CRETACEOUS INTRUSIONS AND RIFT FEATURES IN THE CHAMPLAIN VALLEY OF VERMONT

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INTRODUCTION

On this field trip we will examine sites near Burlington, Vermont where alkalic dikes and fractures are exposed that could be related to Cretaceous rifting. The setting of these and many similar features is the structural (as opposed to sedimentary) basin of the Lake Champlain Valley, which invites comparison with younger and better-studied continental rifts, such as the Rio Grande Rift of eastern New Mexico or the Gregory Rift of eastern Africa. The validity of such an interpretation depends upon careful study of the tectonic history of the Valley, especially the timing of faulting and its relation to magmatism.

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. The best exposures exist along the lake shores, some river and stream banks, highway cuts, and quarries. 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.

The six stops of this field log include outcrops of the three major igneous rock types - monchiquite and camptonite (varieties of volatile-rich alkali basalt), and bostonite (hypabyssal trachyte) - a bimodal association characteristic of many regions of intra-plate or rift volcanism. The timing of the faulting that produced the Champlain Valley may be constrained by physical or geographic associations with the Early Cretaceous (115-135 Ma) magmas. Although no intersections of major-displacement faults with dikes are clearly exposed in the Champlain Valley, there are good outcrops at these six stops that show minor faults and fractures believed (or hoped) to be related to the major tectonic events.

Dikes and other intrusive 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, 1984), dikes become scarcer southward from Vergennes, but are fairly abundant across the Taconics and Green Mountains to the west and southeast of Rutland, Vermont. The northern Champlain Valley is

