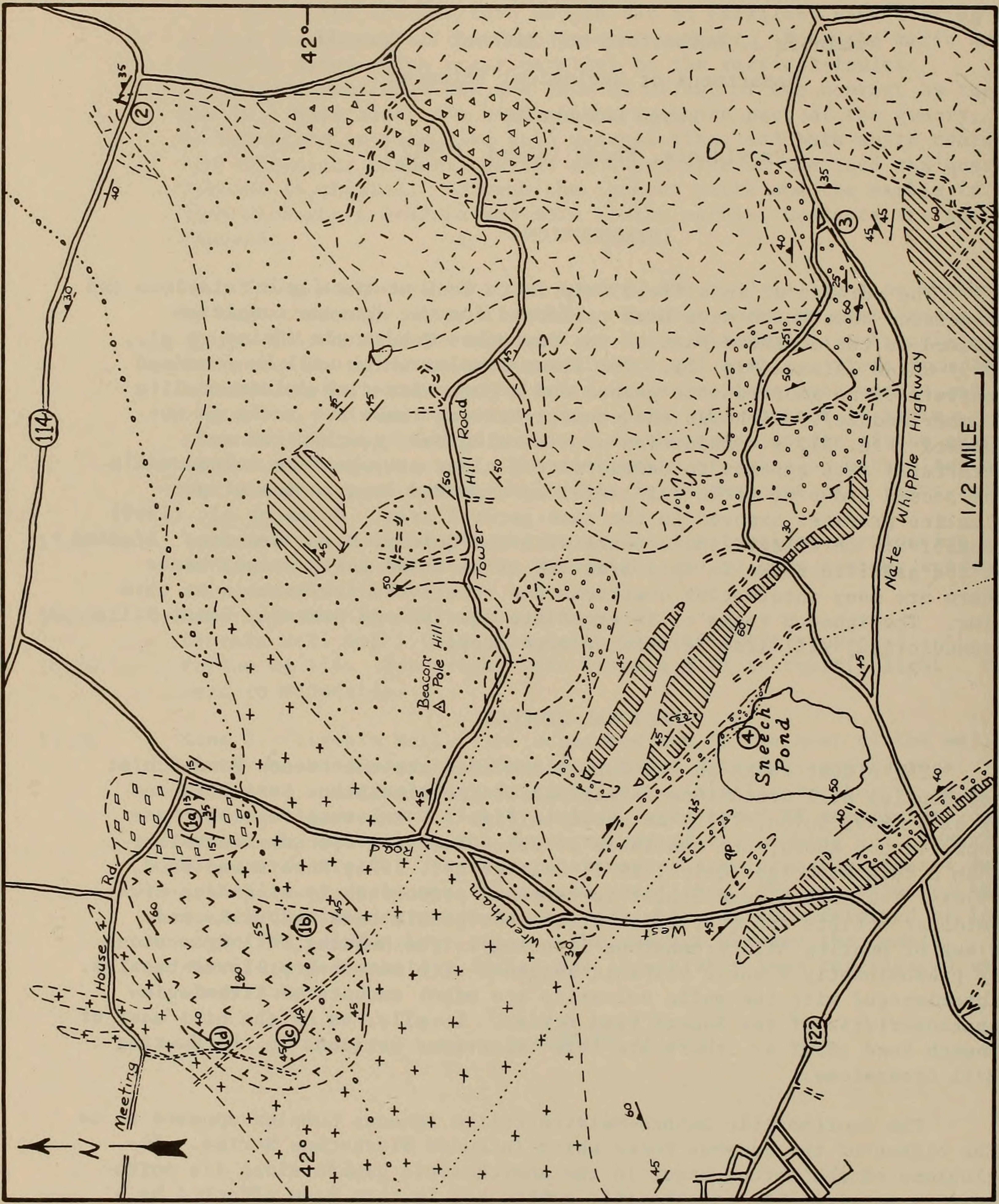
INTRODUCTION

The purpose of this field trip is to look at the field relations and associated data which have been collected for two igneous complexes exposed in the northern part of the Pawtucket Quadrangle (Quinn et al., 1949) Rhode Island (Fig. 1). The first complex which will be examined consists of an anorthositic gabbro and a magnetite-rich melatroctolite (Cumberlandite). Although the contact between these two rocks is not exposed (Fig. 1), a combination of mineralogical, geochemical and structural data appears to demonstrate a clear petrogenetic relationship. The second group of rocks which will be examined is a series of peralkaline granites exposed in the same general area. Quinn et al. (1949) tentatively correlated these rocks with the Quincy, Mass. Granite. Studies of the granitic rocks in this area are still at an early stage, hence there are many interesting questions and relatively few answers at this time. The igneous rocks of intermediate age (Esmond Granite, Grant-Mills Granodiorite) will also be seen at some stops.

REGIONAL GEOLOGY

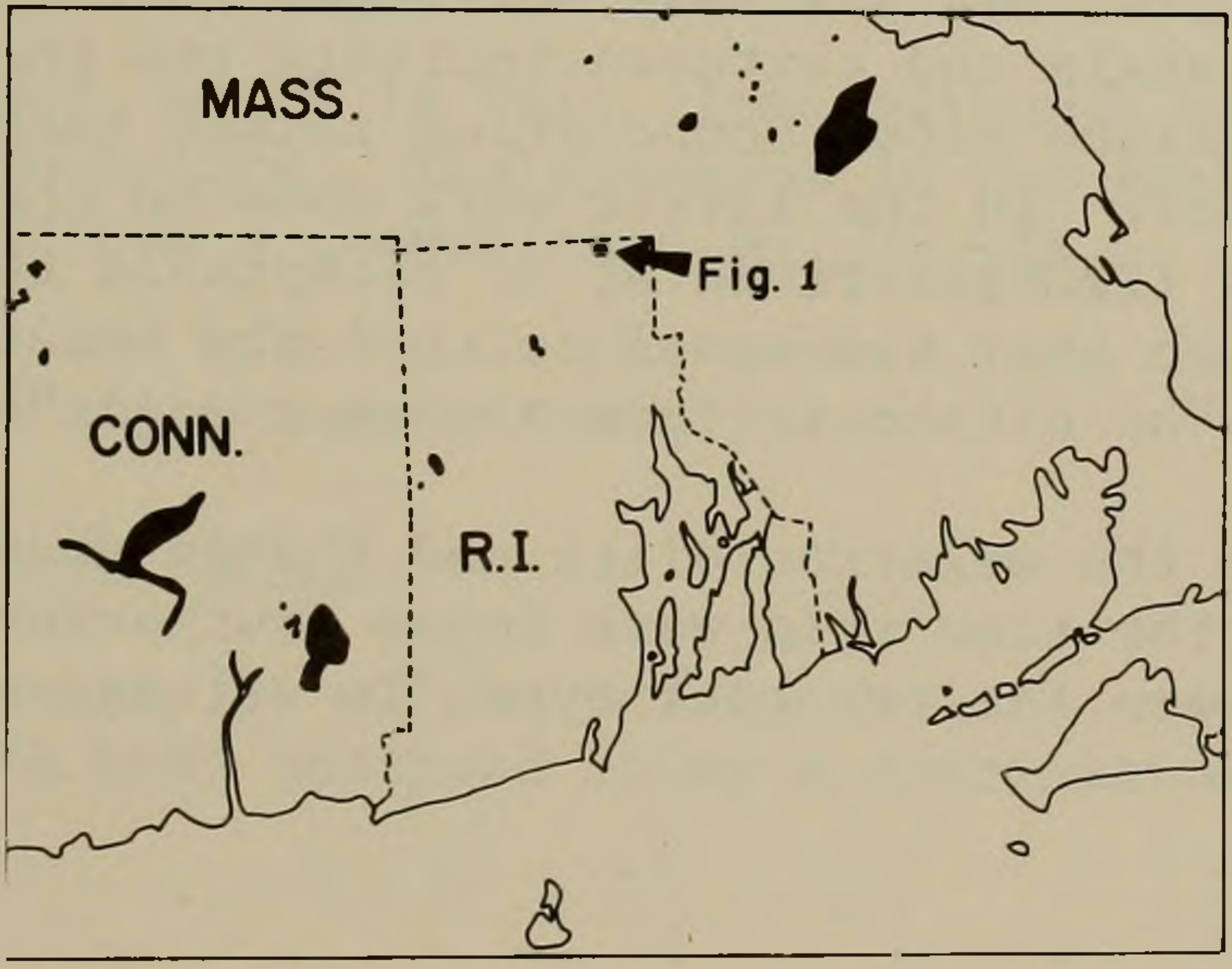
The oldest rocks in the Cumberland area are the Sneech Pond Schist and Hunting Hill Greenstone formations of the Blackstone Series (Quinn et al., 1949; Quinn, 1971) as shown in Fig. 1. The exact age of these rocks is not known, but available evidence favors a Precambrian rather than a Paleozoic age (Quinn, 1971; Rast et al., 1976; Robare and Wood, 1978). The Sneech Pond Schist is composed predominantly of quartz-mica-feldspar schists and quartzites with minor pebble beds and sills and dikes of Hunting Hill Greenstone lithology. The Hunting Hill Greenstone is predominantly a mafic volcanic sequence with numerous pillowed basalts. Interlayered with the mafic volcanics are minor amounts of lithologies characteristic of the Sneech Pond Schist. Locally, as on the hill east of Sneech Pond (STOP 4), there are thin calcareous horizons in the Hunting Hill Greenstone.

