

THE NEW ENGLAND - QUEBEC IGNEOUS PROVINCE IN WESTERN VERMONT

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INTRODUCTION

Early Cretaceous alkalic intrusive rocks are common across northern New England, northeastern New York, and southern Quebec southeast of Montreal. The name of “New England – Quebec” or NEQ province was used by McHone and Butler (1984) to indicate a closely related origin for igneous rocks of the Monteregian Hills petrographic province in Quebec and northwestern Vermont, and the “younger” White Mountain magma series in the rest of northern New England. Many examples of NEQ intrusive rocks are well displayed around Burlington, Vermont, and these rocks were formerly considered to be outliers of the main Monteregian Hills (Philpotts, 1974).

The seven stops of this field excursion include outcrops of the major igneous rock types - monchiquite and camptonite (varieties of volatile-rich alkali basalt), bostonite (hypabyssal trachyte) and alkali syenite - a bimodal mafic/felsic association characteristic of many regions of continental rift volcanism. The timing of high-angle faulting within the Champlain Valley may be constrained by associations with the Early Cretaceous (115-135 Ma) magmas (McHone, 1987). Xenoliths are fairly frequent and occasionally abundant, and they provide samples of the underlying Paleozoic shelf sequence and Proterozoic (Grenville) metamorphic basement. The intrusive rocks provide intriguing petrological clues to mantle events and the origins of the alkalic basalt/trachyte association. All of these topics can be addressed during this short field excursion.

REGIONAL SETTING

The Lake Champlain Valley between Vermont and New York is from 20 to 50 km wide and 140 km long between the northern Taconic Mountains and the Canadian border. Topographically, the Taconic klippe interrupts the southern Champlain Valley, but structurally the same valley terrane widens to connect with the northern Hudson Valley southeast of the Adirondack Mountains. The surface of the lake is only 29 m above sea level while the deepest part of the lake, near the western side, approaches 120 m below sea level. Many peaks of the Adirondacks to the west and the Green Mountains to the east rise above 1000 m, providing considerable relief to the Valley margins.

Excellent exposures are common along lake shores, river and stream banks, highway cuts, and quarries. Our field sites include all of these types of exposures. The glacial soils on many hillsides are thin enough to reveal bedrock rubble (including dike float), but much of the area is also covered by thick, glacial lake and marine sediments that make good farmland but effectively hide the bedrock and structures. On the other hand, the glaciers produced polished surfaces of NEQ intrusions with fine details that would be obscured at more weathered outcrops.

Distribution of NEQ Rocks

Figure 1 (modified from McHone and Corneille, 1980) shows locations for many of the igneous intrusions of the central Lake Champlain Valley. As shown by other regional maps (McHone and McHone, 1993), dikes become scarcer southward from Vergennes, but then are fairly common across the northern Taconics and Green Mountains to the west and southeast of Rutland, Vermont. The northern Champlain Valley is curiously devoid of dikes from North Hero well up into Quebec, but similar dikes are abundant in the Monteregian Hills province ESE of Montreal. Lamprophyre dikes occur with lesser frequency westward as far as the east-central Adirondack Mountains, and are scattered but continuously present eastward across Vermont, New Hampshire, and the southern half of Maine (McHone, 1984).

Special studies of Champlain Valley igneous rocks start with early publications by Thompson (1860) and Hitchcock (1860), followed by petrographical and theoretical work by Kemp and Marsters (1893), Shimer (1903), Alling (1928), Hudson and Cushing (1931), Laurent and Pierson (1973), and McHone and Corneille (1980). Other geologists who mention or describe dikes as part of regional mapping studies are listed in the references section of this paper. The Champlain Valley intrusions are now well located and studied petrographically, and a small number have been chemically analyzed by Kemp and Marsters (1893), Laurent and Pierson (1973), and McHone and Corneille (1980). According to Ratte' and others (1983), several unpublished thesis studies of the dikes are known,

although they vary in availability and therefore usefulness.

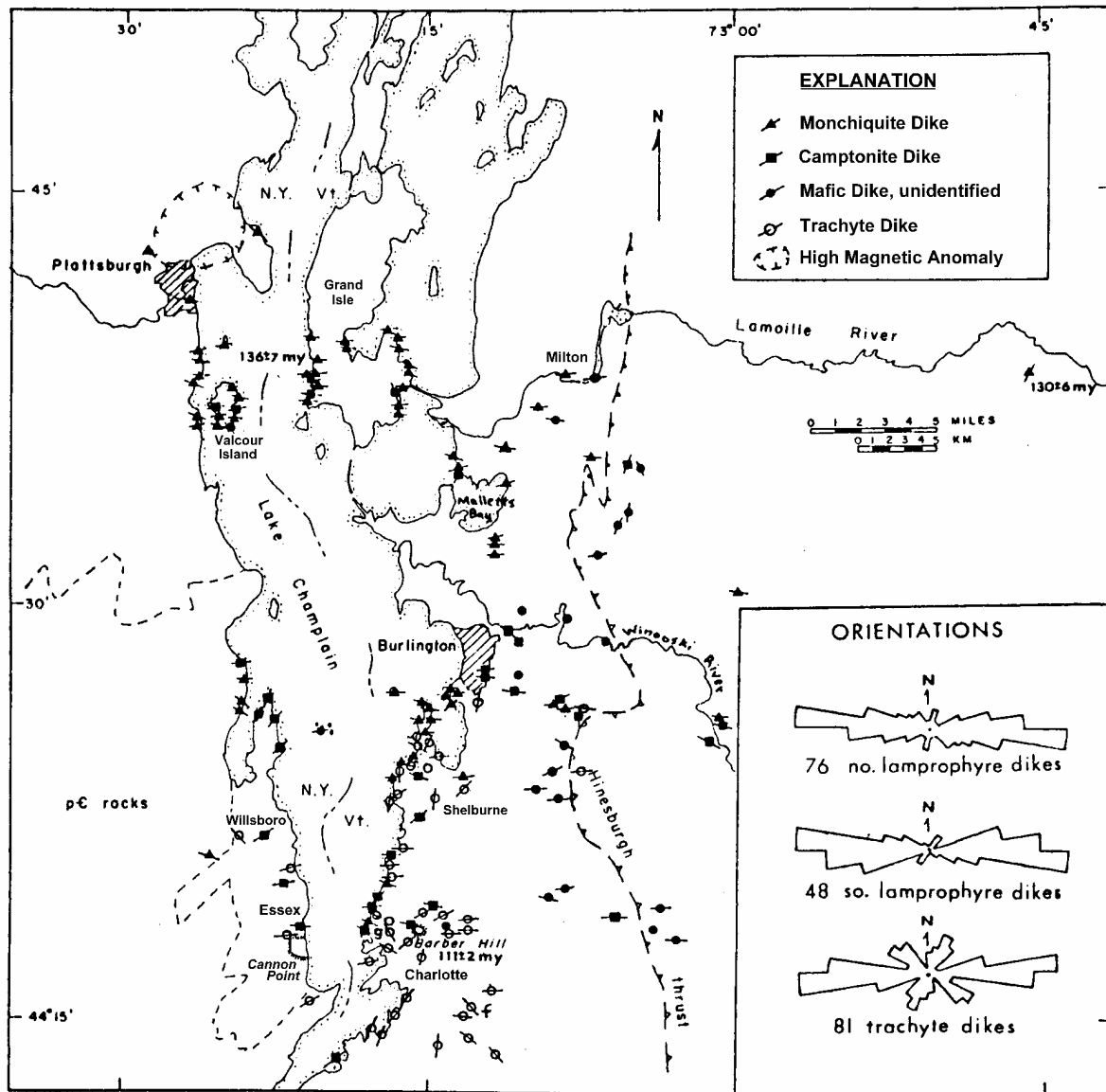


Figure 1. NEQ dikes and plutons of the Lake Champlain Valley, Vermont and New York (adapted from Fig. 1 of McHone and Corneille, 1980).

