

## PLUTONIC AND HYPABYSSAL INTRUSIONS OF THE EARLY CRETACEOUS CUTTINGSVILLE COMPLEX, VERMONT

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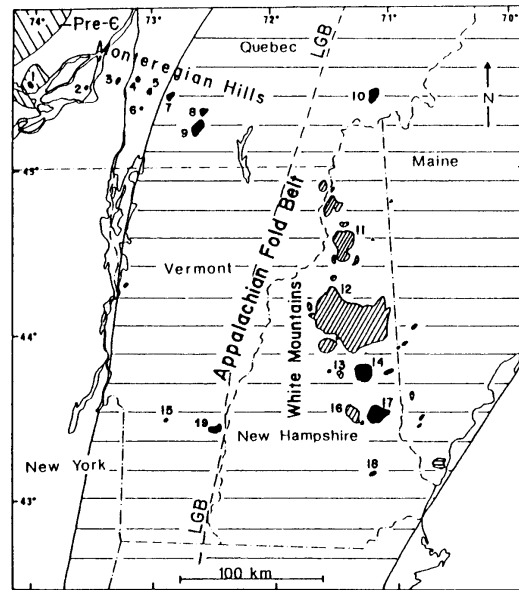
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### INTRODUCTION

The Montereian Hills (MH) and White Mountain (WM) igneous provinces represent a major period of continental anorogenic igneous activity that occurred between 240 and 100 Ma (Foland and Faul, 1977). The continental magmatism can be temporally divided into two major episodes, Jurassic (170-200 Ma) and Cretaceous (*ca.* 125 Ma). The older period of igneous activity is confined to the WM province (Fig. 1), is largely felsic in character, and, with the notable exceptions of Red Hill and Rattlesnake Mountain, the rocks are silica-saturated to silica-oversaturated. The largest intrusive complex is the White Mountain batholith which consists of a number of overlapping caldera complexes and associated granitic plutons (Eby et al., 1992). The younger period of igneous activity encompasses both the MH and WM provinces and is the focus of this field trip.

In several stages from 130 to 100 million years ago, groups of plutons, dike swarms, and individual intrusive complexes combined to form an igneous province that stretches 400 km from the central Adirondack Highlands of New York eastward through southern Maine, and 350 km from the Montereian Hills (MH) of southern Quebec southeastward through New Hampshire (Fig. 1). Early Cretaceous alkalic plutons in New England are called the younger White Mountain (WM) igneous province by Eby (1987), and all of the Early Cretaceous intrusions have been labeled the New England-Quebec (NEQ) igneous province by McHone and Butler (1984). The MH and WM igneous provinces appear to be products of anorogenic, intraplate rifting, perhaps forming in concert with stages of North Atlantic oceanic rifting events (McHone and Butler, 1984), although tholeiitic Mesozoic magmas associated with Triassic-Jurassic basins around the entire North Atlantic ocean are much more widespread (Manspeizer, 1988).

Similar but somewhat younger intrusions (and volcanic products) are found in the continental shelf (Hurtubise and others, 1987), and other intraplate alkaline intrusions/volcanoes extend into the western North Atlantic as the New England seamount chain (Duncan, 1984). Morgan (1983), Duncan (1984) and others have linked the Cretaceous MH and WM intrusions to the New England seamounts as expressions of an age-progressive *hotspot track*, analogous with the Hawaiian model. In the New England model, the northwestern MH plutons are at the older (*ca.* 124 Ma) end, progressing through 122 Ma WM plutons in New Hampshire, and through the seamounts from about 110 to 70 Ma far out into the North Atlantic Ocean.



**Fig. 1.** Geological setting and locations of the major Montereian Hills and White Mountain plutons. Horizontally shaded areas, plutons emplaced between 240 and 200 Ma. Diagonally shaded areas, plutons emplaced between 200 and 165 Ma. Filled areas, plutons emplaced between 140 and 100 Ma. Plutons indicated by number: 1, Oka; 2, Mont Royal; 3, Mont St. Bruno; 4, Mont St. Hilaire; 5, Mont Rougemont; 6, Mont Johnson; 7, Mont Yamaska; 8, Mont Shefford; 9, Mont Brome; 10, Mont Megantic; 11, Pliny Range; 12, White Mountain batholith; 13, Red Hill; 14, Ossipee; 15, Cuttingsville; 16, Belknap Mountain; 17, Merrymeeting Lake; 18, Mount Pawtuckaway; 19, Ascutney. LGB, limit of Grenville basement. After Eby (1987).

The hotspot track model has immediate appeal but also immediate problems, some of which have been discussed by McHone (1996). The Cuttingsville complex is petrologically similar to the MH plutons, but it is located at least 120 km southwest of the MH-WM section of the *hotspot track*. More importantly, the Cuttingsville magmas formed about the same time as New England seamounts far to the southeast, which is at least 20 m.y. too young for the New England portion of the track.

The younger WM and MH plutons are intruded into several terranes: the Precambrian Grenville province of the Canadian shield, the flat lying Cambro-Ordovician sediments of the St. Lawrence Lowland, and the deformed Lower Paleozoic section of the Appalachian orogene. A notable feature is that silica-undersaturated rocks are confined to plutons emplaced to the west of Logan's line (i.e. into thinner continental crust). This is well illustrated by the MH plutons which cross all three terranes. Plutons emplaced into the Grenville province and St. Lawrence Lowlands are characterized by the near absence of silica-saturated rocks and their largely mafic character. Eastward the plutons become larger, felsic rocks become a significant component, and silica-saturated to oversaturated lithologies are found. Only silica-saturated rocks are found at Mont Megantic (Fig. 1). Unlike the older WM, mafic rocks are important components of most of the younger WM plutons. Basalt outcrops at Ossipee, diorite at Merrymeeting Lake, Mount Pawtuckaway, and Ascutney, and essexite at Cuttingsville. Eby (1987) suggested that these variations could be explained by differences in the thickness of the continental crust and the depth of melting. In the thicker Appalachian section larger volumes of melt were produced in the mantle at shallower depths, and there was more opportunity for interaction between these melts and the crust. Eby (1985) noted that in terms of Sr and Pb mafic silica-undersaturated rocks in the MH and mafic silica-saturated rocks in the WM were isotopically indistinguishable, suggesting a similar source (isotopically depleted mantle) but different degrees of melting.

At Mont Shefford, Mont Brome, and Cuttingsville quartz-bearing and nepheline-bearing rocks exist in spatial and temporal proximity. These three plutons occur in the transition zone between the Pre-Cambrian Grenville and the folded Appalachians. Landoll and Foland (1996) have argued that the undersaturated and oversaturated rocks are derived from the same magma with production of the oversaturated rocks by AFC processes occurring at high level. On this field trip we will examine the Cuttingsville complex where both mafic and felsic silica-undersaturated and oversaturated rocks occur in the same pluton.

Alkalic dikes across the region display a bimodal range of mafic and felsic types in overlapping swarms, each group having somewhat distinctive ages and physical characteristics. Given that they cooled only a few kilometers below today's surface, the dikes are intermediate in crystal character between phaneritic plutons and aphanitic volcanic rocks. Good eyesight and a hand lens are required to distinguish the minerals and textures of the dikes, but with care and experience, most can be classified in the field. Unlike the great quartz tholeiite intrusions of southern and eastern New England, most of the dikes are too small to have produced flood basalts or large volcanic edifices. Yet, as shown by xenoliths of spinel peridotite and other mantle rocks (McHone and Williams, 1985), these magmas, in dikes only a few meters wide, ascended from mantle depths of 100 km or more.

