FIELD GUIDE TO CRETACEOUS INTRUSIONS IN THE NORTHERN TACONIC MOUNTAINS REGION, VERMONT

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Introduction

Northern New England and adjacent Canada were host to widespread, mid-plate, non-orogenic alkalic igneous intrusions during Early Cretaceous times. In several stages, from 130 to 100 million years ago, groups of plutons, dike swarms, and individual igneous complexes were intruded and now 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 Monteregian Hills of southern Québec southeastward through New Hampshire (Fig. 1). We have been calling this the New England-Québec ("NEQ") igneous province (McHone and Butler, 1984). Still more of these intrusions are found in the continental shelf (Puffer, 1989), and they continue across the western North Atlantic as the New England seamount chain.

If an "eogeologist" could do field work in the Vermont of 110 million years ago, some members of the NEQ province would be mapped as volcanic mountains in a tectonic setting perhaps not too different from that of East Africa today. The evolution of our present topography of valley basins and mountain ranges was far from finished and "terrible lizards" walked upon stratigraphic formations that were several kilometers above the present surface. Those formations may well have included Mesozoic clastic and volcanic rocks, especially within the structural basins that flank Vermont (McHone, 1982). One proven area of volcanism in eastern Vermont is the great monadnock of Ascutney Mountain, which has blocks of volcanic rocks preserved within plutonic rocks near its peak. Other intrusions, such as the Cuttingsville complex and Barber Hill stock of western Vermont, show no evidence for associated extrusive rocks. We have no sure idea of whether dikes of hypabyssal magmas, such as those visited on this trip, ever reached the surface anywhere in the region.

Differential erosion, controlled by faulting, uplift, down-drop, and weathering, has removed the stratigraphic evidence of Vermont's Mesozoic volcanic and sedimentary rocks, yet that same erosion now provides views of the plutonic chambers that once lay beneath Cretaceous volcanoes. Erosion has also exposed thousands of dikes across the NEQ province, some of which we describe in this paper and others of which are described in works listed in the bibliography. High-angle faults, mostly normal, are also exposed and may be relicts of Mesozoic tectonism in the region (McHone, 1987).

NEQ dikes display a bimodal range of mafic and felsic types in overlapping sets and swarms, each with somewhat distinctive ages and physical characteristics. Given that they cooled in contact with rocks only a few kilometers below the surface, the dikes are naturally intermediate in crystal character between phaneritic plutons and aphanitic volcanic rocks. Good eyesight and a hand lens are required to make out 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 NEQ dikes are too small to have produced flood basalts or large volcanic edifices. Yet, as shown by xenoliths of spinel peridotites and other mantle rocks (McHone and Williams, 1985), these magmas, in dikes with just a few meters of exposed width, ascended from mantle depths.

This field excursion presents work that characterizes the little-known northern Taconics (NT) subprovince of the New England-Québec igneous province. We have described only a few of the NT intrusions; the group is worthy of a thesis or other research efforts (let us know if you are interested). As in other regions, relatively few of the geologists who produced the quadrangle bedrock maps for the area paid much attention to these intrusions. Some older papers contain very useful information, such as those by Marsters (1889), Dale (1899), Eggleston (1918), and Fowler (1950). More recent work centers on the pluton at Cuttingsville (e.g. Laurent and Pierson, 1973; Robinson, 1990; Wood, 1984; and Eby, 1992).

Dikes at Stops 1, 2, 3, and 5 were first shown to J.G.M. by E. Stanley Corneille, who shared these geological interests while doing graduate work at the University of Vermont in the early 1970's. Other field visits were made with J. Robert Butler during and after J.G.M.'s Ph.D. work at the University of North Carolina at Chapel Hill (1974–1978) and some field work was also conducted with Chiasma Consultants, Inc. for the National

Uranium Resource Evaluation (1978–1980). We made a field tour in September of 1992 for this log.

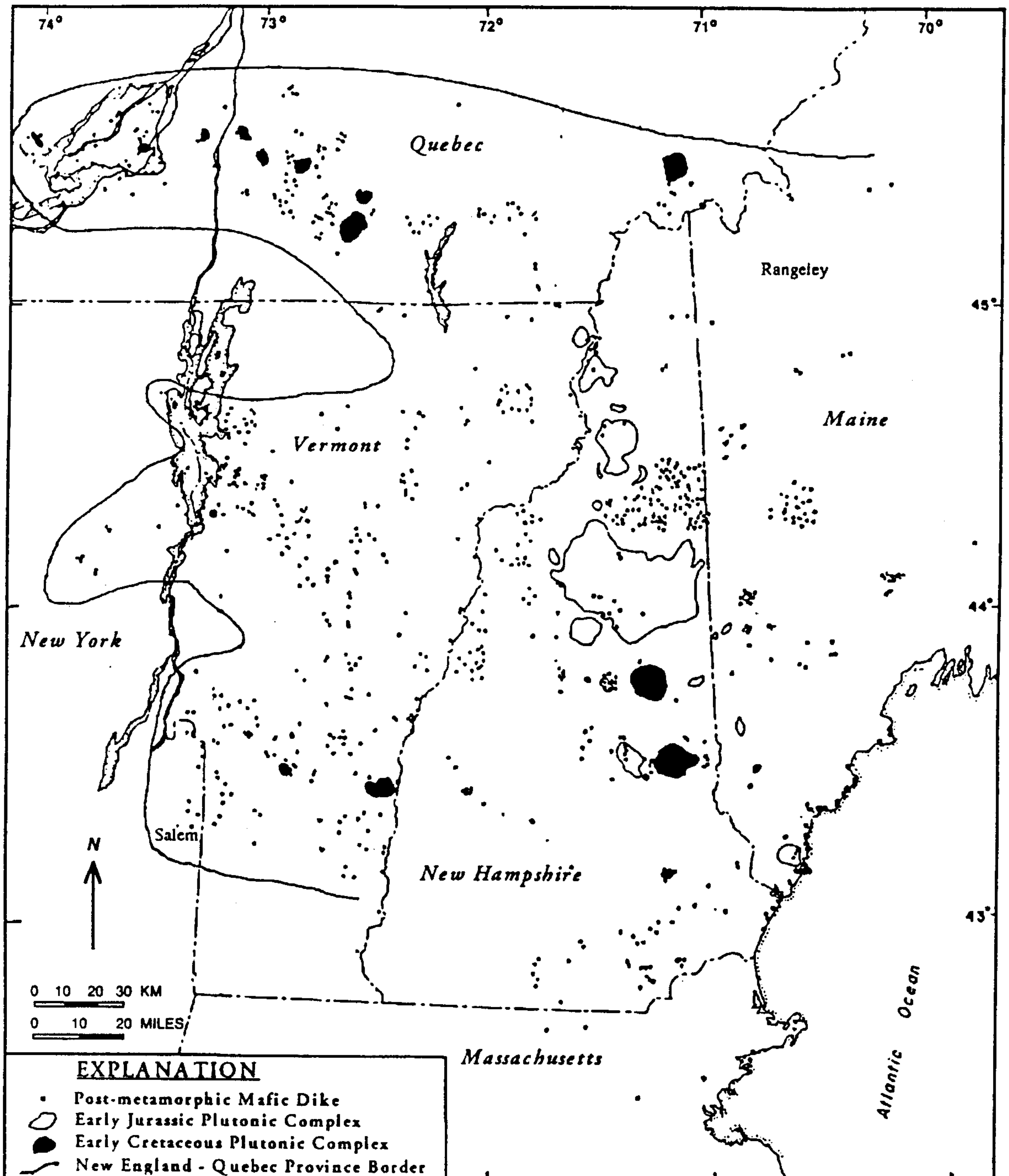

Figure 1. Geographic extent of the New England-Québec igneous province showing the distribution of unmetamorphosed (post-Acadian) dikes and larger intrusions.