As indicated on Figure 1, the dikes are separated into two swarms within the valley, which cross the lake between Vermont and New York. At least 80 dikes of monchiquite, a few camptonite dikes, but no trachyte types are found in the northern swarm across Milton, Malletts Bay, southern Grande Isle, and the Plattsburgh area (Shimer, 1903; Fisher, 1968; McHone and Corneille, 1980). Although we will not visit the northern swarm on this trip, monchiquite dikes in this area are exposed along Route 2 west of I-89 (Table 1) and in several roadcuts along I-89 east of Malletts Bay. Diment (1968) has outlined a strong geophysical anomaly east of Plattsburgh that probably is caused by an unexposed gabbroic pluton, similar to some plutons of the Monteregian Hills in adjacent Quebec. Monchiquite, camptonite, and all of the trachytic dikes occur in the southern swarm (over 150 dikes) across from Burlington and Charlotte, Vermont to Willsboro and Essex, New York (Fig. 1).

For most of the Champlain Valley, east-west to N80W dike trends are the rule (Fig. 1). Northeasterly trends are more common in New York and also to the east in Vermont. The trachytes show much more variation,

especially near the Barber Hill stock in Charlotte, where Gillespie (1970) observed a radial pattern. A massive trachyte sill, covering a square mile or more, is exposed at Cannon point and inland south of Essex, New York (Buddington and Whitcomb, 1941). Trachyte dikes, sills, and intrusive breccias are abundant in southern Shelburne Point, which may indicate another syenitic pluton at shallow depth.

Trends of post-metamorphic dikes throughout the NEQ province vary by geographic regions (Fig. 2). Contrary to the initial conclusion of McHone (1978), Cretaceous NEQ lamprophyre dikes in New Hampshire and Maine do not maintain roughly east-west trends as in the Champlain Valley; instead, most mimic the northeasterly trend of the abundant older (Early Jurassic and Middle Triassic) diabase dikes in the eastern areas (McHone and Sundeen, 1995). Early Cretaceous dikes in the western lobes of the NEQ province also vary by trend groups (Fig. 2, areas A, B, and C). The northeasterly-trending dikes of the northern Taconics appear to be about 101 Ma in age, or 25 m.y. younger than the Champlain and Quebec dikes (Eby and McHone, 1997; McHone and McHone, 1993). There is also some suggestion of linear boundaries between groups which might reflect crustal structures (McHone and Shake, 1992). Perhaps each of the three western trend groups are of different ages, and they record different stress regimes in the lithosphere. In eastern New England, the stress pattern must not have changed much from Triassic into Cretaceous times.

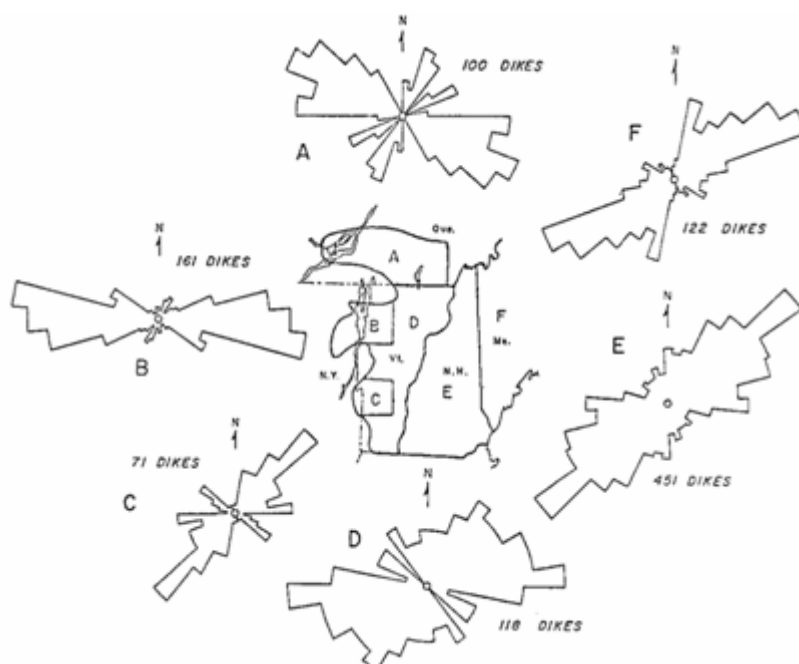


Figure 2. Rose diagrams of post-metamorphic dikes in northern New England and adjacent Quebec, measured within regions labeled A through F (compiled by McHone, 1984).

PETROLOGY AND AGES

The experts have been trying for many years to categorize and classify lamprophyre dike types. One of the most recent versions is as follows: "Lamprophyres are mesocratic to melanocratic igneous rocks, usually hypabyssal, with a panidiomorphic texture and abundant mafic phenocrysts of dark mica or amphibole (or both) with or without pyroxene, with or without olivine, set in a matrix of the same minerals, and with feldspar (usually alkali feldspar) restricted to the groundmass" (Wooley et al., 1996, p. 180). Lamprophyres of our area are mainly camptonite and monchiquite, which have been called members of the "alkali lamprophyre clan" by Métais and Chayes (1962). Their main difference is that plagioclase (alkali feldspar is actually rare in these mafic dikes) is more abundant than zeolites in camptonite, while zeolites (mainly analcime in the groundmass) is more abundant in monchiquite (Fig. 3). Both have abundant Ti-rich pyroxenes in two generations, more or less abundant kaersutite (brown basaltic amphibole) also in two generations, and often either phlogopitic biotite or olivine (not both) in small amounts

Some lamprophyres particularly rich in biotite have been called "ouachitite," such as the dike on the western shore of Grand Isle dated by Zartman et al. (1967). These usually have no feldspar or olivine, but an abundance of carbonate (calcite or dolomitic calcite). A ouachitite in which calcite forms most of the matrix (it

effervesces readily in weak acid) occurs along I-89 near the northern edge of Burlington. Such dikes may grade into carbonatite, as are found near Oka (west of Montreal, Quebec). Monchiquite that lacks olivine has also been called "fourchite," which has been noted on the west side of the valley by Hudson and Cushing (1931). Because the types appear to grade into one another anyway, the distinction between monchiquite and camptonite is probably sufficient for naming Champlain lamprophyres.