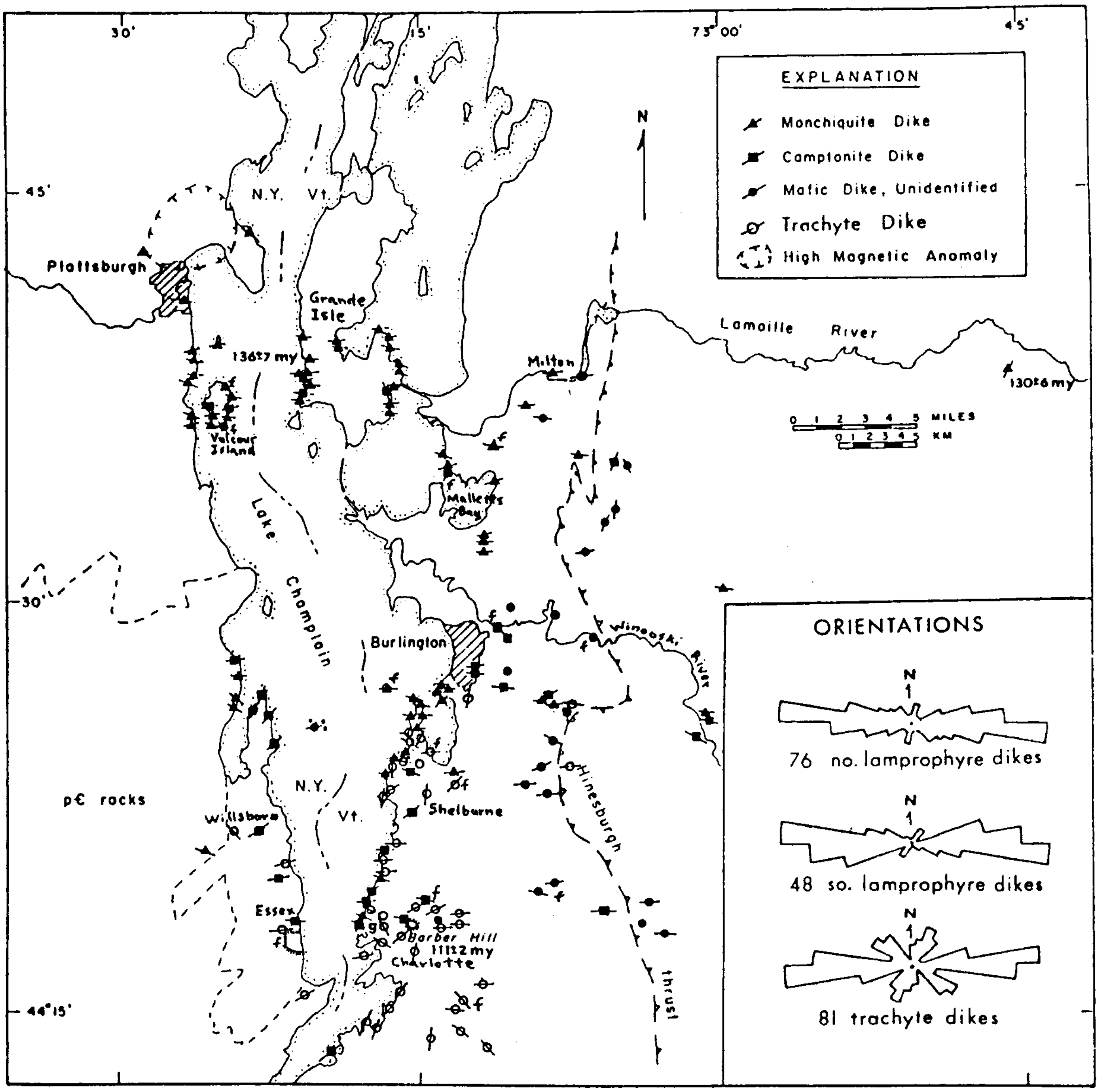

Figure 1. Locations and orientations of alkalic dikes in the central Lake Champlain Valley of Vermont and New York (after McHone and Corneille, 1980). F = fault-related dike (Table 1).

curiously devoid of dikes from North Hero well up into Quebec, but similar dikes are again 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.

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.

As indicated on Figure 1, the dikes apparently separate into two swarms across the lake into New York. At least 80 dikes of monchiquite, a few camptonite dikes, and 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). The monchiquite dikes lack significant feldpar, and are commonly rich in Ti-augite, calcite, kaersutite, and/or olivine or phlogopite, with analcime in the matrix. Some of the dikes approach alnöite or carbonatite in composition. Although we will not visit the northern swarm because of time constraints, 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). The trachytic dikes are commonly called bostonite (fine-grained, alkali-feldspars in clusters), despite the wide variations of beige, brown, and red colors with anorthoclase, albite, and quartz phenocrysts in an altered felsic matrix. Some show corroded oxybiotite grains. Camptonite has more plagioclase (restricted to groundmass) than analcime, much augite and rarely olivine, and variable amounts of kaersutite (a Ti-rich variety of brown hornblende). Amygdules and ocelli (formed as immiscible felsic-magma blebs) are common in camptonite. Phenocrysts of augite and kersutite are visible.

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 and probably indicate another syenitic pluton at shallow depth.

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 (1978) 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 (1985) verbally 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 mis-acknowledged sample provided by Gillespie (1970) of "slightly altered" biotite. The Barber Hill stock is considered to be cogenetic with the bostonite (trachyte) dikes of the area. Seven bostonite dike samples fall along 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 also fits onto the 125 Ma isochron. Isachsen (1983, pers. comm.) has found a K-Ar age of 120 Ma for a trachyte dike in Willsboro, New York. The 111 Ma date for Barber Hill could be reinterpreted as a cooling date, about 10 Ma later than intrusion.

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". In combination with the radiometric data, these crosscutting relationships are consistent with ages generally about 135 Ma for monchiquite, 125 Ma for trachyte/bostonite/syenite, and 115 Ma for camptonite, plus or minus 5 to 10 Ma for each type. These ages use old radiometric constants, and dates recalculated to new constants are 3 to 5 Ma older but do not change the age relationships.