This field excursion presents ideas and data that have been slowly gathered for nearly twenty years. As in other regions, relatively few of the geologists who produced the quadrangle bedrock maps for the area paid much attention to the intrusions. Some older papers contain very useful information, such as those by Marsters (1889), Eggleston (1918) and Brace (1953). More recent work on the pluton at Cuttingsville includes papers by Laurent and Pierson (1973) and Robinson (1990), and studies by Wood (1984) and Eby (1992).

Dike locations in Vermont were studied by McHone during his thesis work at the University of Vermont in the early 1970's. Other field visits were made with J. Robert Butler during and after McHone's Ph.D. work at the University of North Carolina at Chapel Hill (1974-1978), and some field work was conducted with Chiasma Consultants, Inc. for the National Uranium Resource Evaluation (1978-1980). Eby investigated the Cuttingsville plutonic complex in the mid-1980s (NSF EAR-8600058). We made a field tour in June of 1997 in preparation for this field trip.

The western margin of the Cretaceous New England - Quebec igneous province is formed with three lobes, or subprovinces, that extend westward from northern New England (Fig. 2). On the northern side, the Monteregian Hills subprovince of southern Quebec is known for its carbonatites and ultramafic stocks, as well as for alkali lamprophyre dikes. Older K-Ar radiometric dates in Quebec are mainly between 110 and 130 Ma (Eby, 1984), although subsequent work by Foland *et al.* (1986) suggests that many of the Monteregian Hills intrusions are close to 124 Ma in age.

Igneous rocks are unknown in the northernmost Lake Champlain Valley, but north and south of Burlington, Vermont there are several hundred lamprophyre and trachyte dikes exposed along shorelines, roadcuts, streams, and hillsides. Lamprophyre dikes of this subprovince are distributed westward into the central Adirondack Highlands of New York, and eastward into north-central Vermont (McHone and Corneille, 1980). Champlain dikes are identical to Monteregian dikes, including carbonate-rich types, but associated plutonic complexes are fewer and smaller in the Lake Champlain region than in Quebec. Radiometric dates indicate ages near 135 Ma for monchiquites, 125 Ma for trachytes and syenites, and 115 Ma for camptonites (McHone, 1987), but this very neat division needs better confirmation. Because the Champlain Valley intrusions are close analogs to the Monteregian intrusions, their ages might actually all be nearer to 122 to 124 Ma.

In the southern, upper Champlain Valley (the lake flows northward), there is a "virtual" gap in igneous rocks, with only a few stray dikes known at Vergennes, Middlebury, Westport (New York), and Orwell. The third lobe (herein labeled "NT", for Northern Taconics) has around 70 known dike localities, some of which are probably exposures of the same dike, distributed along the northern Taconic region between Proctor and Dorset, westward a few kilometers into eastern New York, and eastward across the Vermont Valley into the Green Mountains southeast of Rutland (Fig. 3). Many of the intrusions have petrologic characteristics that are distinct from the northern NEQ dikes, but there are also some very similar examples. Except for a few trachytes near Rutland, all of the dikes so far studied are lamprophyres. Dates are mostly 100-110 Ma (Table 1).

Little detailed work has been done on the dike rocks, but the Cuttingsville plutonic complex southwest of Rutland has received attention since the 1970's from mineral companies as well as by research geologists. We consider the Cuttingsville intrusion to be connected with the Taconic subprovince on the basis of age and petrology, although the distribution of dikes does show fewer examples towards Cuttingsville (Fig. 3). Eastward from Cuttingsville, dikes remain fairly common (10 to 20 examples have been mapped in some of the 7.5' quadrangles), and they merge into the regional camptonite swarms of eastern Vermont, New Hampshire, and Maine (McHone, 1984).

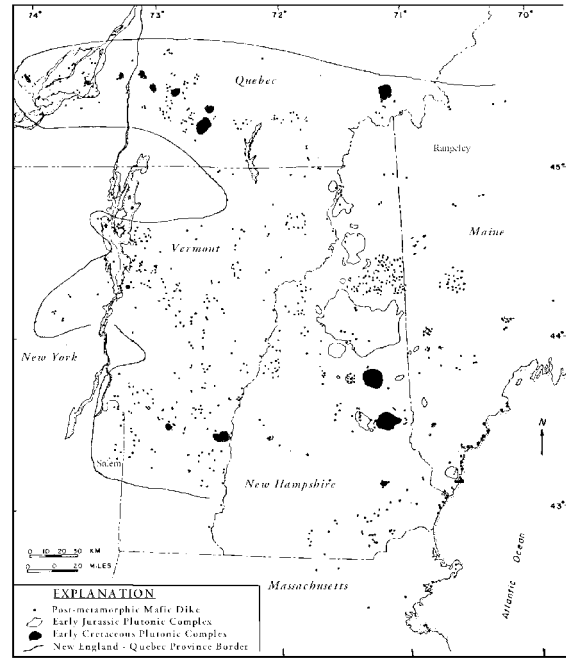


Fig. 2. Distribution of post-metamorphic dikes in northern New England.

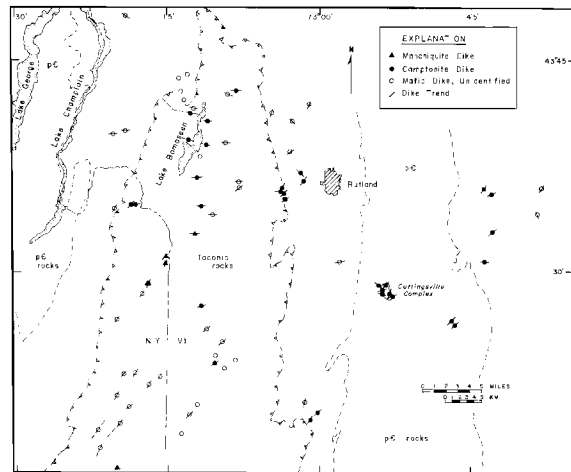


Fig. 3. Dike locations in the northern Taconics region, Vermont and New York.

## INTRUSIVE TRENDS AND STRUCTURES

Dikes around Cuttingsville, Vermont have a NE-SW preference, unlike dike groups farther north (Fig. 4). In southern Quebec, the Monteregian Hills dike group has a WNW-ESE maxima, examples for which are found the entire distance from Montreal to northwestern Maine (McHone, 1978a). Dikes of the Lake Champlain Valley region have a very distinct E-W preference (McHone and Corneille, 1980). The NE-SW dike trend is common not only across southern Vermont, but also prevails across northern New England east of the Green Mountain anticlinorium (Fig. 4).

## ALKALIC DIKE TYPES

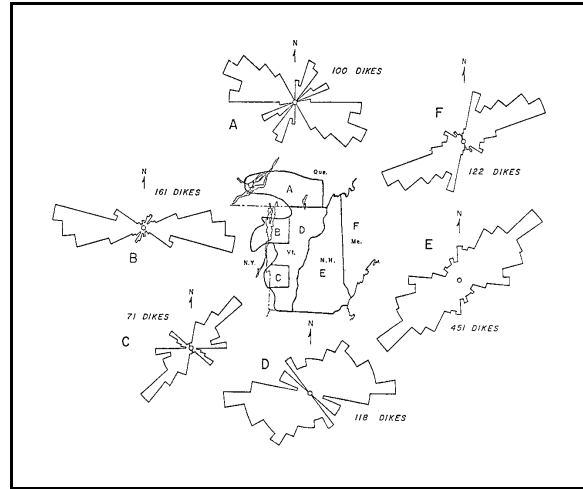
Regional dike types around Cuttingsville include monchiquite (nephelinite), camptonite (basanite), bostonite (trachyte), and spessartite (andesite). All of these igneous types are presumed to be related through mantle/crustal processes of fractional melting, differentiation, and crystallization, but it may be unlikely that they were at one time all co-magmatic.