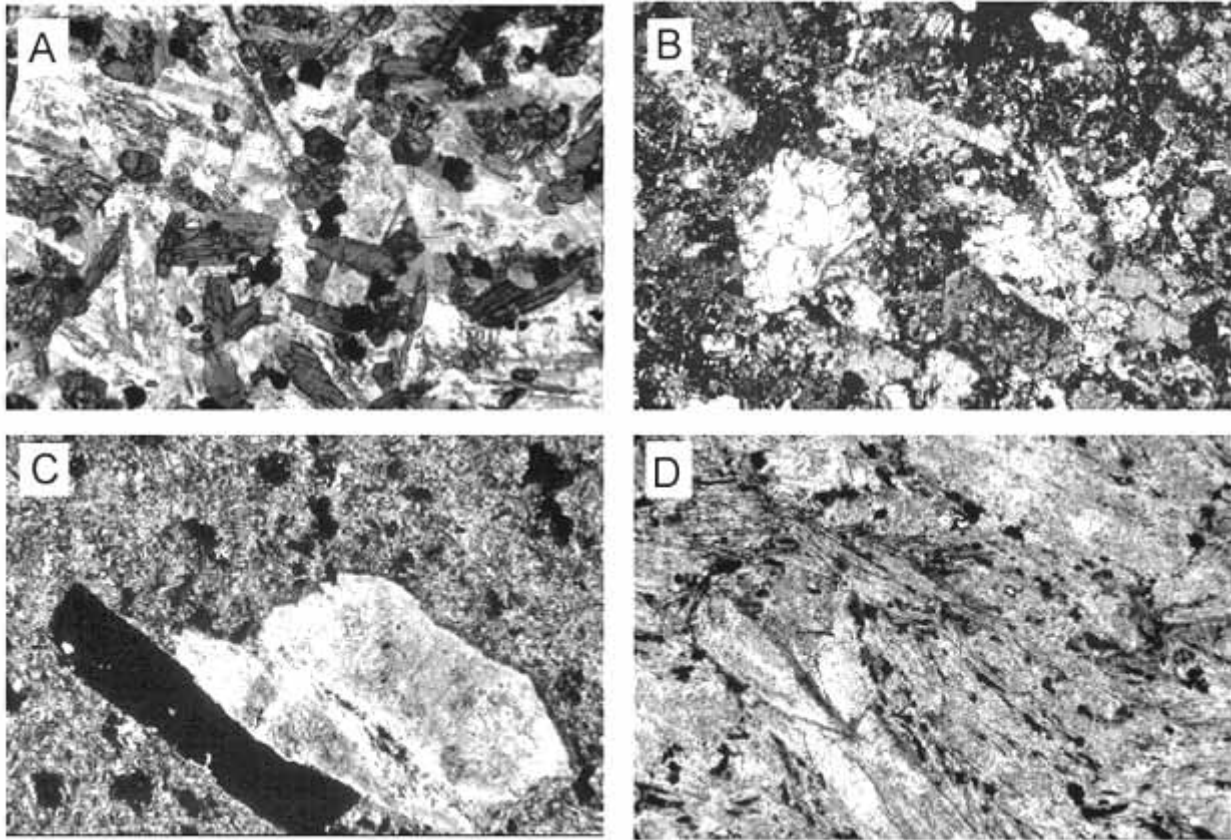


Figure 3. Dike textures in thin section (each view about 6 mm wide; B is with crossed polarizers).
 A: Camptonite dike CH-1 (Richmond); kaersutite, augite, and apatite crystals in a plagioclase matrix.
 B: monchiquite dike BU-1 (Williston Quarry); zoned augite and biotite in two generations, little feldspar.
 C: Trachyte dike MPMB (Rte. 7 at Pease Mtn.), showing corroded anorthoclase and biotite phenocrysts, and abundant pyrite in a field of poorly-formed alkali feldspar grains.
 D: Dike MWB (Williston Quarry), showing a "typical" bostonite texture of clumps of anorthoclase, outlined by pyrite and hematite.

Bostonite is a term for trachyte that has a texture of "felty" clumps of alkali feldspar (usually, anorthoclase or albite) apparent only in thin section (Fig. 3). Although "bostonite" is a legitimate term that is widely applied to felsic dikes of this region, not all of the dikes display this texture, so the volcanic term of trachyte may be preferred. Although typically dominated by fine-grained anorthoclase, the trachyte dikes often display euhedral phenocrysts of beta-quartz, corroded biotite, and orthoclase.

In many camptonites and several monchiquites, small pink globular segregations up to a few cm across are scattered though the rock. The segregations are called ocelli (eye-like), which are not xenoliths but rather display co-liquid boundaries with the lamprophyre matrix. The ocelli usually contain abundant sodic or potassic feldspar, analcime and calcite, as well as hydrous minerals such as kaersutite, which may be observed across the boundary between the liquids.

Intrusion ages

The few radiometric dates for Champlain Valley igneous rocks compare well with Early Cretaceous dates of the Monteregian Hills of adjacent Quebec, and for other intrusions of the New England-Quebec igneous province of McHone and Butler (1984). McHone (1984) summarized radiometric ages of northern New England dikes, including two for local lamprophyre dikes. Zartman and others (1967) found a Rb-Sr age of 136 +/- 7 Ma, using phlogopite from a dike of lamprophyre (ouachitite or monchiquite) on the western shore of Grande Isle. Using kaersutite separated from a monchiquite dike located about 35 km to the east (in the Green Mountains), McHone (1975) obtained a K-Ar age of 130 +/- 6 Ma. To the south, in the northern Taconics west of Rutland, Vermont, camptonite dikes have dates of 105 +/- 4 Ma and 110 +/- 4 Ma (McHone, 1984). In the eastern Adirondacks, Isachsen and Seiderman (1983) reported K-Ar dates of 113, 123, and 127 Ma on camptonite dikes, and 137 and 146 Ma on dikes that apparently are monchiquite.

Armstrong and Stump (1971) reported a K-Ar date of 111 +/- 2 Ma for the syenitic Barber Hill stock at Charlotte, using a biotite separate. The Barber Hill stock is considered to be cogenetic with the bostonite (trachyte) dikes of the area. Seven trachyte dike samples from the Burlington area analyzed by McHone define a whole-rock Rb-Sr isochron of 125 +/- 5 Ma (McHone and Corneille, 1980). Partial Rb-Sr data collected by Fisher (1968) for the Cannon Point trachyte sill, across the lake at Essex, New York, indicated an age of "less than 140" Ma, but which also fits the 125 Ma isochron. Isachsen and Seiderman (1983) reported a whole-rock K-Ar age of 120 Ma for a trachyte dike in Willsboro, New York.

Two monchiquite dikes are crosscut by a bostonite dike and a bostonite sill along the shoreline SW of Shelburne Point (Kemp, 1893; Welby, 1961). Welby (1961, p. 188) reported that a camptonite dike crosscuts the Barber Hill syenite "near the crest of the hill at its northwest corner," but we did not find it in June of 1999. Our group will pass near that area in Stop 4, and perhaps someone will relocate this feature. In combination with the radiometric data, these crosscutting relationships are consistent with ages generally about 135 Ma for monchiquite, 125 Ma for trachyte/bostonite, and 115 Ma for camptonite, plus or minus perhaps 5 Ma for each type. Older dates that are recalculated to new radiometric constants become 3 or 4 Ma older, but do not change the age relationships.