The Anorthositic Gabbro-Melatroctolite Igneous Complex appears to be the oldest of the igneous rocks which intruded Blackstone Series. Inclusions of the latter occur in the anorthositic gabbro along its northwestern margin. The anorthositic gabbro has in turn been affected by a


42°
42°
114
122
Tower Hill Road
Beacon Pole Hill
Nate Whipple Highway
1/2 MILE
Sneech Pond
West Wrentham Road
Meeting House Rd.
N
1a
1b
1c
1d
2
3
4

LEGEND

Triassic (?)	⧄	Diabase Dikes
SIL (?)	○	Per-Alkaline Granite Porphyry.
	•	Per-Alkaline Granite. Microperthitic feldspar, aegirine and riebeckite granite.
Early Plutonic Series Precambrian or Early Paleozoic	+	Esmond Granite. Two feldspar, biotite granite.
	/	Grant Mills Granodiotite. Porphyritic.
	△	Quartz Diorite.
	^	Anorthositic Gabbro.
	▱	Magnetite-rich Melatroctolite.
Blackstone Series PC	▨	Hunting Hill Greenstone. Basic volcanics with minor quartzo-feldspathic schists and marble.
	☐	Sneech Pond Schist. Quartzo-feldspathic schists and pebble beds; minor basic volcanics.
	—— - - -	Contact, dashed where approximate.
	—⊥—	Compositional banding of sedimentary or igneous origin.
	—▲—	Foliation, strike and dip.
	··········	Power transmission lines.



Location Map for
Figure 1 (opposite)

deformation event which produced prominent shear zones throughout the gabbro, particularly along its margins. A massive plug of Esmond granite has been found in one of the shear zones. This observation has been interpreted as indicating the Esmond Granite is younger than the anorthositic gabbro (Rutherford and Hermes, MS).

The Esmond Granite is a massive to gneissic, two feldspar, biotite granite in which the original biotite and feldspar have often been partially altered to a fine-grained assemblage rich in chlorite and epidote. The age of Esmond Granite has not been determined radiometrically. Quinn (1971) states that the Esmond appears to grade into the Grant Mills Granodiorite and is intruded by the Quincy granite in the Pawtucket Quadrangle. This observation indicates the Esmond could be late Precambrian or Early Paleozoic. The latter constraint comes from the correlation of the peralkaline granite in this area with the Quincy Granite in Massachusetts, which is thought to have been emplaced at about 420 m.y.b.p. (Naylor and Sayer, 1976).

The two types of peralkaline granite, the equigranular and the prophyry (Fig. 1), both have a foliation which appears to have developed after the rocks crystallized. In places there is also a flow banding or flow lineation in the same rocks. The tectonic foliation resulted from a deformation event that affected rocks in the area sometime after the emplacement of the peralkaline granites, but prior to the emplacement of a series of north-trending diabase dikes. The unmetamorphosed diabase dikes (STOP 2) have been correlated with the Triassic diabases and basalts (Quinn, 1971) found throughout the state.

THE MELATROCTOLITE-ANORTHOSITIC GABBRO COMPLEX

General Petrology and Structure

The melatroctolite is a black, dense (S.G. = 4.0) massive to weakly laminated rock exposed in a small area (Fig. 1) at the north edge of the Pawtucket Quadrangle (Quinn *et al.*, 1949; Rutherford and Hermes, MS). It is an impressive looking rock composed of olivine (49%), titaniferous magnetite (32%), large (2 cm) tabular plagioclase (15%), and minor ilmenite and Al-rich spinel. The plagioclase in the melatroctolite tends to have a preferred orientation which produces the weak foliation in the rock. Although the nature of the minerals and textures indicate the rock is probably igneous, the rather unique modal composition raises questions about how such a rock originates. In the latest work done on the melatroctolite, Johnson and Warren (1908) arrived at no acceptable theory for the origin of the rock, although they did conclude that the melatroctolite and anorthositic gabbro might "be offshoots from a common magma".

The relationship between the melatroctolite and the adjacent anorthositic gabbro was not known at the time this work began (Rutherford and Hermes, MS). The contact between the two rock types is not exposed and the two closest outcrops are 1000 feet apart. Inclusions of gabbro have been found in the melatroctolite, but while some have sharp and angular boundaries (Fig. 2b), others have very irregular outlines and look like large (10 cm) aggregates of cumulus plagioclase. Macroscopically the melatroctolite and gabbro look quite different, but the same minerals occur in both rocks; only the modes (and the bulk compositions) are different. The two rocks are also similar in that both appear to have an igneous lamination, although it is much better developed in the gabbro (Fig. 2c). The following sections review the results of a study of the mineralogy and petrology of the melatroctolite and anorthositic gabbro carried out (Rutherford and Hermes, MS) to determine the origin of the rocks.