Faults and faulting

Published maps of the Champlain Valley by Hudson (1931), Quinn (1933), Welby (1961), Doll and others (1961), Fisher (1968), and Isachsen and Fisher (1971) all seem to show different high-angle faults. Figure 2 is a somewhat generalized summary map, omitting some of the more imaginative faults suggested by Hudson (1931). Quinn's 1931 dissertation work included calculations of the percentage and directions of crustal extension caused by normal faulting in the region, and are reproduced in Figure 2. The north-south St. George fault system along the eastern side of the Valley is described by Stanley (1980), partly based upon his highly-valued student mapping projects. Stanley and Sarkesian (1972) and Stanley (1974) have made careful analyses of joint and fault strains, quartz lamellae orientations, and other structures to interpret stress patterns for these features.

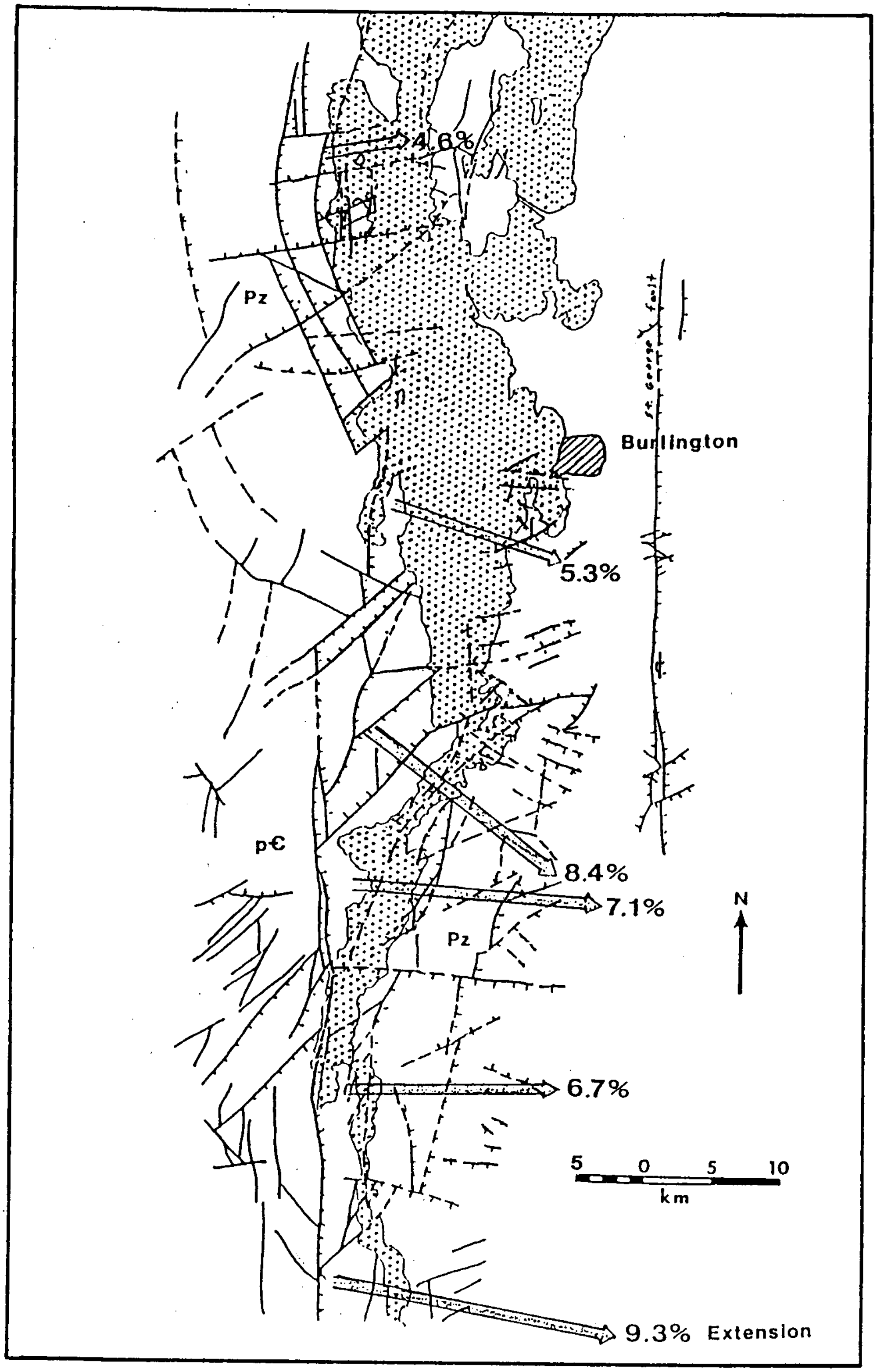

Figure 2. High-angle faults of the central Lake Champlain Valley, adapted from Quinn (1933), Welby (1961), Fisher (1968), Isachsen and Fisher (1970), and Stanley (1980). Extension vectors from Quinn (1933).

Most of the high-angle faults can be grouped as "longitudinal faults" (roughly N-S) or "cross faults" with both E-W and NE-SW trends. Geologists who originally mapped these structures related the faults to Paleozoic tectonic events, perhaps associated with westward movements of the Champlain and Hinesburgh thrust faults (Taconic/Acadian). Welby (1961) makes it clear that many cross faults have offset the Champlain thrust, and that cross faults also offset longitudinal faults (e.g. Stanley, 1980). The fault pattern in New York (Fig. 2) appears to show that several of the major longitudinal Adirondack border faults (Isachsen and Fisher, 1971) crosscut NE-trending Adirondack faults. Several longitudinal and cross faults of the eastern Adirondack border are well exposed, such as at Port Henry (McHone, 1987).

The high-angle faults are usually described as having dip-slip or normal offsets, but Stanley and Sarkesian (1972) and Stanley (1974) cite evidence for strike-slip or wrench movements of cross faults in the Shelburne Bay area. The faults have brittle features, and apparently moved at shallow (less than 2 km) depth (Stanley, 1974). Because vertical offsets of at least 850 m are preserved along some of the faults, roughly 2 to 3 km of post-faulting erosion of overlying rock is indicated. If the stratigraphy of the Champlain Valley was once complete with Silurian and Devonian or younger units, much uplift and erosion must have preceded faulting.