*Monchiquite* is a very mafic, granular, analcite-bearing, olivine-bearing, augite-rich alkali basalt, often with appreciable calcite (in spheroidal bodies), phlogopitic mica, and kaersutitic amphibole. Feldspar (Ca-plagioclase) is poorly developed or lacking. Monchiquite is commonly dark gray in color.

*Camptonite* can look much like monchiquite, except that olivine is rare or absent, kaersutite is common to abundant, and plagioclase is more abundant than analcite. Phenocrysts are only mafic (augite and/or kaersutite), rather than felsic, although feldspar in fact does occur as phenocrysts in some dikes that otherwise are "good" camptonites. Camptonite dikes usually have a brownish to rusty gray range of colors.

*Spessartite* dikes lack olivine and analcite, but plagioclase (intermediate Ca) is well developed and present as phenocrysts as well as intergrown with augite in the groundmass. Phenocrysts (or megacrysts) of kaersutite serve to distinguish spessartite from tholeiitic dolerite (diabase) dikes that are common in other parts of New England. Spessartite often shows a distinctly greenish or purplish cast as well as gray colors. The intrusive breccias north of Cuttingsville (stops 3 and 4 of this trip) have a spessartitic to "andesitic" matrix.

*Bostonite* is a name that in a strict sense applies only to felsic (anorthoclase-rich) dikes that have a "felty" clumped-grain texture, which is not always present. Trachyte, although used for volcanic rocks as well, is a better general term. Minor minerals include oxidized biotite, quartz, and clay products. Some examples show well-formed alkali feldspar and/or quartz phenocrysts. Trachyte dikes may be iron-stained, but they are generally light brown to cream-colored on fresh surfaces. The quartz syenite of the Cuttingsville complex is chemically similar to trachyte, but at stops 5 and 7, the syenite has been altered and enriched by sulfides.



**Fig. 4.** Dike trends (rose diagrams) in northern New England. Rose diagram labels refer to areas shown in the central figure, with rose C representing dikes around Cuttingsville and the northern Taconic Mountains.

**TABLE 1. RADIOMETRIC DATES, NORTHERN TACONIC IGNEOUS ROCKS**

Sample	Description	Date (Ma)	Reference
PO-1	Hbl spessartite, Route 4 roadcut Poultney quadrangle lat 43°32'05"N lon 73°10'34"W	113 ± 4	(1)
WR-3	Hbl spessartite, Route 4 roadcut West Rutland quadrangle lat 43°30'49"N lon 73°03'20"W	108 ± 4	(2)
RT-7	Andesitic breccia, Shrewsbury Rutland quadrangle lat 43°30'57"N lon 72°53'56"W	101 ± 2	(1)
Cuttingsville complex	Sodalite syenite	100 ± 2	(3)
	Biotite foyaite	103 ± 2	(4)
	Essexite	99 ± 2	(4)
	Essexite	103 ± 4	(5)
	Bio-hbl syenite	98 ± 11	(6)
	Bio-hbl syenite	100 ± 8	(6)
	Hornblende syenite	97 ± 8	(6)
	Essexite	100 ± 8	(6)

Note: K-Ar whole-rock or biotite ages, except for Cuttingsville (Ref. 5) which are titanite fission track ages. Ages have been corrected, where necessary, using the new IUGS decay constants (Steiger and Jäger, 1977). References: (1) McHone and McHone (1993); (2) Zen, 1972; (3) personal communication, H. Kreuger, Geochron; (4) Armstrong and Stump, 1971; (5) Stone & Webster, unpublished date referenced in Kanteng (1976); (6) Eby, unpublished titanite fission track ages.

## CUTTINGSVILLE

### General Geology

The Cuttingsville complex is an elliptical shaped, northwest trending intrusion, 2.3 km long and 1.7 km wide. The various plutonic and hypabyssal units were intruded into Precambrian schists and gneisses. The pluton was originally mapped by Eggleston (1918) and subsequently re-investigated by Kanteng (1972), Laurent and Pierson (1973) and Wood (1984). The geological map (Fig. 5) is modified from Eggleston (1918) on the basis of additional field work in the summer of 1986. Geophysical studies indicate that the intrusion is pipe-shaped with near-vertical sides which extend to a depth of at least 2 km (Griscom and Bromery, 1968). Radiometric dating (Table 1) indicates an emplacement age of *ca.* 100 Ma, significantly younger than the ages of the other younger White Mountain intrusions.

The intrusive contacts with the country rock are discordant and have near vertical dips. The contact zone is 5 to 10 meters wide and contains country rock xenoliths that are rounded due to abrasion (Pierson, 1970). The contacts between the intrusive phases are both sharp and gradational indicating that the various phases were emplaced in a

relatively short time. The contacts between the late stage dikes and the rocks of the pluton are sharp, but the absence of chilled margins suggests that the dikes were emplaced before the pluton had cooled to near ambient temperatures.

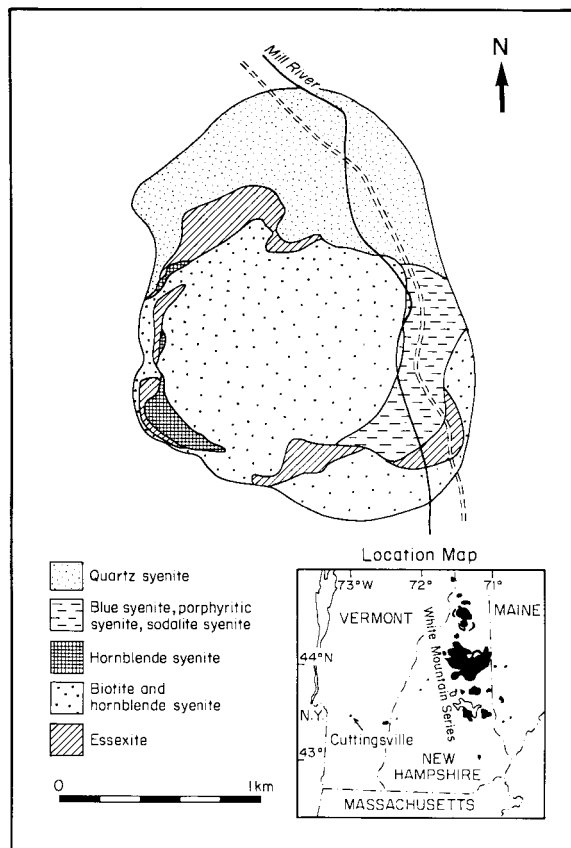
Laurent and Pierson (1973) distinguished, from core to margin, four main intrusive phases. (1) - hastingsite foyaitite and biotite foyaitite (pulaskites), (2) - diorite and porphyritic diorite, (3) - essexite, porphyritic essexite, plagifoyaitite and sodalite foyaitite, (4) - alkaline quartz syenite (larvikite) and syenite. The nomenclature of Laurent and Pierson (1973) has been modified (as shown on the geological map) to conform to that recommended by the IUGS Subcommittee on the Systematics of Igneous Rocks, the term essexite has been retained for the nepheline-bearing gabbro (diorite). Except for very local contamination the diorites are all nepheline normative (and usually nepheline bearing) and hence mapped as essexites. In addition to the intrusive phases distinguished by Laurent and Pierson (1973) there is a porphyritic syenite, which varies from slightly nepheline normative to slightly quartz normative, that contains inclusions of all the other intrusive units. With the exception of late stage felsic and mafic dikes, the porphyritic syenite represents the last phase of intrusive activity.