Mineral Chemistry

The anorthositic gabbro and melatroctolite have been sampled extensively and the minerals analyzed with the electron microprobe. The minerals in the melatroctolite are completely unzoned; the plagioclase is $An_{59}Ab_{30}$, and the olivine is Fo_{64}. The large ilmenite and titaniferous magnetite grains in the melatroctolite were also analyzed. The ilmenites are homogeneous, but a wide beam technique was necessary in analyzing the titaniferous magnetites because of the microscopic exsolution and oxidation (Fig. 2d and 2e). The compositions of the large grains ($Ilm_{94}Hm_{6}$ and $Mt_{26}Ulv_{63}Hc_{10}$) yield temperatures of 950° C ± 100° and an f_{O_2} of $10^{-12.5 \pm 1.0}$ using Lindsley's (1977) data. The large error bars on these values are primarily the result of the large hercynite component in the spinel phase.

The euhedral, tabular (1 cm x 1 mm) cumulus plagioclase crystals in the gabbro have exactly the same composition as the plagioclase in the melatroctolite, An_{59}, but they have intercumulus overgrowths which range from An_{60} to An_{40}. Other cumulus phases in the gabbro are olivine, ilmenite and titaniferous magnetite (See Fig. 2c and Fig. 4). Very few unaltered olivines were found in the gabbro and most were embayed and obviously in reaction relation with the Ca-rich pyroxene. The few olivines that were suitable for analysis were unzoned and ranged from Fo_{54} to Fo_{40}. The titaniferous magnetite and ilmenite were $Mt_{21}Ulv_{70}Hc_{9}$ and $Ilm_{95}Hm_{5}$ respectively, which is very close, although not identical to those found in the melatroctolite. The pyroxene in the gabbro appears entirely intercumulus and has a composition $En_{34}Wo_{48}Fs_{17}$. There is also minor late hornblende and apatite in the gabbro, and they, like the pyroxene, are not present in the melatroctolite.

Whole Rock Chemistry

Four samples of the melatroctolite and ten of the anorthositic gabbro have been analyzed using a combination of wet chemical and atomic

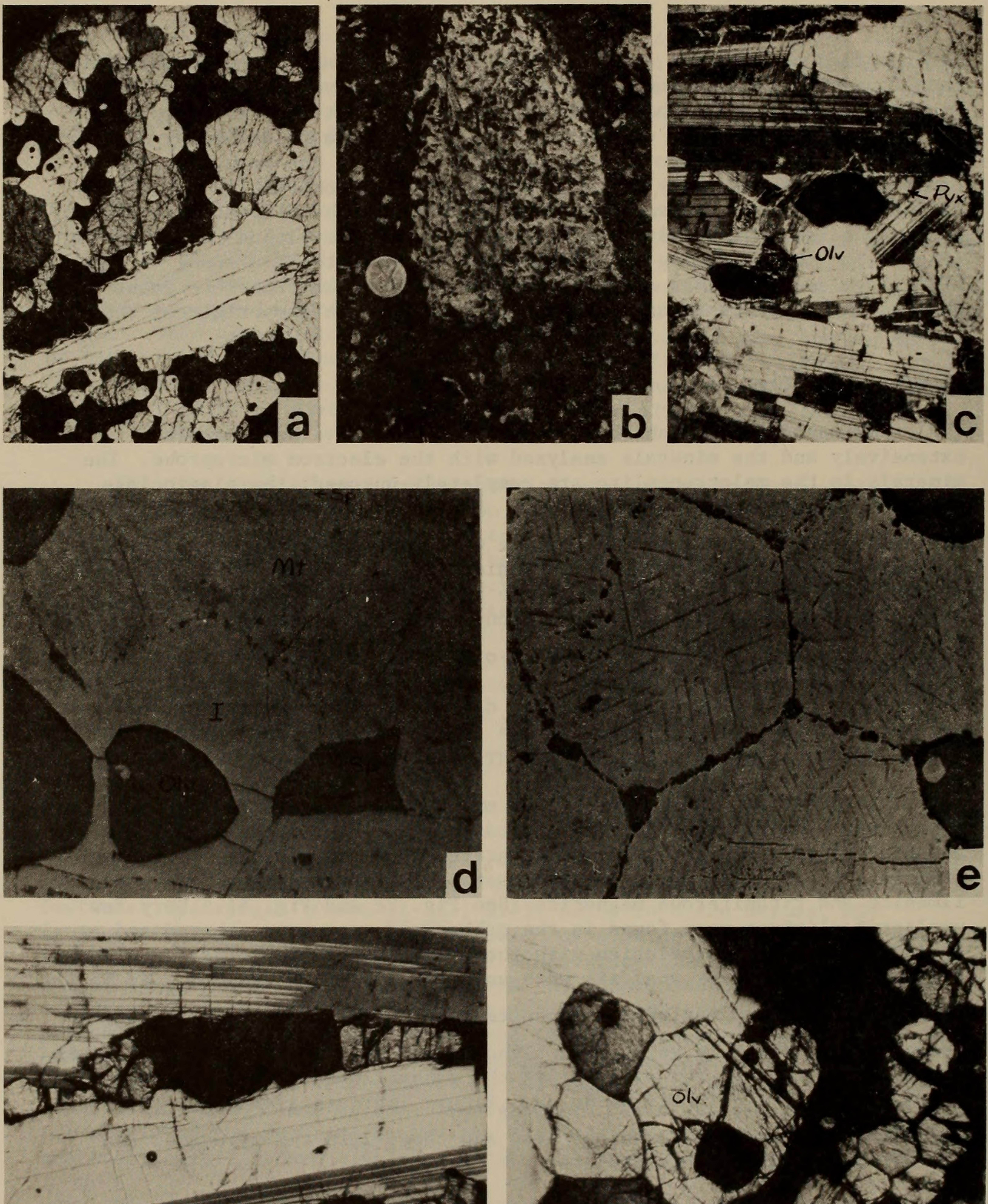

a
b
c
Pyx
Olv
Mt
I
Olv
Sp
d
e
Olv.
f
Olv.
Plag.
g

Figure 2

2A: Melatroctolite, plane light, tabular plagioclase aggregate is 2 cm long. Note intergrowth of grains along their margins and apparent interstitial nature of Fe-Ti oxides.

2B: Anorthositic gabbro inclusion in melatroctolite. The only pyroxene in the melatroctolite is in these inclusions. See text for explanation.

2C: Anorthositic Gabbro, crossed nicols. Longest plagioclase is 1 cm. Cumulus minerals are plagioclase, olivine and titaniferous magnetite; intercumulus minerals are Ca-rich pyroxene and plagioclase.

2d and 2e: Melatroctolite in reflected light. Field of view is 4 mm wide. Titaniferous magnetite has exsolved aluminum spinel along (100) and ilmenite (exsolution and oxidation) along (111). Some movement of aluminum spinel from magnetite rims to grain boundaries has occurred. Note apparent 120° intersections between grains of Ti-magnetite, ilmenite and olivine.

2f: Melatroctolite in crossed nicols, transmitted light. Field of view is 2 mm. Note intergrowth of olivine and plagioclase and also olivine and Ti-magnetite included in plagioclase aggregate.