The Northern Taconic NEQ Subprovince

The western border of the NEQ province outlines three lobes, or subprovinces, that extend westward from northern New England (Fig. 1). The northernmost lobe is the Monteregian Hills subprovince of southern Québec which is well known for its carbonatites and ultramafic stocks as well as for alkali lamprophyre dikes. Most radiometric dates are near 110 (±5) Ma.

Table 1. Radiometric Dates, Northern Taconic Igneous rocks

Site	Description	Date (Ma)	Reference
Stop 3 (PO-1)	Spessartite, Rte. 4 road cut Poultney quadrangle lat. 43°32'05"N long. 73°10'35"W	113 ±4	(1)
Stop 6 (WR-3)	Hbl spessartite, Rt.4 road cut West Rutland quadrangle lat. 43°30'49"N long. 73°03'20"W	108 ±4	(2)
Stop 9 (RT-7)	Andesitic breccia, Shrewsbury Rutland quadrangle lat. 43°30'57"N long. 72°53'56"W	101 ±4	(1)
Stop 10	Biotite syenite, Cuttingsville	102 ±2	(3)
	essexite	98.8 ±2	(3)
	essexite	103 ±4	(4)
	quartz syenite	108 ±1	(5)
	quartz syenite	100 ±3	(6)

Note: All dates are by K-Ar analysis of whole-rock and mineral samples, except for Cuttingsville date by Ref. 5, which is by Rb/Sr isochron. Dates have been revised, where appropriate, to newer IUGS decay constants.

References: (1) This paper; dates courtesy of H. Kreuger, Geochron Labs; (2) Zen, 1972; (3) Armstrong and Stump, 1971; (4) Stone & Webster unpub. date, Ref. Kanteng (1976); (5) Eby, 1992; (6) G.N. Eby, pers. comm., 1992.

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, road cuts, streams, and hillsides (Fig. 1). Lamprophyre dikes of this Champlain lobe or subprovince are distributed westward into the central Adirondack Highlands of New York and eastward into north-central Vermont (McHone and Corneille, 1980). Champlain Valley dikes are identical to Monteregian dikes, including carbonate rich types, but associated plutonic complexes are fewer and smaller in the Lake

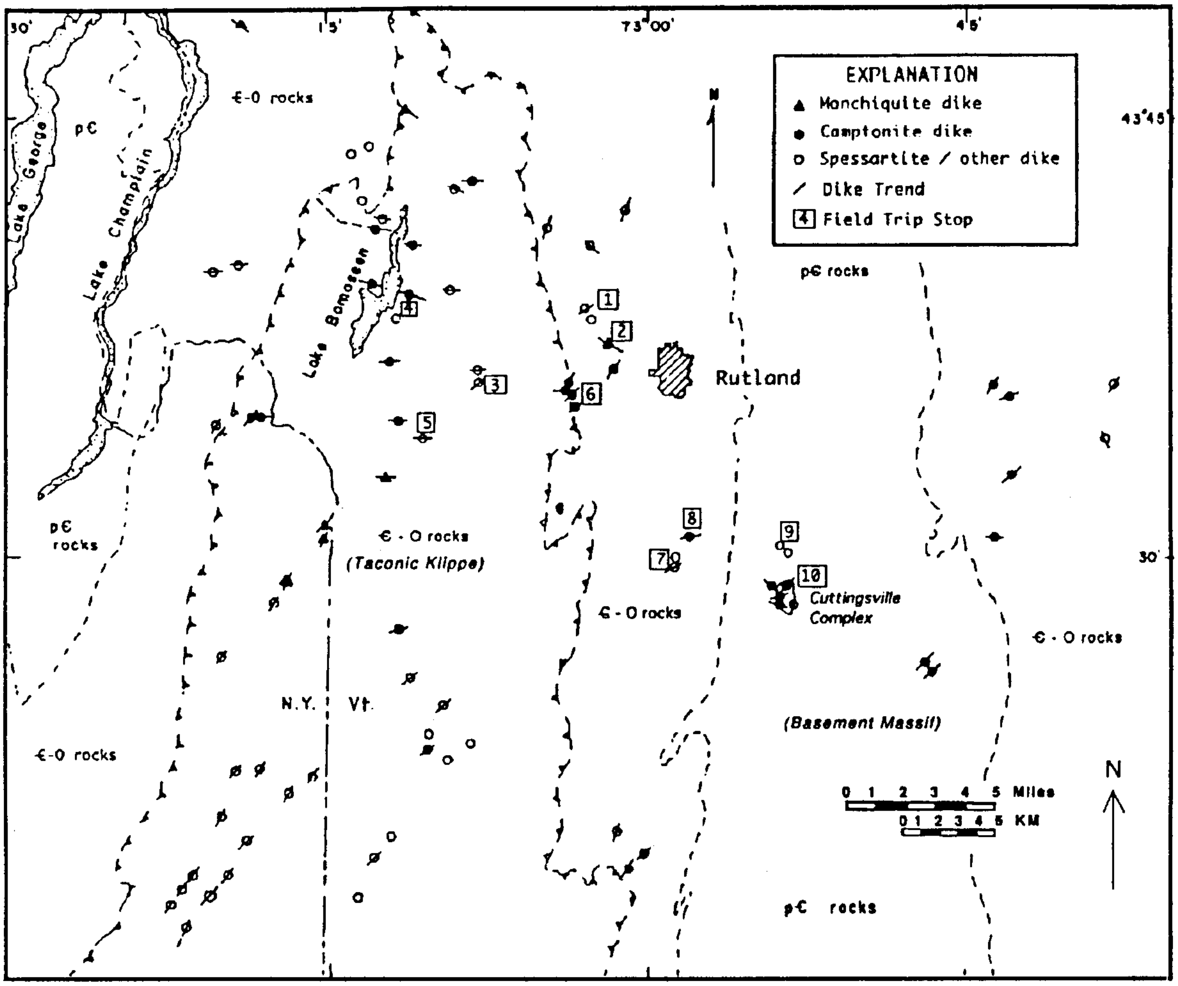

Figure 2. Dike locations in the northern Taconics region, Vermont and New York.

Champlain region than in Québec. Radiometric dates indicate ages near 135 Ma for monchiquites, 125 Ma for trachytes and syenites, and 115 Ma for camptonites (McHone, 1987), although this very neat correlation of rock type and age needs better confirmation.

In the southern or 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 (Fig. 1). 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. 2). Many of these 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).