After all of the earlier considerations, we still need modern $^{40}\text{Ar}/^{39}\text{Ar}$ dates, because in other areas of the NEQ province, Kenneth Foland and his students have good evidence for much more confined timing of magmatism. Their dates in the Monteregian Hills (Foland et al., 1986) cluster near 124 Ma, while several other NEQ plutons in New Hampshire are close to 122 Ma (Hubacher and Foland, 1991). Based on those results, we might suspect that all Champlain Valley magmatism occurred at about the same time, perhaps near 124 Ma as in Quebec.

Xenoliths and Intrusive Breccias

Xenoliths of sedimentary and metamorphic rocks have always been noted in Champlain dikes, but the most careful catalog was made by Corneille (1975). He observed a wide variety of xenoliths in 35 dikes, about evenly divided between lamprophyres and bostonites. The largest xenoliths occur in bostonite dikes wider than about 1.2 meters, some of which are actually "intrusive breccias" that are mostly xenoliths by volume. Inclusions of anorthosite in dikes at Shelburne Point demonstrate the eastward extension of Adirondack massif anorthosite under the Paleozoic strata of the valley (McHone, 1975).

At least four trachyte (bostonite) dikes are found on the eastern side of Shelburne Point, three of which contain abundant xenoliths of many Paleozoic and Proterozoic rocks that underlie the region. These intrusive breccias received attention from Hitchcock (1860), Kemp and Marsters (1893), Perkins (1908), Powers (1915), Hawley (1956), and Welby (1961). The most southerly breccia dike is about 4 feet wide and is more than half xenoliths by volume, including many Grenvillian basement rocks as well as shale, quartzite, limestone, and porphyritic syenite cobbles. A great deal of similar material occurs as float along the hillside above and southwest of this dike. At least one other breccia dike farther north is very narrow (a foot or so), and has been eroded into a "chasm squeeze" into which you must fit sideways for sampling.

Kemp and Marsters (1893) suggested that the abundant xenoliths are derived from breccia along an older fault that has been intruded by bostonite magma. Many of the xenoliths are remarkably rounded, almost like stream cobbles. Similar breccia dikes, perhaps the same ones, also appear on the southwest shore of Shelburne Point. Welby (1961) has mapped a high-angle fault that displaces the Champlain thrust nearby to these breccias, lending support to Kemp's idea. The concentration of trachytes and their syenite xenoliths (autoliths?) indicates the presence of a syenitic pluton directly beneath southern Shelburne Point. Other xenolith-rich dikes across the region are also associated with faults (McHone and Shake, 1992).

Barber Hill

Barber Hill was originally described as a laccolith (Welby, 1961; Dimon, 1962), which indicates a sill-like form inflated into an upward bulge. Probably this description was influenced by the large trachyte sill at Cannon Point, across the lake in Essex, New York, which crops out along the shoreline with the upper horizontal contact exposed. Barber Hill was re-mapped by Roger Laurent in the early 1970's as the double-dome top of a small stock of syenite, with coarser zones toward the interior. As also shown by Laurent and Pierson (1973; Fig. 4 below), there are numerous bostonite or trachyte dikes in the immediate area and crosscutting the stock. These have more random orientations than the regional dikes, and Gillespie (1970) described the surrounding bostonite dikes as having a radial pattern around Barber Hill. Welby (1961) mentions a camptonite dike cutting the syenite near its top, an important crosscutting observation, but we have not found that locality. A small prospect for molybdenite occurs in a hornfelsic portion of the roof zone.

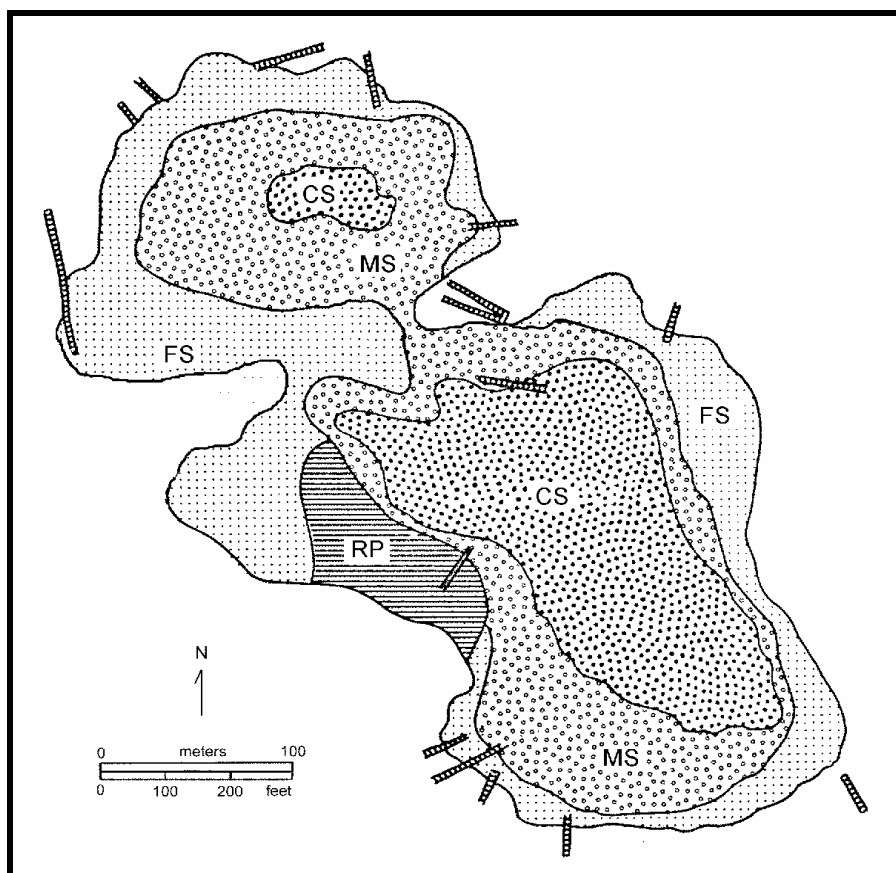


Figure 4. Geologic map of Barber Hill, modified from Fig. 3 of Laurent and Pierson (1973). Labels: CS = coarse grained alkali syenite; MS = medium grained alkali syenite; FS = fine grained quartz syenite; RP = roof pendant zone (blocks of hornfelsic shale in FS). Cross-hatched bars = trachyte dikes.

Using a sample of "slightly altered biotite" collected by Richard Gillespie from the coarse-grained syenite, Armstrong and Stump (1971) derived a K-Ar age of 111 ± 2 Ma (114 ± 2 Ma with newer standards) for Barber Hill. Ar can easily escape from altered mica, which could cause the K/Ar date to be too young. Because we regard the trachyte dikes as co-genetic with the syenite, 125 Ma is a better cooling date, as indicated by the Rb/Sr isochron of McHone and Corneille (1980) and by Ar/Ar dates for the Monteregian Hills (Foland et al., 1986).