2g: Melatroctolite, transmitted light, crossed nicols. Field of view is 3 mm. Note 120° angle of intersection between adjacent olivine grains.

absorption techniques (Rutherford and Hermes, MS). The results of these analyses are shown in Fig. 3 where the major oxides are plotted versus Al_2O_3. Several of the gabbros are chemically identical, and only the six different analyses are plotted in this diagram. The Al_2O_3 of the gabbros ranges from 19% wt% in WG-14 to 25% in the more plagioclase-rich gabbros. Until recently WG-14 was considered to be a good chilled margin sample, but we are now studying a new sample (STOP 1d) which texturally looks like a better candidate.

The average and range of the four samples of the melatroctolite analyzed are also plotted on Fig. 3 (5.6 wt% Al_2O_3). The lines of Fig. 3 have been drawn from the average melatroctolite through the data for the gabbros for each of the oxides. The lines qualitatively illustrate the model that we have developed for the origin of these rocks. This idea, which is discussed more extensively below, is that the separation of the melatroctolite from a parent magma something like WG-14 (19% Al_2O_3) would produce a range of more Al_2O_3 rich rocks such as the anorthositic gabbros.

Origin of the Melatroctolite and Anorthositic Gabbro

The structures, mineral textures, mineral chemistry and whole rock chemistry indicate that the melatroctolite and associated anorthositic gabbro can most logically be interpreted as the crystallization products of a relatively common magma, one having an anorthositic-gabbro composition somewhat enriched in iron, i.e. gabbro sample WG-14. After emplacement, this magma cooled and crystallized slowly so that the denser phases, olivine, ilmenite, titaniferous magnetite and aluminum spinel, settled under the influence of gravity. Cumulophyric aggregates of plagioclase much larger than the olivine, ilmenite and titaniferous magnetite also settled, but apparently only when denser mineral grains were included in the aggregates. Plagioclase grains by themselves appear to have floated because the cumulus plagioclase making up the framework of the gabbroic rocks is the same composition as that in the melatroctolite. Plagioclase of this composition (An_{59}) would, at 1200°C and pressures in the 0 to 2 kb range, have a density of about 2.63 gm/cc (Skinner, 1966). However, if a cumulophyric aggregate of these plagioclases included 5 percent olivine (Fo_{63}) by volume, a reasonable estimate based on thin section studies of these rocks, the density of the aggregate would be increased to 2.68 gm/cc under the same P-T conditions. Inclusion of a few grains of titaniferous magnetite would increase the density even further. Now if individual crystals of plagioclase An_{59} actually did float in the parent magma of the Melatroctolite-Gabbro Complex, the density of this magma would have to lie between 2.63 and 2.68 gm/cc. Using the data of Bottinga and Weill (1970), the density of a magma with the composition of sample WG-14 (19 wt% Al_2O_3) was calculated and found to be 2.66 gm/cc at 1250°C and 1 atmosphere pressure. This number would be changed by the addition of some small amount of water to the magma, and by the fact

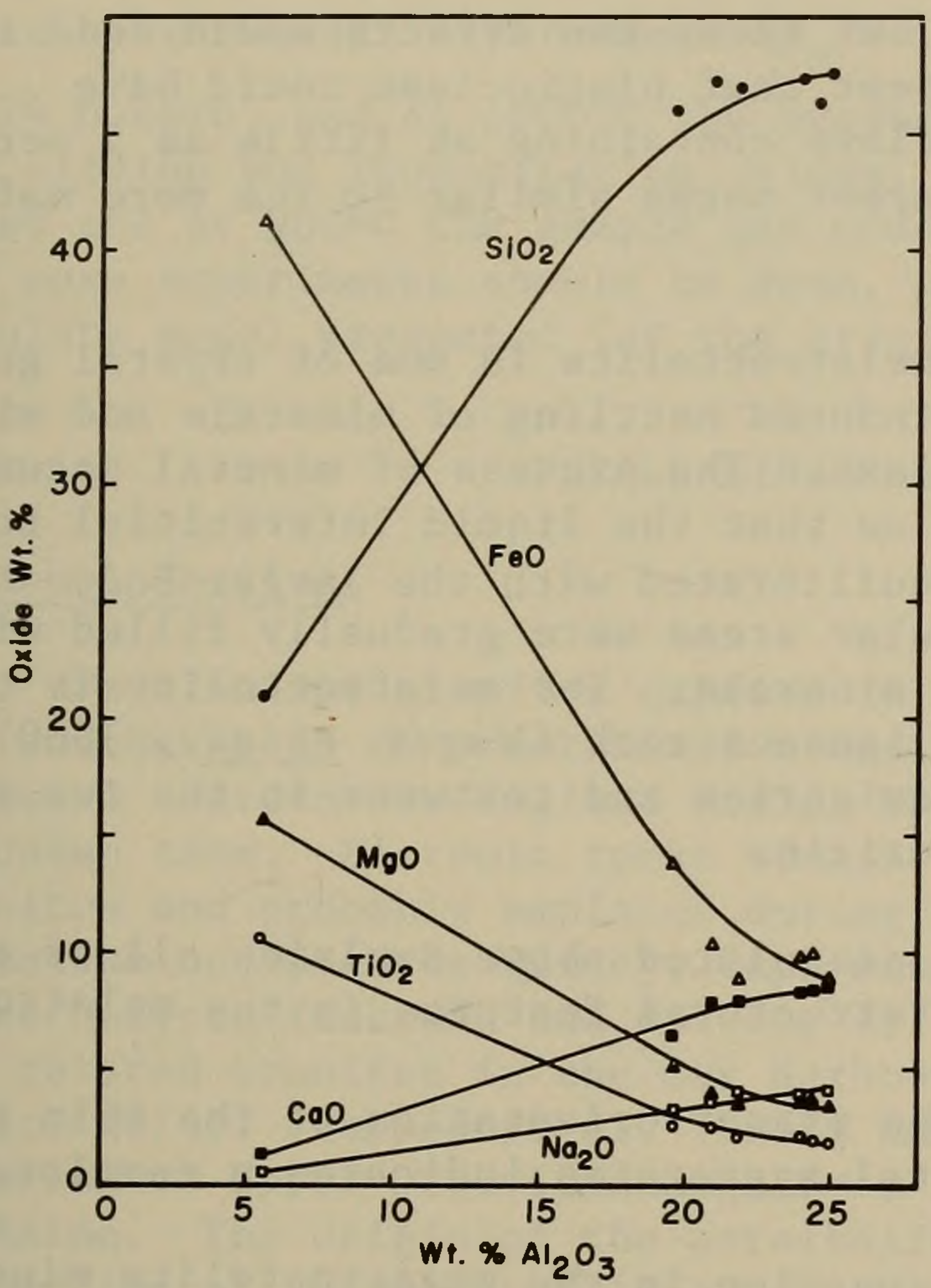


Figure 3: Variation diagram in which the major oxides are plotted against Al_2O_3 for the average melatroctolite and the six gabbro samples analyzed. Of the samples analyzed, WG-14, the assumed chill margin sample, has the lowest Al_2O_3 abundance.