While the dikes in the NT subprovince have only been subject to reconnaissance study, the Cuttingsville plutonic complex, southwest of Rutland, has received attention since the 1970's from mineral companies as well as by research geologists (e.g. Laurent and Pierson, 1973; Robinson, 1990; Wood, 1984; and Eby, 1992). We consider the Cuttingsville intrusions to be part of the Northern Taconic subprovince on the basis of age and petrology, although the density of presently known dikes diminishes towards Cuttingsville (Fig. 2). Eastward from Cuttingsville dikes remain fairly common (2 to 6 dikes have been sampled per 15' quadrangle) where they merge with the regional camptonite swarms of eastern Vermont, New Hampshire, and Maine (McHone, 1984).

Trends and Structures

Each of the three western NEQ lobes has different orientation maxima for dikes (Fig. 3). The Monteregian subgroup has a WNW–ESE maxima for dikes, examples for which are found the entire distance from Montreal to northwestern Maine (McHone, 1978a). Dikes of the Champlain Valley subprovince have a very distinct E–W preference (McHone and Corneille, 1980). When plotted together, dikes in the northern Taconics lobe display a NE–SW maxima (Fig. 3, 'Rose C'). Most of the dikes in the southern and eastern portions of the subprovince show this NE–SW trend, but there are also several dikes in the northern portions that trend between E–W and SE–NW (Fig. 2).

We believe that most dike magmas intrude along directions of simple extension, widening fractures against the direction of minimum compression within the upper crust (McHone, 1988). But how can dikes of (presumably) the same generation have different trends across such a small area? Possibilities include: (1) Dikes radiate from a plutonic center or chamber analogous to the exposed Spanish Peaks (Colorado) volcanic center. Such a hidden pluton would have to exist somewhere near Rutland to be roughly at the intersection of local dike trends. (2) Dikes have originated at different times in the same areas, responding to a changing stress field as they formed. (3) Some dikes have filled "shear" fractures in addition to extensional fractures during the same event. Finally, (4)

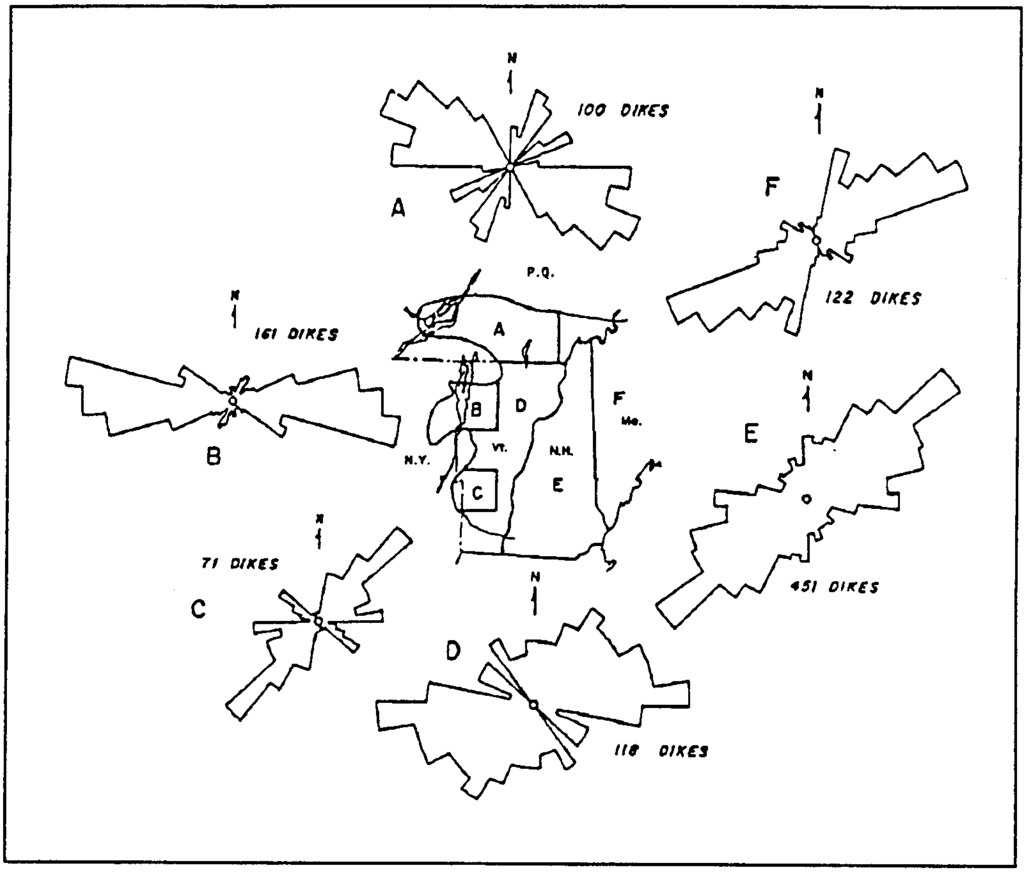

Figure 3. Dike trends (rose diagrams) in northern New England. Rose diagram labels refer to areas shown in the central figure, with rose C representing northern Taconic dikes.

we are intrigued by the notion of a major lithospheric break (see below) that acted as a tectonic boundary to stress (and strain) fields in the region.

McHone and Shake (1992) suggested that the shift of the Cretaceous NEQ dikes from E–W and ESE–WNW trends in northern areas to a NE–SW trend toward southeastern New England (Fig. 3), is controlled by a lithospheric cross-structure that is partly expressed by major topographic lineaments (Shake and McHone, 1987). The proposed structure underlies a lineament that extends across the region in a northeasterly direction from the vicinity of Salem, New York at least to Rangeley, Maine (Fig. 1). The Salem-Rangeley zone is contiguous with the Alabama-New York lineament of King and Zietz (1978), which they proposed to be due to a major high-angle structure. This proposed structure was a boundary that reoriented stress fields in New England which in turn controlled the orientation of dikes in the NEQ province. We have, however, no direct field evidence for such a major "basement break."

Northern Taconic Igneous Rock Types

The NT dike types include monchiquite (nephelinite), camptonite (basanite), bostonite (trachyte), and spessartite (andesite), all of which can be examined during this trip. During this trip, observe the different colors for mafic and felsic dikes types. The quartz syenite member of the Cuttingsville complex is visited on the final stop, depending on field conditions. All of these igneous rocks are presumed to be related through an event that included fractional melting, differentiation, and crystallization, but it is 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 hornblende. 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 kersutite), rather than felsic. Camptonite dikes usually have a brownish to medium gray range of colors.

Spessartite dikes lack olivine and analcite, but plagioclase (intermediate Ca) is well developed and present both 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.

Bostonite is a name that in a strict sense applies only to felsic (anorthoclase-rich) dikes that have a "felty" clumped-grain texture, which actually 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 Cuttingsville can be chemically like trachyte (Table 2), but at Stop 10 the syenite has been enriched by sulfides.