Geochemical relationships

NEQ dike analyses have been reported by Woodland (1962), Hodgson (1969), Laurent and Pierson (1973), McHone (1975, 1978), Hale and Freiberg (1995), and others. Average compositions for camptonite, monchiquite, and bostonite from Vermont are comparable to worldwide averages for basanite, nephelinite, and alkali trachyte, except that lamprophyres are richer in water and carbon dioxide than their volcanic equivalents (Table 1). As also

expected, the calculated density of trachyte magma is lower than lamprophyre magma, but trachyte viscosity at 1 kb is up to a power of 6 (in poise) greater than lamprophyre magma. For trachyte magma to flow, dike fractures should be generally wider and depths of origin perhaps shallower than the lamprophyric mantle melts. High volatile contents may also be necessary.

TABLE 1. AVERAGE COMPOSITIONS OF VERMONT NEQ DIKE TYPES

Group	1a	1b	2a	2b	3a	3b
SiO ₂	38.60	40.60	43.07	44.30	65.31	61.95
TiO ₂	2.73	2.66	2.80	2.51	0.17	0.73
Al ₂ O ₃	12.30	14.33	13.89	14.70	17.75	18.03
Fe ₂ O ₃	4.85	5.48	3.62	3.94	2.54(t)	2.33
FeO	6.41	6.17	7.55	7.50	-	1.51
MnO	0.22	0.26	0.25	0.16	0.18	0.13
MgO	7.91	6.39	7.08	8.54	0.37	0.63
CaO	13.78	11.89	9.79	10.19	1.60	1.89
Na ₂ O	3.24	4.79	3.02	3.55	5.95	6.55
K ₂ O	1.91	3.46	1.93	1.96	4.39	5.53
P ₂ O ₅	1.35	1.07	0.74	0.74	0.07	0.18
H ₂ O+	2.46	1.65	2.36	1.20	0.53	0.54
CO ₂	3.48	0.60	2.97	0.18	0.18	-
Mg#	73.0	58.9	65.0	74.2	25.5	25.6
Viscosity	5.94e1	6.93e1	1.39e1	2.73e1	2.35e5	4.05e6
Density	2.42	2.56	2.42	2.55	2.37	2.38
CIPW NORMS						
Q	0	0	0	0	9.33	0
Or	11.38	3.16	11.51	11.61	25.96	32.15
Ab	10.06	0	25.79	12.42	53.47	55.93
An	13.48	7.39	18.82	18.38	7.49	3.41
Ne	9.51	21.95	0	9.55	0	1.16
Di	19.33	32.36	5.13	21.03	0	3.64
Hy	0	0	4.00	0	1.12	0
Ol	10.55	2.32	13.40	12.38	0	0
Mt	7.09	7.95	5.30	5.72	1.75	2.29
Il	5.22	5.05	5.37	4.77	0.24	1.00
Ap	3.22	2.51	1.77	1.74	0.15	0.37
Cc	7.98	1.37	6.82	0.40	0.41	0
Lc	0	13.57	0	0	0	0

Labels: 1a - 14 New England monchiquites; 1b - avg. nephelinite (Le Maitre, 1976)

2a - 35 New England camptonites; 2b - avg. basanite (Le Maitre, 1976)

3a - 8 Vermont bostonites; 3b - avg. alkali trachyte (Nockolds, 1954)

CIPW norms are calculated with IGPET99 (Terra Softa, Inc.). Viscosity (poise) and density (g/cm³) are calculated with IGNEOUS (T. Dunn, 1997), using the Mt-Hmt buffer.

T-P for basalt calculations was 1200 °C and 1 kb; for trachytes, 1000 °C and 1 kb.

Modern petrological software such as IGPET99 (Michael Carr, Terra Softa, Inc., 1999) and IGNEOUS (Todd Dunn, University of New Brunswick, 1997) have greatly improved our ability to calculate geochemical parameters and plot diagrams. Chemical data for Vermont, plotted on the silica vs. total alkalis classification diagram of Lebas et al. (1986), show the expected magmatic types (Fig. 5). Monchiquite foid is modal analcime rather than nomative nepheline.

The lamprophyres show almost no linear fractionation trend on an AFM diagram (Fig. 6). The non-linear scatter of lamprophyre analyses is evidence against any simple crystal fractionation scheme to derive their magmas from a common parental melt. The non-systematic variation of lamprophyre dike compositions is in great contrast to Early Jurassic tholeiitic dikes of eastern North America, which comprise a small number of basalt magma types in a few very large intrusions across northeastern North America (McHone, 1992 and 1996).

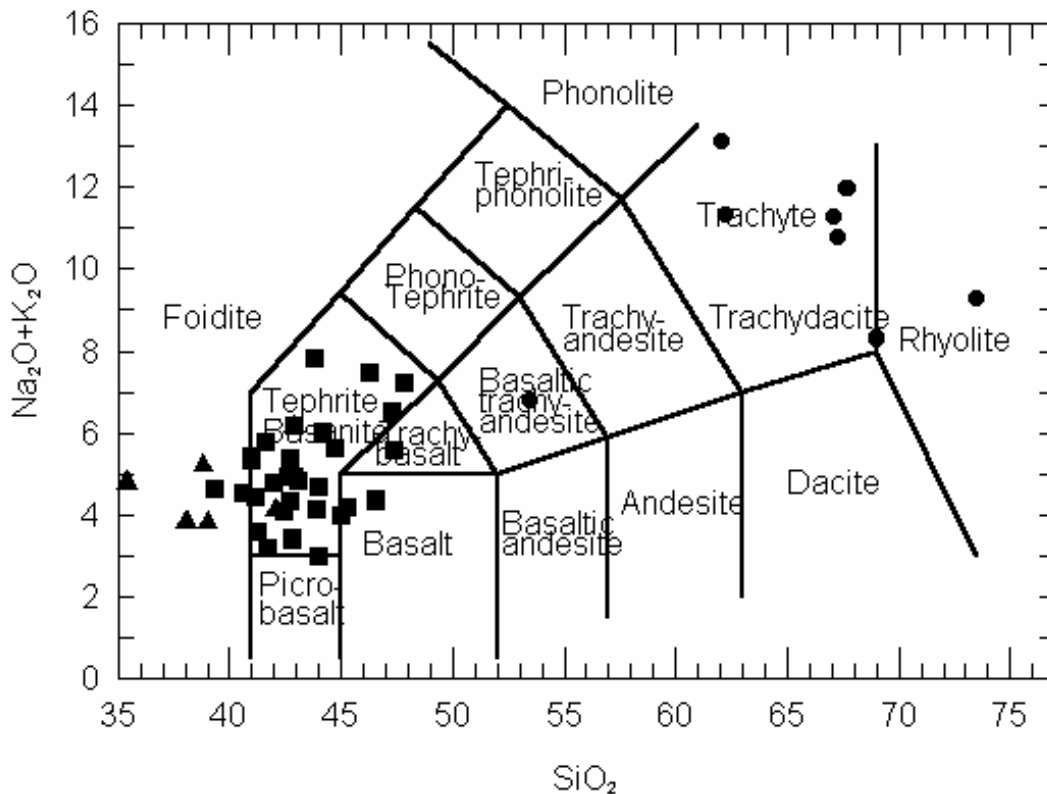


Figure 5. Silica-total alkali classification diagram for volcanic rocks, after LaBas et al., 1986. Triangles = monchiquite; squares = camptonite; circles = trachyte (bostonite) and syenite. Analyses are from McHone and Corneille (1980) and Laurent and Pierson (1973).