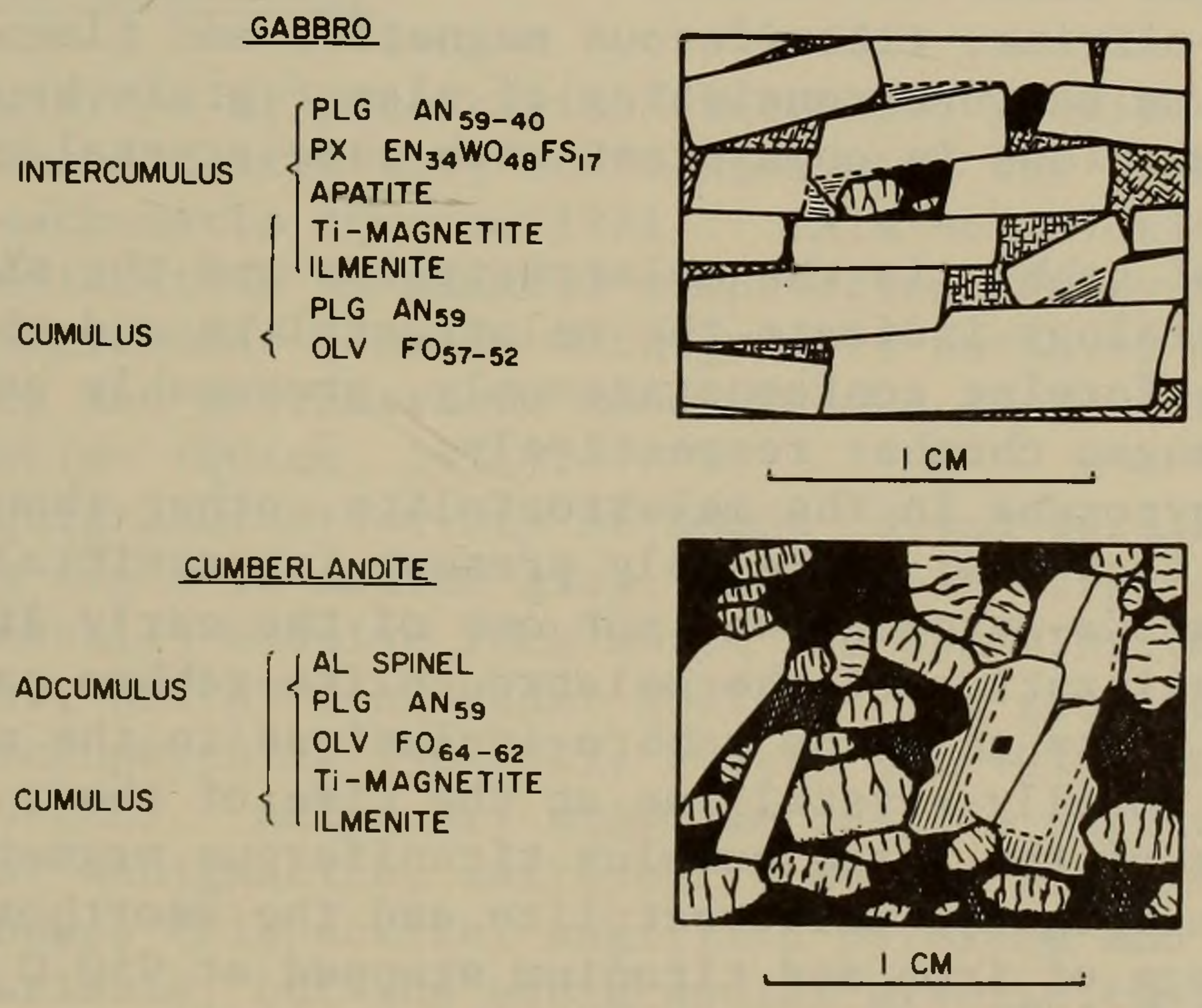


Figure 4: Summary of textures and mineral chemistries in the melatroctolite and anorthositic gabbro in the context of a comulus and adcumulus origin.

the magma was under some pressure, but these two effects would tend to compensate each other. It does appear that plagioclase could have floated while aggregates of plagioclase containing as little as 5 percent olivine by volume sank in a parent magma similar to the more mafic of the anorthositic gabbros.

The origin proposed for the melatroctolite is one of crystal growth in a magma accompanied by gravity induced settling of minerals and mineral aggregates more dense than plagioclase. The process of mineral accumulation apparently was sufficiently slow that the liquid interstitial to the cumulus minerals continuously re-equilibrated with the larger body of liquid above, and the intergranular areas were gradually filled with unzoned overgrowths of the cumulus minerals. The melatroctolite is thus a perfect example of an adcumulate igneous rock (Wager _et al._, 1960). Figure 4 summarizes the mineral chemistries and textures in the two rocks in terms of the cumulus-adcumulus origin.

The cumulus-adcumulus origin postulated above explains all of the unique mineralogical, textural and structural features in the melatroctolite and the anorthositic gabbro.
1) The foliation resulting from the planar orientation of the thin tabular plagioclase crystals and crystal aggregates indicates a cumulate origin for the rocks.
2) The complete lack of chemical zonation in the melatroctolite minerals and the subophitic texture of plagioclase with respect to olivine and opaques would be expected if crystal cumulation were slow, with the opportunity for large amounts of adcumulate overgrowth buffered by a relatively large magma reservoir above.
3) The tendency of olivine, titaniferous magnetite and ilmenite to develop an equilibrium texture consisting of planar grain boundaries and near 120° triple junctions is consistent with slow crystal growth and accumulation.
4) The inclusions of gabbro in the melatroctolite and the similarities in the cumulate mineralogy indicate the melatroctolite and the anorthositic gabbro were forming contemporaneously, presumably at the base and the top of the magma chamber respectively.
5) The absence of pyroxene in the melatroctolite, other than in gabbro inclusions, and the fact that it is only present interstitially in the gabbro indicates that Ca-pyroxene was not one of the early liquidus phases in the crystallization of the melatroctolite-gabbro parent magma. This interpretation means that the gabbro inclusions in the melatroctolite would not have been totally crystalline at the time of their inclusion.
6) The compositions of the large cumulus titaniferous magnetite and ilmenite crystals in both the melatroctolite and the anorthositic indicate that exchange of iron and titanium stopped at 950°C ± 100°C and at an f_{O_2} of $10^{-12.5 \pm 1.0}$. This appears a bit low to be an igneous crystallization temperature, but it is the temperature at which an iron titanium oxides first appear on the liquidus of a moderately primitive oceanic tholeiite (Helz, 1973; Dixon and Rutherford, 1980). In addition,

three hydrothermal experiments ($P_F = .67\ P_{H_2O}$) have been done on the WG-14 Gabbro, and at 1000°C the products contain glass and less than 10% olivine and iron-titanium oxides. At 1060°C the sample was completely glass and at 900°C the sample had undergone very little melting. A few more experiments should be done, but the results to date support the cumulate model presented for the origin of these rocks.