TABLE 2. Chemical Analyses of Intrusive Rocks and Minerals, Northern Taconics

OXIDE (Wt. %)	WR-4B	PO-1	MPMB	QTZ-SYEN	PO-1k	PO-1a	PO-1p	PO-1i
SiO_2	45.09	50.85	69.00	65.86	41.32	50.77	55.32	6.61
TiO_2	2.89	1.71	0.24	1.03	4.84	1.08	0.15	55.62
Al_2O_3	13.58	16.66	16.50	17.19	11.60	4.43	28.08	2.56
FeO*	10.97	6.71	2.25	2.88	12.03	5.45	0.70	18.15
MnO	0.19	0.22	0.20	0.17	0.28	0.17	0.01	0.84
MgO	7.02	3.86	0.06	0.06	12.09	15.83	0.06	2.58
CaO	10.38	7.32	0.50	0.84	11.86	21.35	10.48	1.58
Na_2O	2.94	5.15	4.30	6.78	2.82	0.80	4.66	0.51
K_2O	1.25	2.63	4.00	5.24	1.09	n.a.	0.38	0.18
P_2O_5	0.71	0.35	0.10	0.03	n.a.	n.a.	n.a.	n.a.
H_2O^+	1.10	1.49	3.00	n.a.	n.a.	n.a.	n.a.	n.a.
CO_2	3.28	2.85	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
H_2O^-	0.30	0.39	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Total	99.70	100.19	100.15	100.08	97.75	99.88	99.84	88.63

TRACE ELEMENTS (ppm)	WR-4B	PO-1	MPMB	QTZ-SYEN
Rb	25.9	58.3	43.0	111
Sr	805	843	205	29.0
Y	28.7	27.5	n.a.	n.a.
Zr	279	261	532	469
V	234	144	n.a.	5.0
Cr	267	179	n.a.	50.9
Ni	142	51.0	n.a.	12.8
Ba	609	1120	n.a.	181

Note: FeO* = total Fe as FeO
n.a. = not analyzed
WR-4B = camptonite near Stop 6, ref. McHone, 1978b
PO-1 = spessartite at Stop 3, ref. McHone, 1978b
MPMB = trachyte dike at Charlotte, ref. McHone and Corneille, 1980
QTZ-SYEN = average of 5 Cuttingsville quartz syenite analyses, ref. Wood, 1984
PO-1k = kaersutite phenocryst from dike PO-1, ref. McHone, 1978b
PO-1a = augite phenocryst from dike PO-1, ref. McHone, 1978b
PO-1p = plagioclase phenocryst from dike PO-1, ref. McHone, 1978b
PO-1i = ilmenite phenocryst from dike PO-1, ref. McHone, 1978b

FIELD TRIP DESCRIPTION

General Information

The region traversed on this field trip is generally rural and famous for its scenery (Fig. 4). Motels and other amenities are most abundant in Rutland, but that city also has the most unpleasant traffic flow of the area. An excellent campground (in season) is Bomoseen State Park located on the west side of Lake Bomoseen a few miles north of Route

4. Some of the ten sites described in this field guide may be difficult to visit during bad weather (snow, ice) or high stream flow...judge for yourself from the stop descriptions.

U.S.G.S. topographic maps are all available at 1:24,000 scale for the area. The route traverses six 7 1/2' quadrangle maps in the following order: Proctor (dated 1944, Rte. 3 no longer as shown), West Rutland (1972), Poultney (1972), Bomoseen (1944), Poultney again, West Rutland again, Rutland (1980), and Wallingford (1986). We have found The Vermont Atlas and Gazeteer (DeLorme Mapping Co.) to be generally useful and widely available. The U.S.G.S. Planimetric Maps for Ticonderoga (Fig. 4) and Rutland include the sites.

Meeting Place

Directions to start: From Burlington, drive south on Route 7 to Pittsford, then follow Route 3 southwest to Proctor. From southern/eastern/western approaches, turn north onto Rte. 3 off Business Route 4 between Rutland and West Rutland, then north to Proctor. The Vermont Marble Company is just across the bridge in the western part of the village. We have permission to assemble in their lot near the information kiosk.

Along the way, a lunch break can be made in the village of Castleton, which is crossed before and after Stop 5. Gasoline is available in Castleton, but not in many other places along the trip route. Restaurants and gas stations can also be found along Rte. 7 in Rutland before or after the trip. The total travel distance from start to finish is about 60 miles.

ROAD LOG AND SITE DESCRIPTIONS

0.0 miles: **START**

Meet at the Vermont Information kiosk in the parking lot of the Vermont Marble Company, Proctor, Vermont. The marble industry in Vermont is nearly 200 years old and this is the only remaining large-scale operation out of many former businesses. If you have time, take a tour of their showcase museum. Some bargains of polished stone seconds can be had at the adjoining sales yard and we can personally recommend their handsome stone table tops from the store inside.

Head south on Rte. 3 for 1.7 miles.

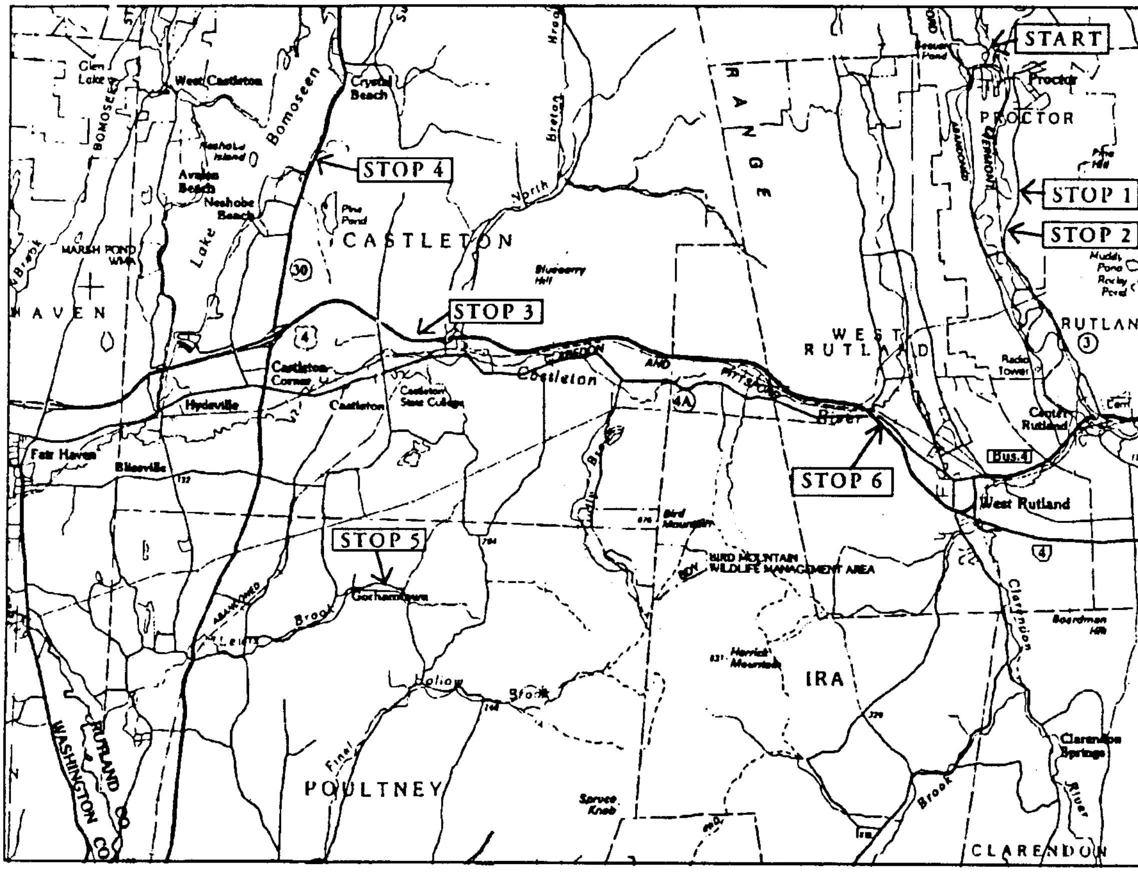

Figure 4. Roads and locations of Stops 1–6, northern Taconics region.