Vermont dike compositions on the AFM ternary (Fig. 6) can also be compared with ocelli-matrix lamprophyre analyses by Philpotts (1976), who proposed a liquid immiscibility model to explain the origins of ocelli in lamprophyres. Ocelli are more common in camptonite dikes than in monchiquite. Philpotts (1976) and others described the segregation and coalescence of ocelli into separate felsic sheets within lamprophyre sills in Quebec. Co-liquid textures include phenocrysts of kaersutite that cross the ocelli-matrix boundaries, and the mechanism apparently requires a critical amount of water, carbon dioxide, phosphorus, and alkalis. The model suggests that camptonite magma can spontaneously divide into separate monchiquite and trachyte magmas, presumably in a large chamber at some depth within the crust.

There is support for the model in the distribution of dikes: camptonite is widespread across the entire region, while monchiquite and bostonite (trachyte) are found in local dike clusters associated with plutonic complexes (McHone, 1984). Presumably, magma chambers that split into separate liquids also represent sources for larger plutonic stocks such as Barber Hill, and for the monchiquite dikes in the same regions. NEQ dikes and the Barber Hill stock in the Champlain Valley could provide excellent material for further tests of this model.

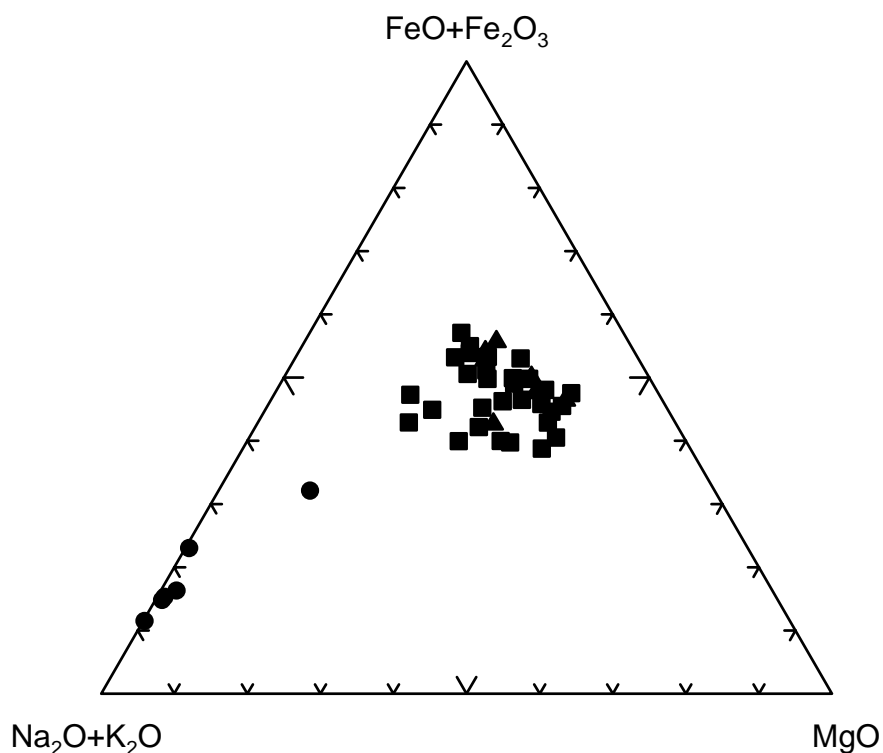


Figure 6. AFM diagram showing camptonite (squares), monchiquite (triangles) and bostonite (circles) from Vermont and adjacent New York. Lines show boundaries for a liquid miscibility gap as proposed by Philpotts, 1976, based on analyses of lamprophyre ocelli and residual matrix (ocelli are more alkali rich, matrix is more mafic). Vermont camptonite analyses within the gap are dikes rich in ocelli that have not been segregated.

ITINERARY

Refer to Figure 7 for map locations of stops 1 - 6. Traffic is commonly heavy and fast along Route 7, so please take your time and drive carefully (you can always catch up later). At stops 1, 2, and 4, parking with access through private property is by special permission. Food can be purchased at our lunch stop at the Old Brick Store in Charlotte Corner.

The stops are within the Burlington and Mt. Philo 7 1/2' USGS quadrangles, and are along or near to local roads and highways. The Vermont Atlas and Gazetteer (DeLorme and Co.), available in local stores, has a convenient format and useful detail. The local geology was mapped by Cady (1945), Welby (1961), and in summary by Doll and others (1961). Other areas of the Champlain Valley that contain dikes were mapped by White (1894), Buddington and Whitcomb (1941), Stone and Dennis (1964), and Fisher (1968). New geologic maps have also been prepared for the upcoming bedrock map of Vermont, which will include Mesozoic dikes and plutons throughout the state (thanks to Nick Ratcliffe and Greg Walsh, among others).

Assemble at the northern end of the boat storage yard of Shelburne Shipyard and Marina. Directions: From Burlington, head south on Rte. 7, turning right onto Bay Road at the light just south of the former Hideaway Restaurant (a much-missed landmark). Go past the southern end of Shelburne Bay, and after 1.7 miles turn right onto Harbor Road (intersection at Shelburne Farms), and then head north for another 3 miles. Enter the marina, bear left and park near the far northern end of the boat yard. Drive carefully near the stored yachts!