PERALKALINE GRANITES

Regional Setting

Peralkaline granites exposed in northern Rhode Island lie near the southern end of a northeast trending zone of igneous activity which affected eastern New England during Upper Ordovician to (possibly) Lower Devonian time. Plutonic rocks similar to the Rhode Island peralkaline granites and probably emplaced during the same general period of magmatism include the Quincy, Cape Ann and Peabody Granites of eastern Massachusetts (Zartman and Marvin, 1971) and the Cadillac, Tunk Lake and related Granites in the Bar Harbor area, coastal Maine (Naylor and Sayer, 1976). Hermes et al. (1978) have also recovered peralkaline granites of Upper Ordovician age from bedrock outcrops in the Gulf of Maine. The origin of the peralkaline granites of New England is a question of fundamental importance. Further study of the granites should improve our understanding of the petrogenesis of these rocks and of peralkaline, silica-rich plutonic rocks generally.

Petrology and Mineralogy

The outcrops of peralkaline riebeckite granite in northern Rhode Island have been tentatively correlated with the Quincy Granite of eastern Massachusetts (Quinn, 1971). This correlation is primarily based on similarities in mineral composition and texture. The occurrence of equigranular granite with granite porphyry in both Quincy, Massachusetts and northeastern Rhode Island lends further support to this correlation (Quinn, 1971).

The equigranular variety of Rhode Island peralkaline granite appears as a light to medium gray, fine (near margins) to coarse grained, generally massive rock which has been introduced as small sills and irregular, partly concordant bodies. The granite is composed mainly of microperthite (40-70%), quartz (15-40%), and reibeckite plus aegirine (10-20%). Accessory minerals include purple fluorite, zircon, Fe-Ti oxides, aenigmatite, astrophyllite, and biotite. The amounts of the Fe-Mg phases (riebeckite, aegiritic pyroxene and Fe-Ti oxides) are quite variable, but the equigranular granite contains primarily amphibole and pyroxene with amphibole being somewhat more abundant.

The porphyritic variety of the Rhode Island peralkaline Granite appears compositionally similar to the equigranular variety based on petrographic work (chemical analyses have not yet been completed) and intrusive bodies containing both varieties have been noted by Quinn (1971). A contact between the equigranular and porphyritic granite types has not yet been observed by the authors. The relationship between the two granite types is important to understanding the origin of these two rock types, however; and more extensive field work must be done. The major differences between the equigranular and porphyritic peralkaline granites is the porphyritic texture in the latter, and the fact the riebeckitic amphibole is rare in the porphyry. However, the quartz and microperthitic feldspar phenocrysts in the prophyry are no larger than those in the equigranular granite, the porphyry just has a fine grained ground mass which comprises 30-70% of the rock. The most abundant ferro-magnesian minerals in the porphyry are the Fe-Ti oxides which occur in the matrix and as inclusions in the phenocrysts rims. The common amphibole is generally green in color rather than the distinctive deep blue of the Na-rich riebeckite.

Origin and Emplacement

Relatively little work has been done on the petrology and petrogenesis of the peralkaline Rhode Island granites and many questions remain unanswered at this time. Some of the major questions we hope to answer include the following:

1. What were the conditions for emplacement i.e., temperature, pressure, f_{O_2}, f_{H_2O} ?
2. How important was fluorine (f_{HF}) and what are its effects on the mineral assemblages produced from a peralkaline granite magma?
3. What is the relationship between the equigranular granite and the granite porphyry? Are they products of the same magma or two similar magmas? What is the reason for the porphyritic texture?

Although much more work is needed before we can answer all of these questions, some preliminary observations can be made. Emplacement of the granites in a liquid or partially liquid state is indicated by the presence of fine grained (1 mm or less) granite showing flow banding near the margins of some intrusions (e.g. Stop 2). Crystallization at relatively high temperatures is indicated by the hypersolvus, one feldspar nature of the granites. The only analysis of a homogenized alkali feldspar phenocryst completed (Ab_{68}), together with available data on the alkali feldspar solvus (Yund, 1975) indicate that the granitic magma must have crystallized at a temperature above 650 ° C. The fact that the alkali feldspar exsolution in both the equigranular and porphyritic granites is on a scale of less than .03 mm would also suggest a fairly rapid cooling rate, that is, emplacement at a relatively shallow level in the crust.

The riebeckitic amphibole in the peralkaline granites is also a potential source of petrogenetic information. The amphibole could have crystallized entirely in the subsolidus as suggested by Buma _et al._ (1971) in describing the Quincy Granite in Massachusetts, but two petrographic observations suggest that the riebeckite crystallized in the presence of a melt in the Rhode Island rocks. First, it is present as euhedral crystals making up part of the granitic mosaic in the fine grained margin sample (Stop 2). Second, riebeckite is present as small but abundant inclusions in the cores of some alkali feldspar crystals in the prophyritic granite. In at least one sample the riebeckite inclusions are replaced by Fe-Ti oxides in the rim of the phenocrysts. Experimental data (Ernst, 1962) indicates that riebeckite is stable as high as 650° C. This would appear to be subsolidus, but we have not yet considered the effect of fluorine, an important component in the magma judging by the fluorite present in the rock. By analogy with the work of Holloway and Ford (1975), fluorine should increase the stability of riebeckite, and it will tend to lower the solidus of the granite (Manning _et al._, 1980). Therefore it does seem possible that the riebeckite in these granites crystallized from a melt.

At this stage of the investigation, the most likely explanation for the textural differences between the equigranular and porphyritic granites is the volatile loss model. As proposed by Tuttle and Bowen (1958) and recently by Lyons and Krueger (1976), a rock like the equigranular peralkaline granite probably crystallized without loss of volatiles. According to this model, the porphyritic granite bodies would have partially crystallized under the same conditions and then suffered volatile loss. This loss of volatiles would quench the remaining melt to form the fine grained, generally anhydrous matrix. An origin such as this would explain the similarity in grain size between the granite and the phenocrysts in the porphyry, the amphibole inclusions in the phenocryst cores, and the Fe-Ti oxides in the matrix (and in some phenocryst rims), of the porphyry. It still remains to be determined whether this model can explain what appears to be significant chemical differences between different bodies of porphyry indicated by the relative abundance of quartz and microperthite phenocrysts.

References

Bottinga, Y., and Weill, D. F., 1970. Densities of liquid silicate systems calculated from partial molar volumes of oxide components. Am. Jour. Sci. 269, 169-182.

Buma, Grant, Frey, F. A. and Wones, D. R., 1971. New England Granites: Trace element evidence regarding their origin and differentiation. Contrib. Mineral. Petrol. 31, 300-320.

Dixon, Susan, and Rutherford, M. J., 1980. Origin of Granitic rocks in Ocean Crust: An experimental Study. E.O.S. 61, 411.

Ernst, W. G., 1962. Synthesis, Stability relations and occurrence of riebeckite and riebeckite-arfedsonite solid solutions. J. Geology. 70, 689-636.

Helz, R.T., 1973. Phase relations of basalts in their melting at P_{H2O} = 5Kb as a function of oxygen lugacity, Part 1. J. of Petrol. 14, 249-302.

Hermes, O. D., Ballard, R. D., and Banks, P. O., 1978. Upper Ordovician peralkalic granites from the Gulf of Maine. Geol. Soc. Amer. Bull. 89, 1761-1774.

Holloway, J. R., and Ford, C. E., 1975. Fluid absent melting of the fluoro-hydroxy amphibole pargasite to 35 kilobors. Earth Planet Lett. 25, 44-48.

Johnson, B. L., and Warren, C. H., 1908. Contribution to the geology of Rhode Island. Am. Jour. Sci. 25, 1-39.