STOP 1: PROCTOR TRACHYTE DIKES

Miles between points: 1.7 Cumulative Mileage: 1.7

Road cut on eastern (left) side of the the highway. Watch for the traffic as you pull onto the wide shoulder on the eastern side, about 3/4 of the way down the cut.

There are two trachyte dikes towards either ends of the cut about 40 m apart; our dike numbers PR-1 to the north and PR-2 to the south. PR-2 is oriented Azimuth 264,55 (when looking along strike, to 264 or 6 degrees south of west, dip is 55 degrees to the right, or north), and is 42 cm wide (measured at chest height). PR-1 is AZ 236,71; 91 cm wide. These two dikes are fairly typical of "bostonite" dikes with their tan color, rhythmic weathering stains, and brittle fracture patterns. Their mineralogy is dominated by anorthoclase, with minor Na-plagioclase, quartz, oxi-biotite, and iron sulfides. The country rock is the Cambrian Dunham dolostone.

The dikes cross a thick, steeply east-dipping quartzite bed that shows much fracturing along the intrusion margins. A few small faults also occur here. Small syn-intrusional steps in the dike walls produced curving flow lines in the dike. Trachyte magma was much more viscous than the magmas that produced the more mafic dikes we will see. Generally the trachyte dikes appear in the vicinity of larger, syenitic plutons or differentiated plutonic complexes. In our discussion of Champlain Valley dikes (McHone and Corneille, 1980), we inferred that trachyte dikes are offshoots of such magma chambers while the widespread lamprophyres are not. Here we are about 25 km northwest of the Cuttingsville complex and so these trachytes are rather isolated...unless there is another pluton, still hidden.

During the National Uranium Resource Evaluation (NURE) of the late 1970's trachyte dikes were found to have gamma radiation levels that are 5 to 10 times higher than surrounding rocks. An analysis of the PR-1 dike shows 9 ppm U_3O_8 and 60 ppm eTh (McHone and Wagener, 1980). These values are high but within the range of 1 to 15 ppm U_3O_8, and up to 105 ppm eTh measured for syenitoids and granitoids of the Cuttingsville and Ascutney plutons. U-enriched trachytes have been mined in Europe.

Continue south on Rte. 3 for 0.4 miles.

STOP 2: PROCTOR MONCHIQUITE DIKE
Miles between points: 0.4 Cumulative Mileage: 2.1

This is another good dolostone road cut on the eastern side of Rte. 3. Dike WR-2 occurs toward the southern end of the outcrop, is oriented AZ 132,85 (a rare NW-SE strike), and is 148 cm wide. This dark gray monchiquite shows "typical" monchiquite features, such as a zone of small pink-white ocelli towards the center, some development of pebbly alteration-texture, and even schistose weathering zones. Note that obvious feldspar is lacking and the fine, granular texture of mafic minerals (augite and olivine). The blocky, cobblestone fracturing evident here is also common among lamprophyres. There is a monchiquite dike west of Orwell village, on strike with WR-2 (also with a NW orientation), but almost 30 km away.

Being basaltic rocks, lamprophyres are not very radioactive. However, two Vermont lamprophyre dikes to the north have 2.2–2.5 ppm U and 9.7–10.5 ppm Th (McHone, 1978b), which is several times higher than the average tholeiite or oceanic basalt. Lamprophyres are relatively rich in other "incompatible" elements as well, probably because they are small melts derived from an "enriched" mantle source.

Continue south on Rte. 3

Miles between points: 1.8 Cumulative Mileage: 3.9

Not a stop, but there is another lamprophyre dike (WR-1) hidden behind brush along this cut. It has a northeasterly strike like others to the south and east.

Miles between points: 0.7 Cumulative Mileage: 4.6

Intersection of Rte. 3 with Business Rte. 4. Turn right, head west on Business Rte 4.

Miles between points: 1.6 Cumulative Mileage: 6.2

Turn right into the interchange with Rte. 4, heading west (bear right where the road splits).

Miles between points: 1.3 Cumulative Mileage: 7.5

For the next mile, there is good exposure along the other lane. Stop 5 is near the northwestern end on the way back.

Miles between points: 6.1 Cumulative Mileage: 13.6

Continue past Exit 5. Outcrop hosting the Castleton dike is along the north side of Rte. 4, 0.8 miles beyond Exit 5.

STOP 3: CASTLETON DIKE

Miles between points: 0.8 Cumulative Mileage: 14.4

This handsome intrusion (PO-1), near the western end of the cut, has a purplish color that contrasts with the surrounding green Mettawee slate. This is a spessartite dike, quite unlike most of the the "alkali lamprophyre" dikes in the Champlain Valley to the north that are camptonite or monchiquite. Its orientation is AZ 076,81; 281 cm. Notice how the northern contact is stepped, in places, 10–20 cm outward from the dike and that, despite its size, thermal metamorphism is not apparent in the Mettawee slate along the margins.

The dike contains phenocrysts of plagioclase and large (up to 1 cm) rounded megacrysts of kaersutite (brown Ti-hornblende). There are also small xenoliths of dark quartzite and gneiss, presumably derived from the Grenvillian basement beneath the Taconic and

Champlain Valley lithologic sequences. The age determination (Table 1) and chemistry (Table 2) make this one of the best-characterized of the northern Taconics dikes. In keeping with its feldspar-rich nature, the chemistry of the rock shows higher concentrations of Si, Al, and Na relative to alkali lamprophyres (Table 2). The kaersutite in this dike (PO-1) is not different from kaersutite in the type-camptonite and in other lamprophyres (Table 2). Similar kaersutite is known from harzburgites and other mantle lithologies that are found as xenoliths in dikes at North Hartland, Vermont and Ayres Cliff, Québec (McHone, 1986). The date of 113 ±4 Ma is a bit older than other NT ages (Table 1).

Continue west on Rte. 4.

Miles between points: 1.5 Cumulative Mileage: 15.9

Exit 4; turn north onto Rte. 30. Follow Rte. 30 north for 2.7 miles. The Stop 4 outcrop is along the east side of the road.

STOP 4: BOMOSEEN DIKE

Miles between points: 2.7 Cumulative Mileage: 18.6

Park in the small lot across from the restaurant just north of the outcrop. Note: because of limited parking and no road shoulder, this stop can only be made safely with a small group, and few vehicles. Walk back (south) about 200 m, past the driveway of a fairly new, contemporary-style house. Exposures are along the east side of the road.