Isachsen (1975) and Isachsen and others (1983) argue that the Adirondack dome could be young, perhaps with Holocene uplift. The relief of the Adirondacks relative to the Champlain Valley is clearly based on movements along faults that are part of the Champlain Valley system, and so Burke (1977) proposed that the Champlain and adjacent Lake George valleys are grabens developed by Neogene continental rifting. Crough (1981) proposed uplift during Cretaceous-early Tertiary time for the Adirondacks and New England, based on fission tracks, stratigraphic arguments, and the presence of the Cretaceous intrusions, and he promoted a "hotspot track" model for the events. The absence of Triassic and Jurassic sediments in the Champlain Valley could indicate a higher elevation for the area during the Early Mesozoic, when Atlantic rifting produced large, deep sedimentary basins in southeastern New England and offshore (McHone, 1982). Finally, the present Champlain topography must predate the Miocene Brandon lignite and kaolin deposits, preserved along the eastern margin of the Valley by the Green Mountain front.

With the ages of the Champlain intrusions fairly well known, crosscutting relationships with the faults are critical to the tectonic model. Unfortunately, no intersections of dikes with major faults are clearly exposed, although a few are close! Locations where dikes intersect Champlain faults are listed in Table 1, and both pre- and post-dike fault movements are indicated. A major problem is estimating true offset, because at several of the exposures only minor apparent lateral offset may result from a great deal of mainly dip-slip motion. Future work with a portable magnetometer could help to show the nature of fault intersections with mafic dikes under shallow cover. Faulting and dike intrusion may be part of the same rifting event, as originally envisioned by Kumarapeli and Saull (1966) for a larger region that includes the Champlain Valley.