### Petrography

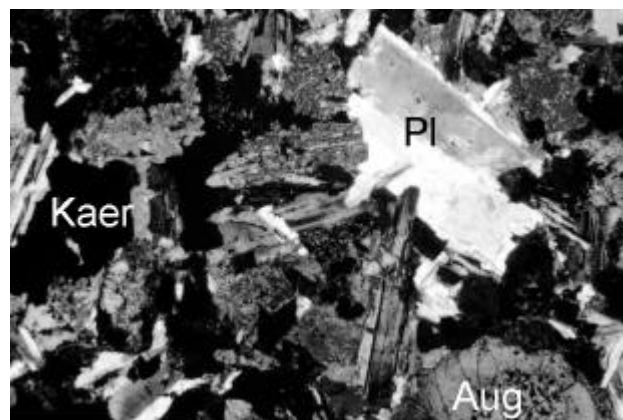
**Essexite.** In hand specimen the rock is light to dark gray, medium- to coarse-grained, and occasionally porphyritic. Mafic minerals often constitute more than 50% of the rock. The clinopyroxene occurs as pink titanite rimmed by light green augite and as separate light green augite grains. The amphibole is kaersutite, in some specimens amphibole is much more abundant than clinopyroxene. Plagioclase is usually strongly zoned. Accessory minerals are Fe-Ti oxides, titanite, and red-brown to straw-brown biotite. Anhydrous nepheline and alkali feldspar occur as interstitial grains (Fig. 6).

**Biotite-hornblende syenite.** In hand specimen the rock is white to light gray and medium- to very-coarse-grained. The rock is dominantly composed of perthitic alkali feldspar, the feldspar occasionally has a plagioclase core. Plagioclase is found as a minor phase in some specimens. Mafic minerals are a light green augite and a red brown biotite. Light green amphibole is occasionally found. Accessory minerals are Fe-Ti oxides, apatite, and titanite.

**Hornblende syenite.** In hand specimen the rock is white to light gray and medium- to coarse-grained. The rock is dominantly composed of perthitic alkali feldspar with minor plagioclase, both showing a lath-like habit. The mafic



**Fig. 5.** Geological map of the Cuttingsville complex. Modified from Eggleston, 1918.



**Fig. 6.** Medium grained essexite (CV2). Width of field of view, 5.4 mm. Crossed nicols. Aug - augite, Kaer - kaersutite, Pl - plagioclase.

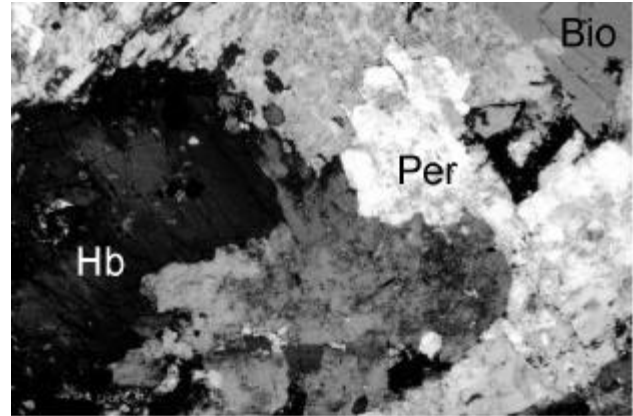
minerals are an olive green to reddish amphibole and a straw brown to dark brown biotite. Titanite is an abundant accessory mineral, apatite and Fe-Ti oxides occur in minor amounts (Fig. 7).

*Porphyritic syenite.* In hand specimen the rock is light gray and porphyritic. Perthitic alkali feldspar, plagioclase, and occasionally a light green augite occur as phenocryst phases in a fine- to medium-grained groundmass of alkali feldspar, plagioclase, light green augite, brown mica and an Fe-Ti oxide. Accessory minerals are titanite, titanomagnetite, and apatite. Kaersutite and titanaugite occur locally as xenocrysts partly to totally altered to red brown biotite (Fig. 8).

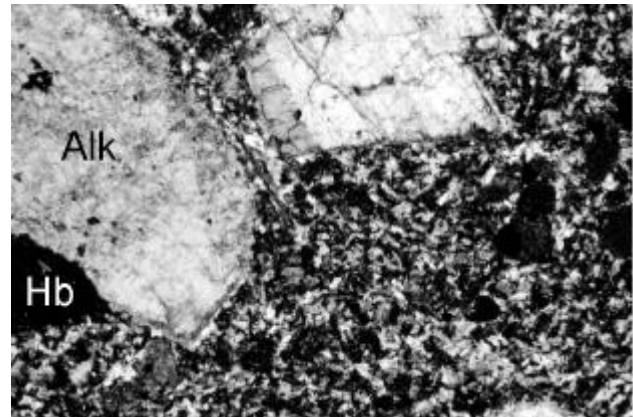
*Sodalite syenite.* In hand specimen the rock is medium gray to blue in color and medium- to coarse-grained. Blocky to lath-shaped perthitic alkali feldspar is the major mineral. Sodalite occurs interstitially in variable amount. Randomly oriented clots of mafic silicates consist of green to greenish-brown aegirine augite, brown to straw brown biotite, and Fe-Ti oxides. Zircon and apatite occur in accessory amounts (Fig. 9).

*Quartz syenite.* In hand specimen the rock is light gray, greenish on fresh surfaces, medium-grained and equigranular. Perthitic alkali feldspar and interstitial quartz comprise 90% to 95% of the rock. Mafic minerals are green pleochroic aegirine, sparse reddish amphibole, and red-brown biotite. Grunerite has been found associated with biotite. An as yet unidentified mineral (provisionally named "honeyite") is found in several specimens. The mineral is light yellow in color, weakly pleochroic, and has an equant to slightly elongate habit. The elongate grains show inclined extinction. Accessory minerals are Fe-Ti oxides, apatite and zircon (Fig. 10).

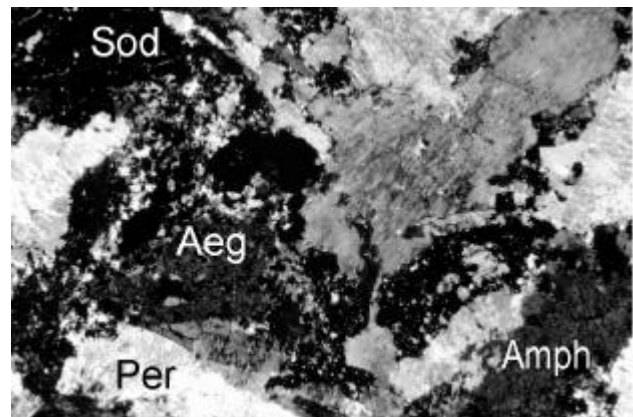
*Dike rocks.* Both felsic and mafic dikes cut the Cuttingsville complex and the country rock. The *phonolites* are very fine-grained, dark green in hand specimen, and in thin section show a felted mass of alkali feldspar and pleochroic green aegirine. The mafic dikes are either fine-grained *diorite* (essexite) or "*camptonites*". The so-called *camptonites* are *sensu stricto* not lamprophyres since they have, in addition to titanaugite and kaersutite, plagioclase phenocrysts. Fe-Ti oxides occasionally occur as a phenocryst mineral. Some of the mafic silicate phenocrysts have been extensively replaced by chlorite and most have reaction rims. The fine-grained matrix consists of plagioclase (and alkali feldspar?), red-brown pleochroic amphibole, Fe-Ti oxides,



**Fig. 7.** Coarse-grained hornblende syenite (CV24). Width of field of view, 5.4 mm. Crossed nicols. Bio - biotite, Hb - hornblende, Per - perthite.