NARROW SHOULDER—WATCH FOR CARS

This dike (our BO-1) was mapped by Fowler (1950, Plate II), who shows it as extending in a WNW direction for about 4 km. The dike runs across the lake just to the north of the slate quarry, visible from here. When we first visited this dike in 1981 it was exposed on both sides of the road. We measured an orientation of AZ 293,89 along its southwestern contact and a width of about 12 meters. More recent construction has since masked much of its northern side, but the remarkably coarse texture of what is left will attest to the great mass of this intrusion.

Thin sections from this dike show a hornblende-bearing plagioclase-rich rock that we are calling spessartite. Groundmass augite is greatly altered to brown minerals. The rock is rather stained and weathered in hand sample, but still looks nothing like the narrower mafic dikes of the NEQ province. Because of its relatively slower cooling, the Bomoseen dike has plutonic textures, properly an alkali diorite, such as occurs at Ascutney or in the Monteregian Hills. There is another "great dike" parallel to BO-1 on the western side of the lake, but farther north, which we have not visited. Fowler (1950, p. 58) reports that dikes in the Castleton 15' quadrangle have no preferred orientation. We note above that dikes farther south and east are predominantly NE–SW trending, while there are several ESE–WNW trends among dikes in this area.

Continue north on Rte. 30 to turn around. Watch blind corner!

Miles between points: 0.5 Cumulative Mileage: 19.1
Crystal Beach; turn around in the parking area to the left; go south on Rte. 30.

Miles between points: 3.3 Cumulative Mileage: 22.4
Cross under Rte. 4.

Miles between points: 0.5 Cumulative Mileage: 22.9
Cross Rte. 4A. Continue south on Rte. 30, unless a lunch stop or break is needed. Castleton village is nearby to the east on Rte. 4A.

Miles between points: 1.1 Cumulative Mileage: 24.0
Turn left (E) at the first crossroad, off Rte. 30.

Miles between points: 0.6 Cumulative Mileage: 24.6
Go straight through the first crossroad and then pass under the old D&H RR bridge, now a foot/bike path.

Miles between points: 0.2 Cumulative Mileage: 24.8
Pond Hill Farm: At the 'T' intersection, just beyond the bridge, turn right (S) onto a gravel road.

Miles between points: 1.3 Cumulative Mileage: 26.1
At the first intersection past the 'T', turn left (E), past a restored farmhouse. Follow this road to a parking area above Lewis Brook.

STOP 5: LEWIS BROOK FLUME DIKE

Miles between points: 0.8 Cumulative Mileage: 26.9

Park at the small pull off along the south side of the road. Note: Visiting this stop is contingent on low stream flow and no ice. As at Stop 4, only a small group can be accommodated. The site requires an athletic scramble down and back up a steep stream bank. Walk towards the west (downstream) to find a place to scramble down. Be careful along this bank.

The Lewis Brook flume is controlled by erosion along a very large, spessartite dike that is oriented AZ 092,90 and is 480 cm wide (our dike PO-2, Fig. 5). This gorge is a little larger than 'The Flume' at Franconia Notch, New Hampshire, but much smaller than Quechee Gorge of Vermont, both of which are also formed by stream erosion along dikes. Such flumes develop both because the mafic dike rock weathers (chemically) faster than the country rock and because fractures along the dike path are more abundant than in the country rock. Often a stream will be "captured" by the dike for a portion of its length, usually starting with a waterfall into the flume and continuing to a less-steep point where the stream can escape. The Lewis Brook dike is well exposed for several hundred meters,

Figure 5. View downstream (west) within the Lewis Brook flume. The dike fills the canyon floor and forms the streambed.

depending partly upon boulders moved by each spring flood. Maps show a very linear stream segment of more than 1 km along and below the flume, but dike exposure is poor downstream because of road fill.

Fowler's (1950) map of the Castleton 15' quadrangle shows several dikes nearby, but misses this one. We found it only because of a sketch in a 19th century reference that describes the wonders of this site (reference since lost to us). It is very rare for a dike to have such a great horizontal exposure; most are only known in vertical segments at road cuts or waterlines. This site has a peaceful if eerie ambience, like being in a large cave.

At the eastern end of the flume, the dike is faulted about 4.5 m in a left lateral sense, so that it disappears not far into the stream bank along the northern side. The fault is partially exposed, and clearly truncates the dike along AZ 140. Lewis Brook follows this fault from upstream, so that the stream turns at this point into the east-west flume not far downstream from a series of falls. The fault must have had lateral or oblique movement, because pure dip-slip would not produce much offset on this near-vertical dike. The fault is not mapped by Fowler (1950) or Zen (1964). The country rock is Mettawee slate.

Retrace path back to Rte. 30 and then north.

Miles between points: 4.0 **Cumulative Mileage: 30.9**
Cross Rte. 4A.

Miles between points: 0.5 **Cumulative Mileage: 31.4**
Turn right onto Rte. 4 East.

Miles between points: 0.2 **Cumulative Mileage: 31.6**
Pass the Castleton uranium occurrence in the slates on your left, a small vein with 150 ppm U_3O_8. Slates and black shales in this region are two to three times more radioactive than are most other rocks, but U concentrations are small.

Continue east along Rte. 4. Stop 6 is a long outcrop along the south side of Rte. 4.

STOP 6: ZEN'S DIKE

Miles between points: 7.5 Cumulative Mileage: 39.1

Pull well off the pavement on the right shoulder of Rte. 4, about a hundred meters past the start of the road cut (Fig. 4). Dike WR-3 (faulted) should be close by (Fig. 6).

This dike is another spessartite with altered augite, but still showing abundant brown hornblende (kaersutite) and plagioclase; it approaches camptonite in its petrography. This dike is oriented AZ 015, 83; is 160 cm wide (our sample code is WR-3), and has been dated (108 ±4 Ma; Zen, 1972; Table 1). We are not far above the Bird Mountain thrust fault of Zen (1964), which here divides the allochthonous Mettawee slate from autochthonous Ira phyllite below.

This dike attracted attention because of its displacement by a prominent normal fault, first described by E-an Zen (1972). The fault is oriented about AZ 019, 66 and has a displacement of about 80 cm. The fault zone has fairly thick gouge, especially near the dike. The fault has not been traced.

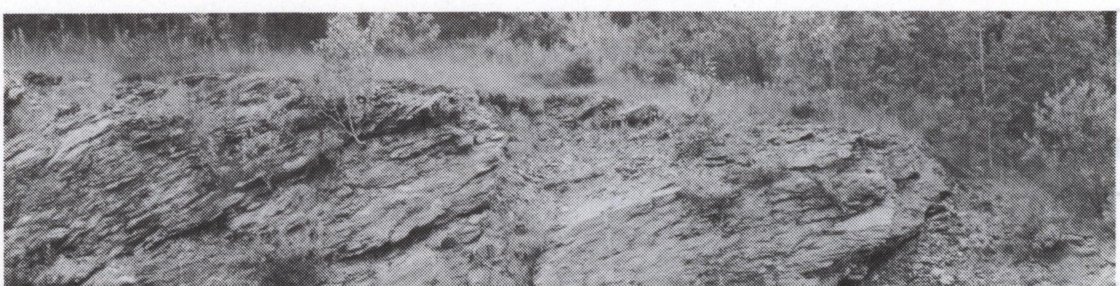

Figure 6. Faulted dike WR-3 exposed along the east bound lane of Rte. 4, West Rutland, Vermont. View is to the southwest.