Lindsley, D. H., 1977. Magnetite-ilmenite geothermometer-oxybarometer an evaluation of old and new data. (Abstr.) Trans Am. Geophys. Union. 58, 519.

Lyons, P. C. and Krueger, H. W., 1976. Petrology, chemistry and age of the Rattlesnake Pluton and implications for other alkalic granites of southern New England. In P. C. Lyons and A. H. Brownlow (eds.). Studies in New England Geology, Geol. Soc. Amer. Memoir, 146.

Manning, D. A. C., Hamilton, D. L., Henderson, C. M. B., 1980. The probably occurrence of interstitial Al in hydrous, F-bearing and F-free aluminasilicate melts. Contrib. Mineral. Petrol. 75, 257-262.

Naylor, R. S. and Sayer, S., 1976. The Blue Hills Igneous Complex, Boston Area, Mass. NEIGC Field Guide, 135-146.

Quinn, A. W., 1971. Bedrock Geology of Rhode Island. U. S. Geol. Survey Prof. Bull. 1295, 68 p.

Quinn, A. W., Ray, R. G., and Seymour, W. L., 1949. The geology and ground-water resources of the Pawtucket quadrangle, R.I. Rhode Island Indus. Comm. Geol. Bull. 3, 85.

Robare, P. L., and Wood, D. S., 1978. The Blackstone Formation of Rhode Island: Glimpese of Sedimentoly and Precambrian deformation in southeastern New England. Geol. Soc. Amer. Abst. w/ prog. 10, 82.

Rast, N., O'Brien, B. H., and Wardle, R. J., 1976. Relationships between Precambrian and Lower Paleozoic Rocks of the "Avalon Platform" in New Brunswick, the northeast Appalachians and the British Isles. Tectonophy. 30, 315-338.

Skinner, B. J., 1966. Thermal expansion. Handbook of physical constants (ed. Clark, S. P.), New York. Geol. Soc. Am. Memoir. 97.

Tuttle, O. F. and Bowen, N. L., 1958. Origin of Granite in the Light of Experiemental Studies in the System $NaAIS_{13}O_8$-$KAIS_{13}O_8$ -SiO_2 -H_2O, Geol. Soc. Amer. Memoir. 74.

Wager, L. R., Brown, G. M. and Wadsworth, W. J., 1960. Types of Igneous Cumulates. Jour. of Petrology. 1, 73-85.

Yund, R. A., 1975. Subsolidus phare relations in the Alkali feldspars with emphasis on coherent phares in Feldspar Minerology. P.H. Ribbe ed., M. S. A.

Zartman, R. E., and Marvin, R. F., 1971. Radiometric age (Late Ordovician) of the Quincy, Cape Ann, and Peabody Granites from eastern Massachusetts. Geol. Soc. Amer. Bull. 82, 937-958.

ROAD LOG

Mileage

0 Mileage starts at intersection of Interstate 295 and RI Route 122 in northern RI. Get off 295 at 122 North (to Cumberland, RI) and drive north on 122.

0.3 Almacs Shopping Center on left. Assemble in shopping center parking lot at 9:00 AM.

\- Drive North on Route 122

2.4 - Nate Whipple Highway goes off to Right

2.6 - Turn Right on West Wrentham Road

3.5 - Quincy-type peralkaline granite porphyry

3.7 - Quincy-type equigranular granite

4.6 - STOP 1. Melatroctolite-Anorthositic Gabbro Complex. Park on the left in the sandy area just past the power line. We will be walking down the power line and will be away from the cars for a couple of hours. Walk 50 yards down the power line then right along the ridge to the first outcrop.

STOP 1-a. In the Melatroctolite Quarry. The melatroctolite (Cumberlandite in literature) is composed of olivine (49%), titaniferous magnetite (32%), plagioclase (15% avg.) and smaller amounts of ilmenite (2%) and hercynitic spinel (2%). Unfortunately most of the exposed melatroctolite is the altered variety - the plagioclase is partially or completely converted to epidote and chlorite (in stages garnet has subsequently formed from these plagioclase alteration products.) Fresh melatroctolite occurs in a ledge along the southwest side of the quarry and is very abundant among the boulders south of the quarry (on the way to Stop 1-b).

The texture of the rock is that of tabular plagioclase aggregates (< 2 cm) in a finer-grained mosaic of olivine (1 mm - 1 cm) and titaniferous magnetite (<2 mm) as shown in Figure 3. The plagioclase tends to have a preferred orientation in much of the melatroctolite giving the rock a weak foliation which has been interpreted as an igneous lamination. In thin section the plagioclase looks to have some overgrowths, but the crystals are completely unzoned (An_{59}). The titaniferous magnetite, olivine and ilmenite often appears to meet with near perfect 120° triple junctions, an equilibrium texture. They are also unzoned (Olv = Fo_{64}, $Ilm_{94}Hm_6$ and $Mt_{26}Olv_{63}Hc_{10}$) although the titaniferous magnetite has undergone subsolidus exsolution and oxidation. The chemistry of the coexisting titaniferous magnetite and ilmenite indicate a last equilibration temperature of 950°C ± 100 and a $Log_{10}\ f_{O_2}$ of -12.5. All of these textural and chemical data appear to be explained by invoking an extreme accumulate origin for the melatroctolite from a magma which was at essentially the same time crystallizing higher in the chamber to form the adjacent Anorthositic Gabbro. The only observation which cannot be easily explained is the different attitudes of the igneous lamination in the two rocks

STOP 1-b. Walk back out to the power line and southwest along it to the first anorthositic gabbro outcrop - Stop 1-b. Along the way are many nice boulders of unaltered melatroctolite. Some of these contain the best inclusions of anorthositic gabbro found in the melatroctolite.

The anorthositic gabbro at Stop 1-b has been affected by metamorphism and deformation more than in most other areas of the intrusion. The altered gabbro weathers grey-white due to the recrystallized nature of the plagioclase. The unaltered gabbro which can be seen here in several places is grey weathering and consists of cumulus plagioclase ($An_{59}Ab_{30}$) with minor olivine (Fo_{54}) and titaniferous magnetite and intercumulus plagioclase and Ca-rich pyroxene (Fig. 3). On a freshly broken surface the plagioclase (1 cm x 1 mm) tablets are black and oriented to give the rock a pronounced foliation (igneous lamination). The attitude of this lamination has been mapped throughout the area.

Sample WG-14 (Table 1) a somewhat finer-grained more equigranular (but partially altered) sample of the gabbro was taken about 100 yards to the south of Stop 1-b. The WG-14 outcrop is only 50' from the Esmond granite contact, and was thought to be the best candidate for a chilled margin sample. A much better chilled margin locality has now been found (Stop 1-d).

STOP 1-c. Continue southwest along the power line (800') to the intersecting NW-SE trail and walk 1000' northwest along the trail.

Stop 1-c is an anorthositic gabbro outcrop 100' west of the trail. This outcrop shows the best example of rhythmic layering found in the gabbro. The layering which strike N 40° W and dips 45° NE is parallel to the igneous laminations in the rock. Apparently with 19% Al_2O_3, the magma became too viscous to allow significant crystal segregation.