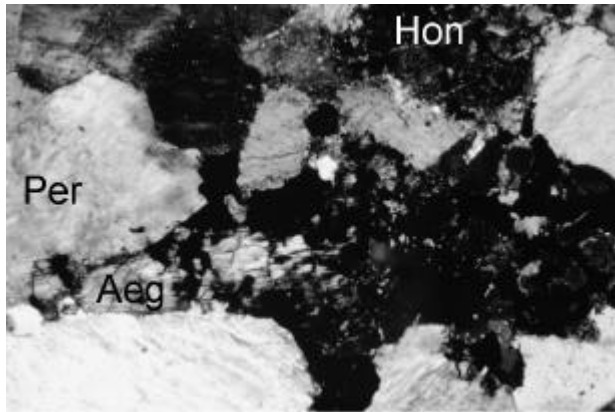


**Fig. 8.** Porphyritic syenite (CV8). Width of field of view, 5.4 mm. Crossed nicols. Alk - alkali feldspar, Hb - hornblende.

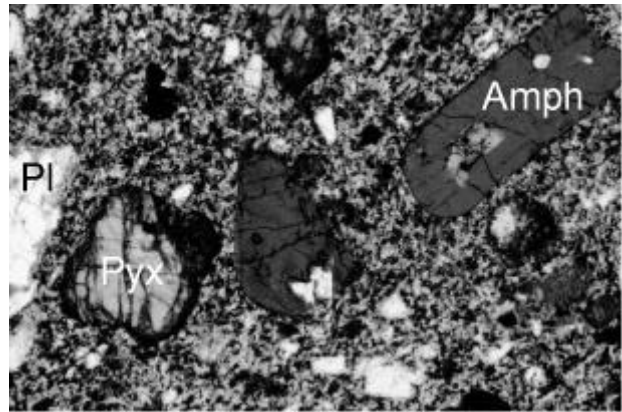


**Fig. 9.** Medium-grained sodalite syenite (CV23). Width of field of view, 5.4 mm. Crossed nicols. Aeg - aegirine, Amph - amphibole, Per - perthite, Sod - sodalite.

and accessory red-brown to brown biotite (Fig. 11).



**Fig. 10.** Coarse-grained quartz syenite (CV38). Width of field of view, 5.4 mm. Crossed nicols. Hon - "honeyite", Per - perthite.



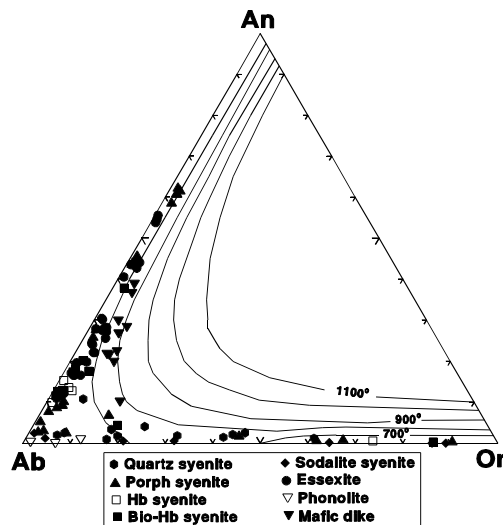
**Fig. 11.** Lamprophyre dike (CV32). Width of field of view, 5.4 mm. Crossed nicols. Amph - amphibole, Pl - plagioclase, Pyx - pyroxene.

### Mineral Chemistry

Cuttingsville minerals have been analyzed by electron microprobe. The data are not yet published, but for some of the major minerals the chemistry is summarized in graphical form and briefly discussed below.

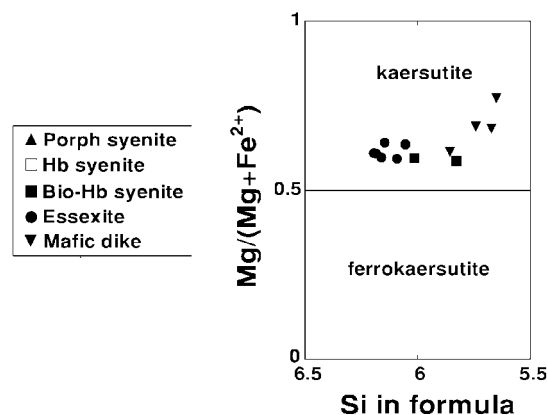
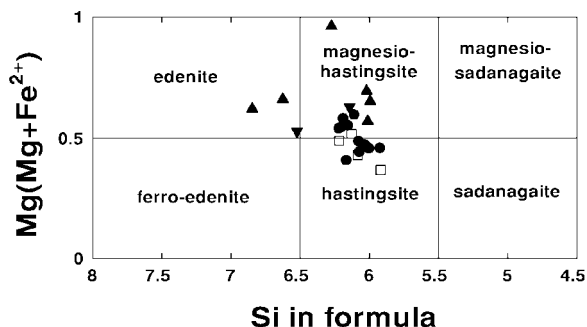
**Feldspar.** Plagioclase compositions vary from  $An_{62}$  to almost pure end member albite (Fig. 12). Some of the most Ca-rich plagioclases are found in the porphyritic syenite, but thin section observations suggest that these are plagioclase xenocrysts. Alkali feldspar compositions vary from  $Or_{90}$  to essentially pure end member albite. Feldspars from the mafic dikes show the highest equilibration temperatures, but the range in feldspar compositions indicates that there has been significant subsolidus unmixing. The two feldspar geothermometer of Fuhrman and Lindsley (1988) yields equilibrium temperatures of 680°C for a porphyritic syenite (CV15), 700°C for a quartz syenite (CV21) and 480°C for a biotite-hornblende syenite. While all the temperatures are subsolidus, the relatively high equilibrium temperatures for the porphyritic syenite and quartz syenite indicate relatively rapid cooling, while the lower equilibrium temperature for the biotite-hornblende syenite indicates that this unit cooled relatively slowly.

**Pyroxene.** Chemically the pyroxenes are diopside and aegirine-augite (Fig. 13). Compared to many alkaline complexes, the Cuttingsville pyroxenes are not particularly Fe- or Na-rich, with only the pyroxenes from the sodalite syenite showing the typical degree of Na-enrichment (but not Fe). Hence the magmas from which these pyroxenes crystallized were not strongly alkaline. This projection does not differentiate between Ti-rich and Ti-poor pyroxenes, but optically the pyroxenes found in the essexite are pink pleochroic titanaugites and light green pleochroic augites. Pink titanaugites are also found in some of the syenites as xenocrysts.