This road cut extends 1.5 km (0.9 miles) to the southeast and shows at least four more dikes, all of which are similar to WR-3 in type and NE trend. The next dike (WR-4) is about 100 m to the south and was chemically analyzed (Table 2). As is evident in Table 2, camptonite has less silica and sodium than does spessartite, reflecting its Na-rich plagioclase content. There are few such continuous outcrops in the area, and the smaller road cuts happen to show only one or two dikes as a rule. But it appears that dikes often do occur together in small parallel groups, as shown by this cut and as observed in several other areas within the NEQ province.

Continue east on Rte. 4 to Rte. 7.

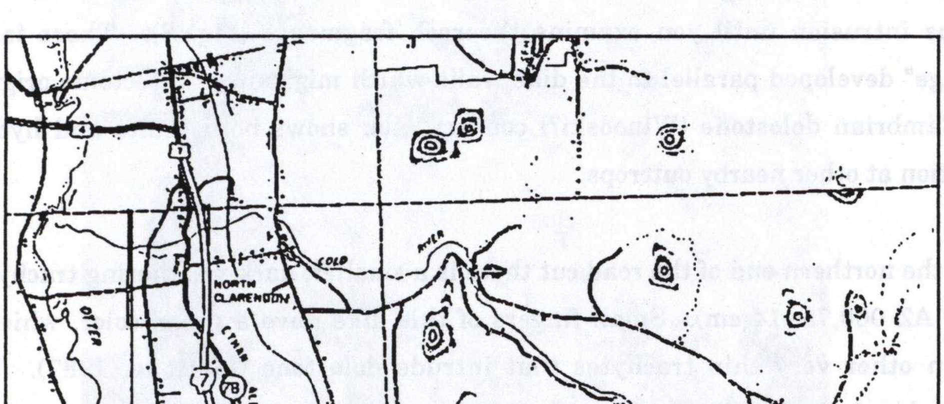

Figure 7. Locations of stops 7–10, southeast of Rutland. Map adapted from The Vermont Atlas, DeLorme Mapping, 1988.

Miles between points: 5.6 Cumulative Mileage: 44.7

Turn right onto Rte. 7, heading south.

Miles between points: 2.7 Cumulative Mileage: 47.4

Pass turnoff to Rte. 103.

STOP 7: SOUTH CLARENDON TRACHYTE DIKES

Miles between points: 2.4 Cumulative Mileage: 49.8

Road cut on west (right) side of Rte. 7. Pull off near southern end of cut (Fig. 7).

This very fractured trachyte dike (RT-4; AZ300,86; 230 cm) is hardly recognizable as an igneous intrusion until you examine the rock fragments (Fig. 8). There is a "shaley cleavage" developed parallel to the dike walls which might have a tectonic origin (Fig. 8). The Cambrian dolostone (Winooski?) country rock shows both faults and hydrothermal alteration at other nearby outcrops.

On the northern end of the road cut there is a smaller, dark-weathering trachyte exposed (RT-1; AZ 060,75; 14 cm). Small fingers of this dike have a green color, which we have 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.

McHone and Wagener (1982) report 6 ppm U_3O_8 and 44 ppm eTh for dike RT-4, in line with concentrations measured in other trachytes.

Miles between points: 0.2 Cumulative Mileage: 50.0

Travel 0.2 miles farther south to turn around. Turn around by pulling into road on right, then crossing Rte. 7 to head north.

STOP 8: SOUTH CLARENDON DIABASE DIKES

Miles between points: 0.7 Cumulative Mileage: 50.7

Road cut with dikes on the east (right) side after crossing Mill Brook. Turn right onto old Rte. 7, then right uphill behind the road cut, park (dead end road).

Diabase, as a term used by us, is essentially a basaltic rock that is appreciably altered, generally by hydrothermal solutions or weathering rather than by burial metamorphism

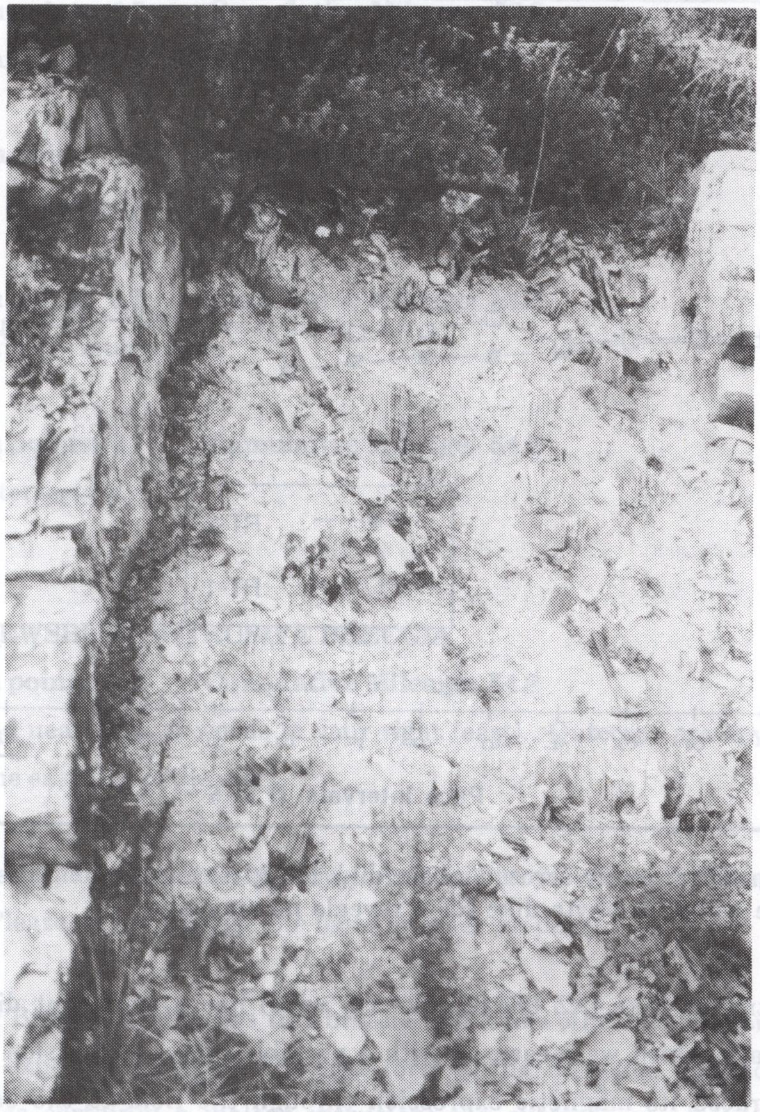

Figure 8. South Clarendon trachyte dike (RT-4), Rte. 7 road cut. View is to the west. The dike has a very shaley fracture, but offset is not apparent.

(although the term has been used for low-grade metamorphosed rocks as well, for which one should use "meta-diabase"). As a result of the alteration, 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 altered that it is difficult to classify.