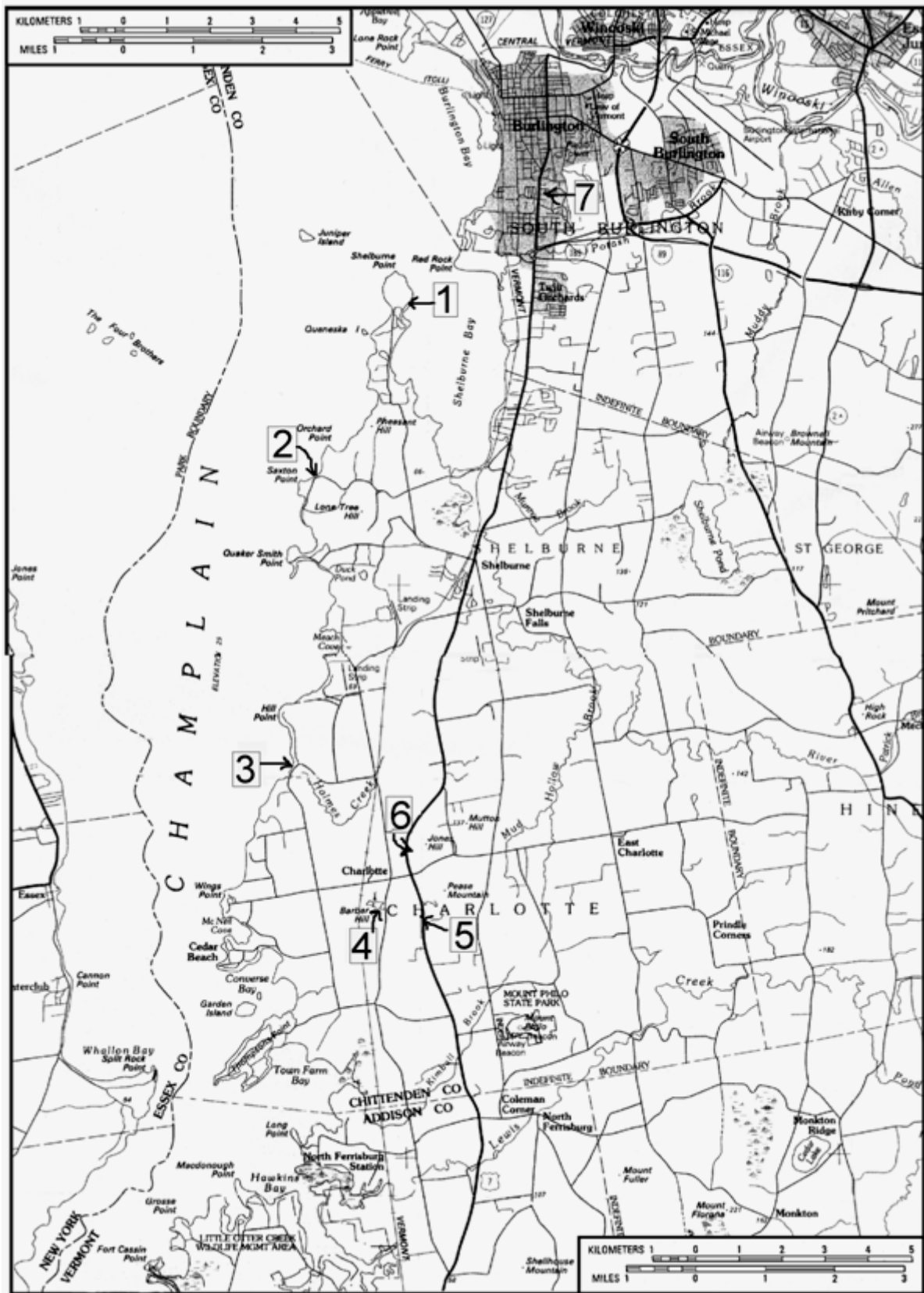


Figure 7. Locations of field stops 1 – 7 south of Burlington, Vermont.

Mileage

Total by Point

0 0 Start of trip at the northern end of Shelburne Shipyard and Marina.

STOP 1. SHELBURNE SHIPYARD MONCHIQUTE DIKE.

Here a monchiquite dike forms a northern wall (overgrown by brush) that bounds the Shelburne Shipyard boat storage area. This is Kemp and Marster's (1893) dike no. 12, Corneille's (1975) no. 36, and McHone's (1978) BU-14. It is about 2 m wide, AZ 98, dip 85 S, color medium dark gray. In thin section it is a fairly typical monchiquite, with much porphyritic zoned augite (salite), a small amount of phlogopite, and little feldspar. Many augite phenocrysts show cores of green Na-rich pyroxene, pale gray-green intermediate sections, and rims of reddish Ti-rich pyroxene. These zones were described as separate pyroxene types by McHone (1986), each of which can be related to P-T-X stages of the magma between its origin in the mantle and its final shallow emplacement. Additional analysis of these interesting mineral varieties was made by Bédard et al. (1988).

The dike probably crosses the point, and Corneille (1975) mapped several monchiquites on the western shore. Corneille (1975) noted that some monchiquite dikes in this area contain small xenoliths of limestone, shale, quartzite, and pink felsite, which perhaps could be found with better searching in this example.

Head back south along Harbor Road.

3.0 3.0 Turn right (west) into Shelburne Farms. Proceed past the toll booth after identifying yourselves as members of the field trip.
5.2 2.2 Go past the driveway to the Inn and park in the lot off the left side of the road. Walk back to the lakeside wall north of the Inn, and climb down to the shoreline.

STOP 2. SHELBURNE FARMS TRACHYTE DIKE.

This wonderful estate was the home of Dr. Seward Webb and his wife, Lila Vanderbilt Webb. Mrs. Webb was the older sister of George Vanderbilt, who was possibly inspired by this great pastoral Vermont estate to construct his fabulous Biltmore near Asheville, North Carolina. The Webb manor house on the high bluff of Saxton Point is now Shelburne Farms Inn. You should consider returning to visit the gift shop and tour Shelburne Farms, which is a non-profit, education-oriented organization. The Inn is also a grand place to spend a few days.

This is dike 113 of Kemp and Marsters (1893) and dike 7 of Corneille (1975). The dike intrudes Odovician Iberville shale, which easily shows deformation from the many local and regional faults of the Champlain Valley. Low angles of intrusion are more common for trachyte dikes than for the mafic types; this example is virtually a sill, with a trend near N-S, dip 47E, and thickness about 3.5 m. It weathers to a reddish tan color but fresh pieces are more light gray. The coarse texture with large alkali feldspar phenocrysts qualifies it as a good trachyte, but it is also not too different from the Barber Hill syenite that we will see at the next stop.

Return on the same estate road to the entrance.

7.4 2.2 Turn right (south) onto Harbor Road.
9.0 1.6 In Shelburne Village, turn right (south) onto Rte. 7
9.8 0.8 Turn right (southwest) onto Boswick Road.
11.71.9 Turn right (west) onto Orchard Road.
13.01.3 Turn left into the parking lot for the town beach (Hills Bay on older topo maps). Park and walk to the shore.

STOP 3. CHARLOTTE TOWN BEACH BOSTONITE DIKE.

This is dike 58 of Corneille (1975), actually a series of branching dikes intruding Stony Point shale. It is not clear if Kemp and Marsters (1893) visited this locality, although it is well exposed near a very old road. The dikes of this cluster are extraordinarily thin for bostonite, which is generally viscous enough to require fairly wide fracture openings. There are at least seven dikes that together total about 2 m in thickness here, with glossy dark contact surfaces, and pale tan, sandy-textured fresh broken surfaces. The rock is fine grained and not especially porphyritic, unusual features for bostonite. Overall, they trend about E-W with a steep dip.

Continue south on Whaley Road, through the Holmes Creek Covered Bridge.

14.81.8 Turn left (east) onto Ferry Road.

15.81.0 Charlotte Corners. Turn right (south) onto Greenbush Road.

16.30.5 Turn right into the driveway and parking area on the southern side of Old Lantern Campground. Park near the far end below the hill.

STOP 4. BARBER HILL SYENITE STOCK.

We will walk up the field to the top of Barber Hill, a small syenite stock which is probably closely related to the trachyte dikes of this region. From the top, there is a fine view of the "Red Sandrock Range" of hills capped by the Champlain thrust, especially Pease Mountain nearby to the east. Pease Mountain is an excellent site for field mapping practice, and it has numerous mafic and felsic dikes also mapped by many of Rolfe Stanley's field geology students.

The upper west side of Barber Hill has good outcrops of coarse alkali syenite as well as a few felsic dikes. Please stay together as we traverse a short distance through the woods. In the 1970's, molybdenite was visible in hand samples from a small prospect farther south, but we do not have permission to traverse that way. Instead, we hope participants will keep their eyes open for any mafic dikes that may crosscut the syenite.

Return north on Greenbush Road.