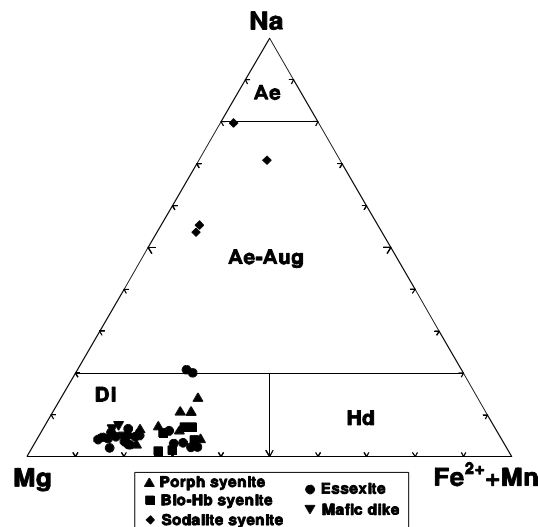
**Fig. 12.** Feldspar compositions projected into the Ab-An-Or ternary diagram. One bar feldspar solvi (°C) are from Nekvasil (1992).

*Amphibole.* Amphiboles in the essexite vary in composition from kaersutite to hastingsite (Fig. 14). Kaersutite is the characteristic amphibole of the essexite and the kaersutite found in the syenites is xenocrystic. Magnesio-hastingsite, hastingsite, and edenite are found in the syenites. These are all calcic amphiboles, and hence the amphiboles are also not alkali-rich, in agreement with the pyroxene chemistry.



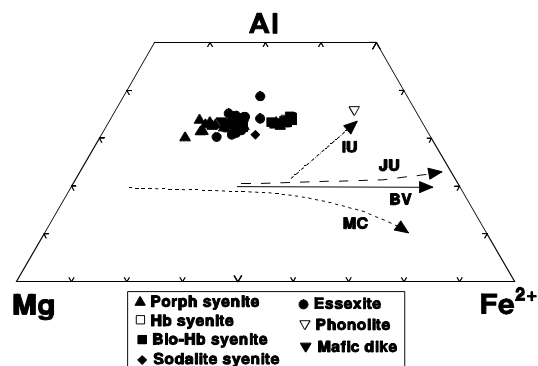
**Fig. 14.** Amphibole compositions plotted on the classification diagrams of Leake et al. (1997). Amphibole formulae calculated on the basis of 23 (O) with 2 (OH, F, Cl).

composition similar to that observed for biotites from some strongly alkaline nepheline syenite complexes in Malawi. While the analyses are not considered reliable due to the large amount of alteration, and are not plotted on Figure 15, biotites from the quartz syenite are Fe-rich. Also plotted on Fig. 15 are trends for biotites from other nepheline syenite complexes: Ilomba and Ulindi, North Nyasa alkaline province,



**Fig. 13.** Pyroxenes compositions plotted on the classification diagram of Flohr and Ross (1990).

*Biotite.* Biotite compositions are projected into a portion of Al-Mg-Fe<sup>2+</sup> on Figure 15. Of note is that the biotites show restricted compositional variation, are not particularly Fe-rich, and are more aluminous than biotites from many other alkaline complexes. The most strongly Fe-enriched biotite is from the phonolite, and has a



**Fig. 15.** Biotite compositions plotted in a portion of the Mg-Al-Fe<sup>2+</sup> ternary diagram. Biotite formulae calculated on the basis of 24 (O+OH+F+Cl). IU = Ilomba and Ulindi (unpublished data, Woolley), JU = Junguni (Woolley and Platt, 1988), BV= Beemerville (unpublished data, Eby) and MC = Magnet Cove (Flohr and Ross, 1990).

Malawi; Junguni, a sodalite-rich syenite complex, Chilwa alkaline province, Malawi; nepheline syenites of the Beemerville complex, New Jersey; and essexites through nepheline syenites of the Magnet Cove complex, Arkansas. The Cuttingsville biotites are characterized by their relatively high Al content compared to the other alkaline complexes.

### Rock Chemistry

An extensive major, trace element, and radiogenic and stable isotope data base now exists for the Cuttingsville complex. A detailed discussion of these data is beyond the scope of this guidebook, but there will be an opportunity to discuss the data in the field. A manuscript is currently in preparation which will describe the results in detail. Laurent and Pierson (1973) distinguished two major petrologic series at Cuttingsville, both starting with essexite, one of which differentiated towards more silica-undersaturated magmas, and the other towards silica-saturated to over-saturated magmas culminating in the quartz syenites. Neither the unpublished data of Eby or Wood (1984) show this sharp two series distinction (Fig. 16). The essexites are all broadly similar in composition irrespective of grain size, usually contain minor nepheline, and are Ne-normative largely because of the presence of kaersutitic amphibole rather than an abundance of modal nepheline. On the basis of petrography and chemistry, many of the syenites are cumulate rocks, and the late-stage porphyritic syenites contain enough xenocrystic material plus phenocrysts so that they do not, in most cases, represent liquid compositions. The quartz syenites do show what could be interpreted as a liquidus trend and the phonolite and sodalite apparently approximate liquid compositions (Fig. 17). The sodalite syenite, phonolite, and some of the porphyritic syenites plot in the thermal trough leading towards

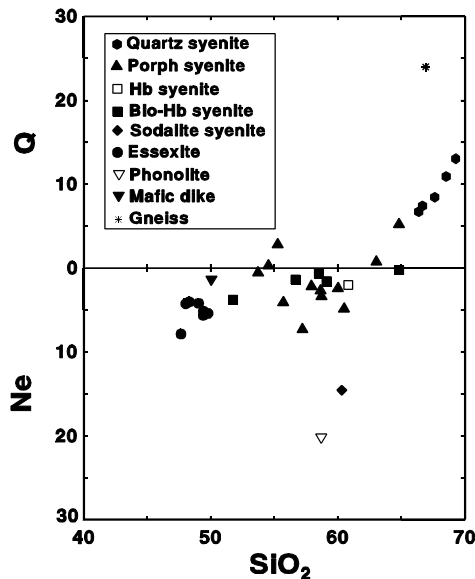


Fig. 16. Normative nepheline and quartz versus  $\text{SiO}_2$  (wt. %).

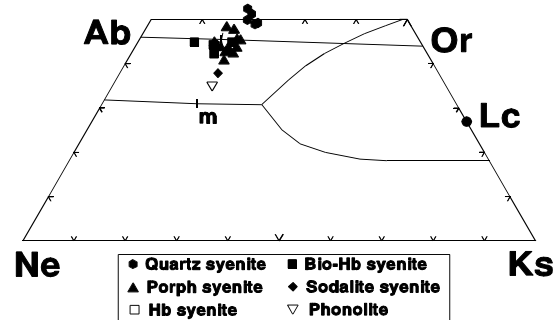


Fig. 17. Syenite compositions projected into the 1 kbar Ne-Qtz-Ks ternary phase diagram (Henderson, 1984). The phonolite and sodalite syenite plot close to the thermal minimum while some of the porphyritic syenites plot in the trough leading to the thermal minimum.

the low temperature minimum in the silica-undersaturated portion of the Ne-Qtz-Ks 1 kbar phase diagram (Fig. 17). The quartz syenites fall in a cluster just in the silica-oversaturated side of the phase diagram. Trace element and isotopic data suggest that these syenites have undergone evolution by AFC processes, however the amount of contaminant is apparently extremely small, probably less than 5%.