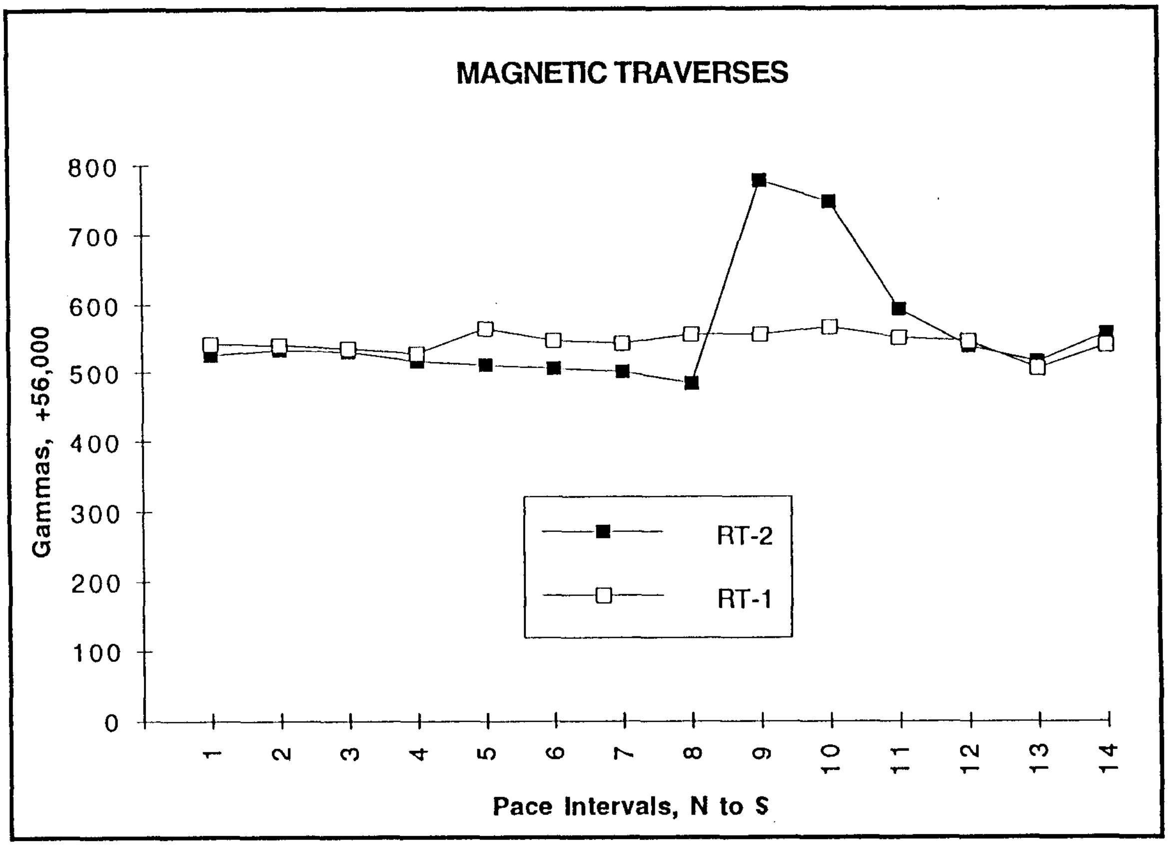

Figure 9. Magnetic anomaly across diabase dike RT-2, traversed along the road ditch. A similar traverse across trachyte dike RT-4 reveals no anomaly.

This E–W striking dike (AZ 084,86; 124 cm wide) has a small but distinct positive magnetic anomaly, which we measured with a portable proton precession magnetometer (Fig. 9). We traced its magnetic expression through the field 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. We are interested in discovering whether datable dikes are offset by faults along the Green Mountain front. A similar magnetic traverse of the trachyte dike at Stop 7 (RT-4) revealed no anomaly (Fig. 9).

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

Miles between points: 1.6 **Cumulative Mileage: 52.3**

Turn right at stop sign.

Miles between points: 0.5 **Cumulative Mileage: 52.8**
Turn right (southeast) onto Rte. 103.

Miles between points: 1.1 **Cumulative Mileage: 53.9**
Turn left onto Maplecrest Farm Road. Go uphill, eastward.

Miles between points: 0.7 **Cumulative Mileage: 54.6**
Bear left at first 'Y' intersection.

Miles between points: 0.1 **Cumulative Mileage: 54.7**
Bear left at intersection.

STOP 9: SHREWSBURY INTRUSIVE BRECCIA

Miles between points: 0.1 **Cumulative Mileage: 54.8**
Stop along road near edge of woods to your right (east). Outcrops are low rock mounds in the woods on the east side of the road.

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. The true form of the intrusion may consist of several "pipes." It was certainly a violent intrusion; the outcrops are full of clasts of local metamorphic rocks of the Grenvillian Mt. Holly complex. This site provided samples for Paul Doss, who cataloged many of the lithologies within the breccia (Doss, 1986). Doss 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 ±4 Ma (Table 1) is reasonable and indicates little contamination by K or Ar from the country rocks.

Turn around, head back to Rte. 103.

Miles between points: 1.0 Cumulative Mileage: 55.85

Turn left (southeast) onto Rte. 103.

STOP 10: CUTTINGSVILLE QUARTZ SYENITE

Miles between points: 3.5 Cumulative Mileage: 59.3

Enter village of Cuttingsville and pull into the Ford dealer lot on the right. Park in the back, away from dealer stock. We will walk south about 150 meters along the Mill River if conditions permit (low water is helpful).

Good exposures of biotite quartz syenite member of the Cuttingsville igneous complex are present here. From this point, the Mill River cuts southward across the complex for approximately 2 km exposing other members of the complex and contacts with essexite, non-quartz syenite, and other petrographic varieties. The juxtaposition of nepheline syenite with quartz syenite is an interesting problem in several plutons of New England. Probably, the quartz-bearing magmas were formed by interaction with crustal rocks, while the Si-poor magmas are closer to differentiates of mantle magmas. Many quartz-bearing trachyte dikes in the Champlain valley are very similar chemically to the quartz syenite here at Cuttingsville (more so than samples MPMB and QTZ-SY, Table 2). Although no grabbroic analog of lamprophyre is exposed at Cuttingsville, there is a strong magnetic anomaly over the stock that indicates a mass of gabbro beneath the felsic phanerites.

McHone and Wagener (1982) report 15.5 ppm U_3O_8 and 105 ppm eTh for syenite in this area. This is higher than most "primary" values, even for alkalic rocks. These relatively high concentrations may result from the hydrothermal enrichment of ore minerals that shows here. The sulfide enrichment of the syenite is evident in the stream bank and a large mass of iron-copper sulfides ("copperas") was once mined on the hillside to the northeast. A tunnel is still present on the hillside above the river, no doubt a prospect for metals. Good crystals of pyrite and quartz are easy to find along this stop, at least during low water. Even more interesting may be the native gold that Robinson (1990) has described from this area.

End of trip: Return to Burlington via Rte. 7, or if you have lots of time, we suggest continuing southeast on Rte. 103 to intersect Rte. 100 and other scenic roadways.

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