STOP 1-d. Continue NW on the trail, crossing a NE-SW trail (about 1800' from the power line) and Stop 1-d is on the hill to the right just past this intersection. Normal anorthositic gabbro occurs on the hill, but as you go further north, down the hill toward the stream, the rock becomes fine-grained (1 mm) and very massive. Large (up to 2 cm) phenocrysts of plagioclase are scattered through the matrix and are the only phenocrysts identified at this time. Work is still in progress on this particular rock-type however because it looks like an excellent chilled margin sample. The Sneech Pond schist with sills and dikes of Esmond granite occurs just across the stream (50').

Return to the cars along the same route followed on the way in.

4.8 - Continue driving north along West Wrentham Road

- Sneech Pond Schist with dikes and sills of Esmond on Right

5.3 - Turn Right on Route 114

6.1 - Sneech Pond Schist over most of this hill, but Hunting Hill Greenstone lithology does occur on the right just past the power line.

6.6 - Stop 2 - We will come back to it after lunch. Mileage stops here, we'll pick it up after lunch.

Lunch stop is in Diamond Hill State Park. Continue past Stop 2, turn right on 114 (South) for 1/2 mile and left into the State Park. There is a picnic area 150 yards in bearing left (North).

- Return to Stop 2 after lunch. Park on road which goes to the North at the bottom of the Hill.

STOP 2. QUINCY-TYPE PER-ALKALINE GRANITE

The outcrop at the bottom of the hill is at the northern edge of the large body of equigranular per-alkaline granite in this area (Fig. 2). At the east and west edges of the road cut outcrop the granite is fine to medium grained (1 mm). The granite in the center of the outcrop is coarse-grained (1 cm) with numerous quartz pads and lenses containing coarse fluorite, amphibole, biotite, and Fe-Ti oxides. The central part of the outcrop is cut by an 8 foot thick, vertically dipping slightly altered diabase dike which has not been noticeably deformed and is therefore probably Triassic (Quinn, 1971). The finer grained granites have a moderately well developed foliation ($120^\circ/40^\circ$N) and a mineral lineation plunging 40° to the NE in the plane of the foliation. The finer-grained rocks also occur close to the margins of the granite, the Porphyritic Grant-Mills Granodiorite on the west and Sneech Pond Schist to the North and East. As a consequence, the foliation and lineation are interpreted as induced by flow during emplacement of the granite, although there certainly has been some post-emplacement deformation. The textures and mineralogy of the rocks as seen in this section are consistent with this interpretation.

The granites are composed of microperthitic alkali feldspar (50%) quartz (30-35%) and variable amounts of aegiritic pyroxene, riebeckite and Fe-Ti oxides totalling from 10-20%. Important minor and trace minerals include fluorite, aenigmatite, sphene and calcite. In thin section the coarse granite appears to have suffered more from deformation in that the large quartz grains which remain show prominent underlatory extinction. The subgrain boundaries are elongate and pseudo parallel giving the rock a weak foliation. Some of what once were large quartz grains appears to have recrystallized to a finer-grained (1-2 mm) mosaic. The ferromagnesian minerals in this coarse-grained granite are predominantly pyroxene and Fe-Ti oxides; minor amounts of riebeckite occur in the matrix and in the feldspar grains. In contrast, riebeckite and aegiritic pyroxene occur in approximately equal amounts and Fe-Ti oxides are a minor phase in the finer-grained granites. The modes of the fine and coarse-grained granites are essentially identical in terms of the quartz (40%) and microperthitic alkali feldspar (45%). These textures and modal variations are consistent with an origin for these per-alkaline granites involving volatile loss during the crystallization of some parts of the intrusion (i.e. see Lyons and Krueger, 1976). However, more work on the rocks is obviously required before this or any emplacement hypothesis can be accepted.

\- Leave STOP 2 going East on 114.

6.8 - Intersection 114 & 122. Turn South on 114

8.6 - Junction of 114 and Nate Whipple Highway. Turn right on Nate Whipple Highway (at traffic light)

9.5 - STOP 3 (optional) PER-ALKALINE GRANITE PORPHYRY

Park on Staples Road which goes off to the Right.

The per-alkaline granite porphyry exposed here is composed of about 25% by volume phenocrysts (<1 cm) of quartz and microperthitic feldspar in a fine (<1 mm) groundmass of microperthitic feldspar, quartz and ferro-magnesian minerals. As a whole the rocks consists of 44% quartz, 35% microperthitic feldspar and 15% ferromagnesian minerals, predominantly olive-green amphibole and Fe-Ti oxides with minor biotite. Fluorite is prominent among the accessory minerals. Green amphibole is present in the cores of feldspar phenocrysts and is replaced by small euhedral crystals of titaniferous magnetite in the phenocryst rims. Is this rock similar to the more equigranular type per-alkaline granite such as seen at Stop 2 and can the differences be explained simply by invoking different emplacement conditions? This is one of the main questions we have been trying to answer, this and the question of the emplacement conditions.

Aside from the differences in the ferromagnesian minerals in the two types of granite, the only other major difference is textural. The quartz and alkali feldspar phenocrysts in the porphyry are almost all frayed looking and somewhat augen shaped. Trains of ferromagnesian minerals in the matrix give the rock a prominent foliation 120°/30°N). The long axes of the augen are parallel to this foliation.

Continue West on Nate Whipple Highway

10.1 - Sneech Pond Schist on the Right

10.7 - Turn Right on road just past the Cumberland Medical Center. Sneech Pond is just to the North. Parking is limited at this stop - some cars may have to use the Medical Center lot.

10.9 - Park on Right in power line right of way.

\- STOP 4 (optional) PER-ALKALINE GRANITE PORPHYRY

Walk North along the power line to the outcrop of granite porphyry at the water's edge (500 yds.). On the way you will pass several outcrops of Sneech Pond Schist.

The granite porphyry at this stop is very similar to that at STOP 3 except the ratio of phenocrysts to matrix is higher in this outcrop (10% vs 25%) and there is almost no foliation visible in thin sections of this (STOP 4) rock. The total abundance of ferromagnesian minerals is somewhat lower in this rock, but once again the main minerals are Fe-Ti oxide and green amphibole. There is a trace of riebeckite in this sample. The rock at STOP 4 appears texturally close to the equigranular per-alkaline granite of STOP 2, but the volatile rich ferromagnesian minerals are not present.

The foliation that can be seen in the outcrop at STOP 4 is not parallel to the trend of this sill-like body (NW-SE; see Fig. 1). However, samples were taken from what is considered to be the same sill-like body across the pond to the northwest, and one sample taken a few feet from the Sneech Pond Schist contact appears to have good flow banding parallel to the sill boundaries.

This particular sample contains approximately 15% by volume of euhedral, sharp cornered phenocrysts (microperthite and quartz) in an extremely well foliated matrix where the main ferromagnesian mineral is an Fe-Ti oxide.

The nearby contact of the granite porphyry with the Sneech Pond Schist is indicated by inclusions of dark schist at the northeast edge of this (STOP 4) outcrop.

Return to cars

- Drive out to Nate Whipple Highway and turn Right
- Intersection of Nate Whipple Highway with Route 122. Turn Left and follow to intersection with Interstate 295.