### Petrogenetic Considerations

This topic will be more fully considered on the field trip. In brief, the sequence of events indicates that the essexites were the first phase emplaced in the conduit. Subsequent intrusions of syenitic magmas removed much of the early essexite, but remnants are preserved both as continuous outcrop and as xenoliths, and xenocrystic minerals, in the

syenites. Because of exposure and accessibility, much of the syenitic material you will see on the field trip is porphyritic. However, the bulk of the intrusion is composed of coarse-grained syenite and the petrography and chemistry of the coarse-grained syenites indicates that they are cumulates from a syenitic magma. While the essexites and some of the syenites are normatively silica-undersaturated, nepheline is found only in minor amounts and sodalite is confined to the sodalite syenite which may have been produced by crystallization from late stage fluids. The quartz syenites, the most silica-oversaturated rocks in the complex, never contain more than 5% modal quartz. Hence the Cuttingsville magmas were slightly silica undersaturated to slightly silica oversaturated.

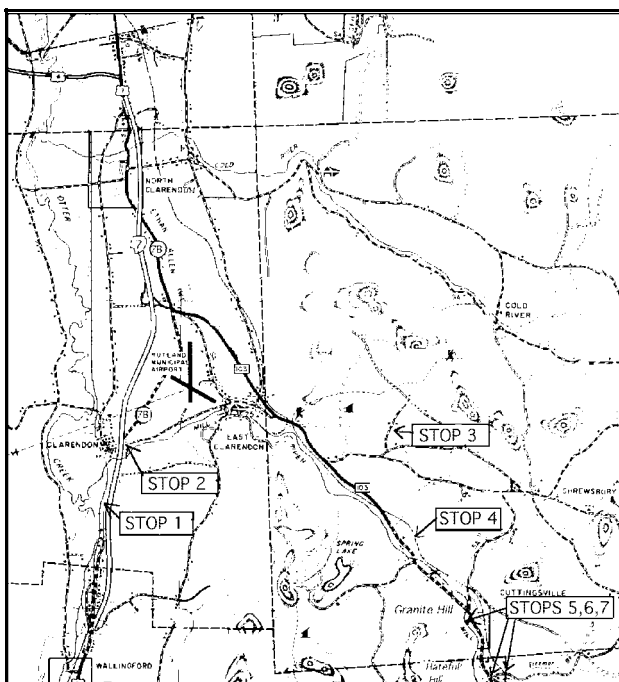
Sr, Pb and O isotopic data indicate that the bulk of the Cuttingsville rocks were crystallized from magmas that had undergone little interaction with crustal rocks. For example, for the essexites and most of the syenites ( $^{87}\text{Sr}/^{86}\text{Sr}$ )<sub>i</sub> varies from 0.7034 to 0.7038. Only in the case of the quartz syenites and the quartz-bearing porphyritic syenites are higher ( $^{87}\text{Sr}/^{86}\text{Sr}$ )<sub>i</sub> ratios found (up to 0.7083). However, in the case of the quartz syenites absolute Sr abundances are low (<50 ppm) so these elevated ratios can be produced through minor interaction with the surrounding gneisses. Both the quartz syenite and the sodalite syenite show significant negative Eu anomalies, none of the other units have negative Eu anomalies and the coarse-grained syenites typically have small positive Eu anomalies. There is abundant evidence that all of the syenitic magmas were feldspar saturated, so these magmas were not above the liquidus. The constraints of phase petrology therefore require that the silica-saturated or undersaturated character of the magmas was determined during the early stages of magmatic evolution. While there is evidence that AFC processes played a role in the evolution of the quartz syenite magma, this magma was already silica saturated and had undergone a significant degree of differentiation, before it was emplaced at high levels. Hence if crustal contamination played a role in determining the silica-saturated or undersaturated character of these magmas, the crustal contamination must have occurred early in the evolution of the original mantle-derived melts while they were still at relatively great depth in the crust.

## SITE LOCATIONS

The region is generally rural, and famous for its scenery. Motels and other amenities are most abundant in Rutland, but that city also has the most unpleasant traffic flow of the area. U.S.G.S. topographic maps at 1:24,000 scale for the area include the Rutland (1980) and Wallingford (1986) sheets. We have found The Vermont Atlas and Gazetteer (DeLorme Mapping Co.) to be generally useful and widely available.

Along the way, a lunch break will be made in the village of Cuttingsville, probably after Stop 5. Gasoline is not available in Cuttingsville, but restaurants and gas stations are abundant along Rte. 7 in Rutland, between the meeting headquarters and the first stop of this trip. The total travel distance from start to finish is about 11 miles.

The first three stops are near roads, while the remaining sites are a few minutes walk from parking areas. Please be sensitive to private property at and near these sites, and watch for traffic, which can be passing by at high speeds.



**Fig. 18.** Roads and field stop locations, Cuttingsville region.

## ROAD LOG AND SITE DESCRIPTIONS

0.0 miles. START, Rte. 7 rest area.

We will assemble and start at 9:00 AM sharp from the highway rest area on the west (right) side of Rte.7, which is about 0.4 miles south of the intersection with Rte 103. The most direct route to this starting point from the Long Trail Lodge is to travel west on Rte. 4 to the intersection with Rte. 7 at Rutland, and then south (left) on Rte. 7. The intersection with Rte. 103 is several miles south of the city. Please arrive at least five minutes before our 9:00 AM start.

From the rest area, continue southbound on Rte. 7.

2.1 miles. Roadcut on west (right) side of Rte. 7. Pull off near southern end of cut.

### STOP 1. SOUTH CLARENDON TRACHYTE DIKES

This very fractured dike (RT-4; AZ300,86; 230 cm) is hardly recognizable as an igneous intrusion until you examine the rock fragments. There is a very "shaley cleavage" developed parallel to the dike walls, which must have a tectonic cause. The Ordovician dolostone country rock shows both faults and hydrothermal alteration at other outcrops in the area.

On the northern end of the cut there is a smaller, dark-weathering trachyte (RT-1; AZ 060,75; 14 cm) exposed. Small fingers of this dike have a green color, similar to that seen in other very thin trachytes that intrude dolostone (McHone, 1987). Perhaps a chemical reaction with the Mg-rich country rock has produced a fine-grained green mineral that is diluted in thicker dikes.

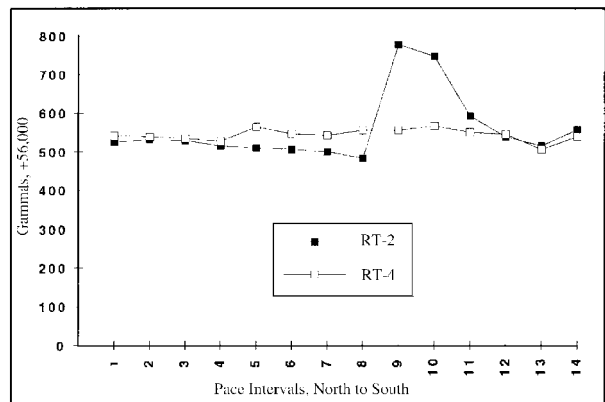
Compositionally, the trachytes are quartz syenite. In contrast to the abundant trachyte/bostonite dikes of the Lake Champlain Valley south of Burlington, there are only a handful of such felsic dikes around Rutland. As an end-member differentiate, the trachyte dikes are thought to be offshoots of shallow-level plutons. McHone and Wagener (1982) report 6 ppm U<sub>3</sub>O<sub>8</sub> and 44 ppm eTh for dike RT-4, in agreement with other trachytes in Vermont.