16.80.5 Charlotte Corners. Food and drinks may be obtained at the Old Brick Store.

Parking is rather limited near the store; so please watch for traffic and do not block the road. After lunch, head east on Ferry Road toward Rte. 7.

17.10.3 Turn right (south) at the light onto Rte. 7.

17.40.3 Turn left into the highway garage access road opposite Vermont Wildflower Farm. Watch traffic! Park along the road to the left and walk back to the highway cut.

STOP 5. PEASE MOUNTAIN RTE. 7 BOSTONITE DIKES.

A dozen or more trachyte and lamprophyre dikes are exposed in the Pease Mountain hillside above this roadcut, and many of the trachyte dikes trend toward Barber Hill. McHone's (1978) dike BU-21 and (1975) dike MPMB (now BU-22) are located along the cut south of the highway garage road. Each are 1 to 2 m wide, oriented about AZ100 and vertical. They are both good trachyte porphyries, with large orthoclase phenocrysts set in a buff-colored matrix. The surrounding Iberville shale was highly deformed before the intrusions, and the trachyte magmas followed some uneven fractures as shown by contact structures. Nevertheless, the dikes incorporated only a few small shale xenoliths.

Return to Rte. 7 and turn right (north)

18.10.7 Pull off the pavement onto the shoulder, adjacent to the camptonite dike

STOP 6. JONES HILL RTE. 7 CAMPTONITE DIKE.

This dike was exposed by highway construction in the late 1960's (dike BU-8 of McHone, 1978). The Champlain thrust fault caps this hill (also called "Mutton Hill" or "Church Hill" on various maps) with durable Cambrian Monkton quartzite, as well as Pease Mountain, Mt. Philo, Buck Mountain, Snake Mountain, and others of the "Red Sandrock Range." According to Welby (1961), younger cross faults cut the Champlain thrust, which

localized the erosion that separated these hills from one another. As at the Pease Mountain roadcut farther south, the Iberville shale is highly contorted and folded.

There is an offset visible halfway up in the dike, with a surface oriented about AZ30, 69, and subparallel to shale cleavage. Apparent offset is 106 cm of this 148 cm dike. The dike partly follows shaley cleavage, but it is clear that the magma crosscuts most of the deformation. Although generally covered by rubble, the southern end of the offset is a sharp break, indicating a post-intrusion fault. However, the dike along the offset is fine-grained like the chill margin, so it may a syn-magmatic feature. As listed in Table 2, the petrography of this dike shows it to be a normal camptonite, with modal variations that might be attributed to cooling rates. Chemical analyses of two of the five cross samples are typical for basanite, except for the high volatile content. This dike may be one studied in detail by Shearer (1974).

TABLE 2. MODAL AND CHEMICAL ANALYSES ACROSS THE JONES HILL DIKE, RTE. 7, CHARLOTTE, VERMONT

SAMPLE	A	B	C	D	E		B	D
MODES						OXIDES		
Ti-augite	18.9	23.0	21.6	25.8	17.1	SiO ₂	43.9	44.57
Alt. cpx	2.3	tr.	tr.	tr.	tr.	TiO ₂	2.31	2.16
Kaersutite	8.7	27.1	25.7	31.2	17.2	Al ₂ O ₃	14.6	13.71
Plagioclase	7.5	25.0	25.1	22.2	15.8	Fe ₂ O ₃	2.24	n.a.
Calcite*	2.6	2.7	3.9	1.1	4.2	FeO	7.07	9.35***
Selvage**	51.4	0.0	0.0	0.0	36.7	MnO	0.17	0.18
Apatite	1.2	2.3	1.9	1.2	0.8	MgO	6.71	8.39
Mag.+Pyr.	7.4	11.4	5.0	7.2	8.2	CaO	9.71	10.44
Analcime	tr.	8.5	14.7	10.3	tr.	Na ₂ O	3.68	2.94
Serpentine*	tr.	tr.	2.1	1.0	tr.	K ₂ O	2.30	2.67
						P ₂ O ₅	0.85	0.55
						H ₂ O+	1.81	0.90
						CO ₂	3.49	3.41
						H ₂ O-	0.63	0.25
						Total	99.47	99.52
						Rb (ppm)	49	79.6
						Sr	1311	1130
						Y	n.a.	25.2
						Zr	336	230
						V	n.a.	189
						Cr	n.a.	444
						Ni	n.a.	168
						Ba	1140	1150
						Sr ⁸⁷ /Sr ⁸⁶	0.7046	n.a.

*mainly replacing olivine phenocrysts

**mainly devitrified glass, incl. microlites of plag., kaers., opaques, analcime, & apatite

***total Fe as FeO

n.a. = not analyzed

Note: A - E are fist-size samples taken across the 148-cm dike from north to south. Approximate locations: A = 0 cm (north contact); B = 17 cm; C = 53 cm; D = 96 cm; E = 148 cm (south contact). Modes are by 1000-point counts of single sections. Source: unpub. 1978 PhD work by J.G. McHone.

Continue north on Rte. 7, through Shelburne toward Burlington.

22.6	4.5	Shelburne Village center, traffic light
23.2	0.6	"S9" roadcut, where a major fault is exposed along with a few dikes. Not safe for a large group to visit, but this site is described elsewhere (Stanley and Sarkesian, 1972; McHone, 1987).
24.3	1.7	Past Bay Road. Stay on Rte. 7, which is Shelburne Road.
28.1	3.8	Turn right (east) onto Hoover Street. Travel 0.2 mile up the hill, and park in the quarry, not in the neighbors' yards.

STOP 7. REDSTONE QUARRY CAMPTONITE DIKES.

This quarry is owned by UVM and has been used for many introductory geology field trips. The red

Cambrian Monkton quartzite also contains pale-yellow dolostone beds at this site, and many 19th century Burlington houses have foundations or walls made of these rocks. Excellent soft-sediment features are exposed, including ripple marks and hailstone (?) impressions. Please do not climb the walls, and stay out of the adjacent private property and gardens.

Three camptonite dikes are exposed in the northern part of the quarry (Kemp and Marsters 70, 71, and 72 (1893) or McHone's BU-10, 11, and 12 (1978). The southernmost is 110 cm wide, AZ85, 85S, and displays its three dimensions well within the quarry. This dike has small nodules of granite, metagabbro and gneiss carried up from Grenvillian basement some distance (several thousand meters?) below, plus several larger dolostone xenoliths. This is the "Willard's Ledge" dike also mentioned by Thompson (1860, p. 580), which he believed to be exposed again "a few rods to the east," perhaps on Spear Street. Kemp and Marsters (1893) referred to this dike as an example of "augite camptonite," in which Ti-augite phenocrysts predominate rather than the brown hornblende that is so important to the camptonite definition. Augite camptonite has since been shown to be common.

The northern dike in the quarry is also augite camptonite, AZ274, 81N, and 66 cm wide, with large pieces of xenolithic gneiss. The middle dike is a narrow stringer of glassy augite camptonite. It is only about 10 m long, pinching out at both ends with a maximum width of 12 cm. It curves from AZ280 (thicker part) to AZ305 (thinner). Obviously, there must be connecting fractures that the dikes follow at depth.

End of trip. Turn north on Rte.7 to go back to UVM, or south on Rte. 7 to I-189 for easy access to I-89 and Montpelier.

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