Continue 0.2 miles farther south to turn around. Turn around by pulling to the right into a side road, then left across Rte. 7 to head back to the north. BEWARE of high-speed traffic!

3.1 miles. Roadcut with dikes on the east (right) side. Turn right onto old Rte. 7, then right uphill behind the roadcut, park (dead end road).

### STOP 2. SOUTH CLARENDON DIABASE DIKES

Diabase, as used here, is essentially a basaltic rock that is appreciably altered, generally by hydrothermal solutions or weathering rather than by burial metamorphism (although the term has been used for low-grade metamorphosed rocks as well, for which we prefer "meta-d diabase"). As at this site, it can be difficult to see much original texture and primary mineralogy. This dike (RT-2) and its small neighbor (RT-3) on the southern end of the cut may have originally been camptonite, but the mafic minerals are so changed that it is difficult to classify.



**Fig. 19.** Magnetic anomaly across diabase dike RT-2, traversed along the road ditch. A similar traverse across trachyte dike RT-4 reveals no magnetic expression, as expected for trachyte.

This E-W dike (AZ 084,86; 124 cm wide) has a small but distinct positive magnetic anomaly, as measured with a portable proton precession magnetometer (Fig. 19). The magnetic expression can be traced to the east for several hundred meters, as far as the Mill River. The dike is exposed in the river gorge on this magnetic line, and could possibly be traced much farther.

Turn right, away from Rte.7 and follow gravel road along the Mill River, to East Clarendon.

2.6 miles. Turn right at stop sign, in tiny village of East Clarendon.

3.0 miles. Turn right (southeast) onto Rte. 103.

4.2 miles. Turn left onto Maplecrest Farm Road. Go uphill, eastward.

5.0 miles. Bear left at intersection.

5.1 miles. Bear right at intersection.

5.2 miles. Stop along road near edge of woods to your right (east). Outcrops are low rock mounds in the woods.

### **STOP 3. SHREWSBURY INTRUSIVE BRECCIA**

This site is on private property of Mr. Arthur Pierce, whose residence is at the last intersection. Please do not damage the fence or other property.

The map by Brace (1953) shows this breccia and a few others to the southeast in vague ovals, because exposure is poor. It was certainly a violent intrusion, full of clasts of local metamorphic rocks of the Grenvillian Mt. Holly complex, and there may be several "pipes" as the true forms of the intrusions. This site provided samples for Paul Doss (1986), who cataloged many of the lithologies within the breccia. Doss (1986) looked especially for sedimentary clasts of the Champlain Valley sequence, which would prove an overthrust relationship of the western Green Mountains, but none were identified.

The dike matrix is fairly fresh in a few places between xenoliths, and has a very volcanic, andesitic look in thin section. The date of 101 Ma (Table 1) is reasonable and indicates little contamination by K or Ar from the country rocks.

Turn around, head back to Rte. 103.

6.2 miles. Turn left (southeast) onto Rte. 103.

7.1 miles. RR crossing. Pull off highway onto right shoulder

### **STOP 4. HYPABYSSAL INTRUSIONS, NORTHERN RR CUT**

Walk south approximately 600 m to the first of two railroad cuts. Eggleston (1918, p. 384) describes the set of outcrops along the railroad as follows: "The northern eruptives, where exposed, are much more involved with the country rocks than is the case on Granite Hill [the main intrusion]. Contorted and brecciated gneisses frequently alternate with eruptives along the railroad, and flank them on the northwest. The geological map [Fig. 1, Eggleston, 1918] owing to the limitations of its scale, gives a quite inadequate impression of the intricate relations between eruptives and country rock, especially in the case of the more northern area." At this stop you will have an opportunity to examine these complex relationships. In the first of the railroad cuts several varieties of porphyritic syenite are found cutting the gneisses. At the southern end of the first set of outcrops is a 6 m wide dike that weathers to a knobly pattern. This dike is crowded with xenocrysts (photomicrograph, Fig. 11). Proceed south another 400 m to the next railroad cut. A porphyritic fine-

grained syenite dike, approximately 20 m wide, cuts the gneisses toward the northern end of the railroad cut. Return to vehicles.

Continue SE on Rte. 103.

8.8 miles. If we have only a few vehicles, turn into the Stewart Ford dealer lot on right, and park in the back away from dealer stock (this is one of the oldest car dealers around, having been in business here since 1915). Several cars can also park in front of the closed storefront across and west of the car dealer. Otherwise, if we have more than 4 or 5 vehicles, we may park a little farther down the road in the hardware store/restaurant lot, and walk back.

#### **STOP 5. NORTHERN GRANITE HILL AND MILL RIVER SYENITE FACIES**

Walk up an old quarry/logging road into the woods above the car lot. Approximately 380 m up the road is an outcrop of quartz syenite cut by porphyritic syenite with pegmatitic zones. Continue for another 210 m to an outcrop of typical coarse-grained essexite. A phonolite dike cuts the essexite at the SW edge of the outcrop.

Return to the parking lot and walk south about 160 meters along the Mill River, if conditions permit (low water is helpful). Outcrops of quartz syenite, cut by porphyritic syenite, are exposed in the river. The contact between the porphyritic syenite and the quartz syenite is irregular indicating that the quartz syenite was still soft at the time of intrusion of the porphyritic syenite. Blocks of quartz syenite and essexite are found in the porphyritic syenite. Continue along the river another 170 m to a lamprophyre dike.

Continue SE across the bridge.

9.0 miles. Turn right into the entry road and parking lot between the restaurant and hardware store.

LUNCH STOP. The restaurant has been warned that we may appear. Soft drinks are also available at the hardware store. Please try to limit your lunch break to 45 minutes.

10.0 miles. Turn left into the left branching road just past the small stream bridge.

10.1 miles. Park along the road near the railroad crossing. Do not block the road, and do not park on the tracks!

#### **STOP 6. SOUTHERN RR CUT**

Walk approximately 400 m to the north along the railroad tracks. Medium-grained sodalite syenite is exposed in a 15 m long outcrop on the east side of the railroad tracks. This is the location of the sodalite syenite (CV23) shown in Figure 9.

Return back down the road to Rte. 103.

10.3 miles. Park on the wide areas at the side road, but not on Rte 103.

#### **STOP 7. SOUTHERN MILL RIVER SYENITE-DIORITE FACIES**

This site requires participants to wade across the Mill River, which is our reason for making this the last stop! Although we do not expect the river to be particularly deep or swift, there is some risk of falling. If you are up for it, this site has some of the most interesting and varied exposures of the plutonic sequence to be found anywhere in the complex.

An almost continuous sequence of outcrops occurs in a 350 m zone along the west side of the Mill River. Going north, the sequence begins with medium-grained, locally porphyritic, essexite. The essexite is cut by both mafic and felsic dikes. The felsic dikes often show a very anastomosing relationship with the essexite, and in places the dikes are disrupted suggesting that the essexite was plastic when the dikes were intruded. Continuing northward larger syenitic zones are encountered, often containing numerous mafic inclusions and abundant sulfides. At approximately 150 m medium-grained syenite with moderately abundant sulfides becomes the dominant unit. Continuing northward fine-grained syenite, often bluish in color, becomes the dominant lithology. Porphyritic syenite is associated with this unit, apparently as a facies of the blue syenite. Locally mafic inclusions are common, and the syenite outcrops are cut by numerous mafic dikes.

At the end of the syenite section, return to the Mill River crossing point. Rewade the Mill River, and return to cars for R&R.

## END OF TRIP

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