TABLE 1. FAULTED (?) AND FAULT-CUTTING DIKES OF THE LAKE CHAMPLAIN VALLEY

Dike Data	Location	Description and Reference (number)
Monchiquite N65W 15" wide	Crosses northern Juniper Island	Dike shows 15" offset on NE side of island (1)
Lamprophyre 10" wide	End of Clay Point, Colchester	Right-lateral offset of 3' along a N-S fault. Shale is also rotated (1,4)
Lamprophyre 3' wide	Hubbell's Falls, Winooski River, Essex	2 left-lateral offsets reported (1), but no offsets seen by Perkins (4)
Camptonite N83W, 78N 148 cm wide	E. side Rte. 7, 0.5 miles N. of Charlotte intersection	Fault about N30E, 69SE, subparallel to shale cleavage. Apparent offset is 106 cm left-lateral (not true offset) (2)
Trachyte N55E, 81SE 6-11 cm	E. side Rte. 7, 0.8 miles N. of Shelburne. 25 m N. of major fault	Silicified, fills fault plane (offset unknown) in Winooski dolostone. Green color may relate to Mg reaction (?)
Camptonite N24W,79 SW 0-79 cm wide	Winooski River below Woolen Mill, Winooski	2 right- and 1 left-lateral offsets of 19 to 64 cm, along N5W to N28E joints and syn-intrusional? fault (3)
Camptonite (no data)	North end Monkton Ridge c.2 miles SW Hinesburgh	Cuts minor N-S normal fault associated with major N-S St. George fault (3)
Trachyte E-W (?)	Near bridge over Lewis Creek, North Ferrisburg	Possibly offset by N80W North Ferrisburg fault (5)
Monchiquite E-W, 2' wide	Shoreline at Orchard Point, Shelburne	One of 2 dikes cut by trachyte, offset 1-2', no other data (1)
Trachyte c.N85E,75NW c.22 ' wide	Crosses Reber Road 1.2 miles SW of Rte. 22 in Willsboro	Silicified "keratophyre" (6). Aligns (no offset) on both sides of Adirondack border fault (disputed by Isachsen)
Trachyte sill (no data)	1 mile SW of Essex Village, SE from road	Abruptly terminates at N50E normal fault, but not well exposed (6)
Monchiquite N84W 34" wide	Just north of Beauty Bay, Valcour Island	Walls of dike are offset 1'11", down to north (7)
Monchiquite (2 dikes)	SE corner of Valcour Island	SW dip due to drag rotation along the adjacent Valcour Cove fault (7)
Monchiquite N83W, 75NE 78 cm wide	North side Rte. 2, c.1.2 miles W. of I-89 exit for Grande Isle	70 cm offset, upper side to North along sub-horizontal fault. Dike brecciated at fault. True offset unknown.

References: (1) Thompson, 1861; (2) McHone, 1978; (3) Stanley, 1980; (4) Perkins, 1908; (5) Welby, 1961; (6) Buddington and Whitcomb, 1941; (7) Hudson and Cushing, 1931

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ITINERARY

The starting point is the parking lot behind Perkins Geology Hall on the western side of the University of Vermont, off Colchester Avenue (Fig. 3). Cars can usually be left here on weekend days or when the University is not in session. Otherwise, get a visitors permit. Refer to Figure 3 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 stop 4, parking and access through private property is by special permission. Food can be purchased at our lunch stop.

The stops are within the Burlington and Mt. Philo 7 1/2' USGS quadrangles, and are along or within a few miles of U.S. Route 7. The Vermont Atlas and Gazetteer (David DeLorme and Co.), available in local stores, has a convenient scale and is recommended as well. The local geology is mapped by Cady (1945), Welby (1961), and in summary by Doll and others (1961). Other areas of the Champlain Valley that contain dikes are mapped by White (1894), Buddington and Whitcomb (1941), Stone and Dennis (1964), and Fisher (1968).

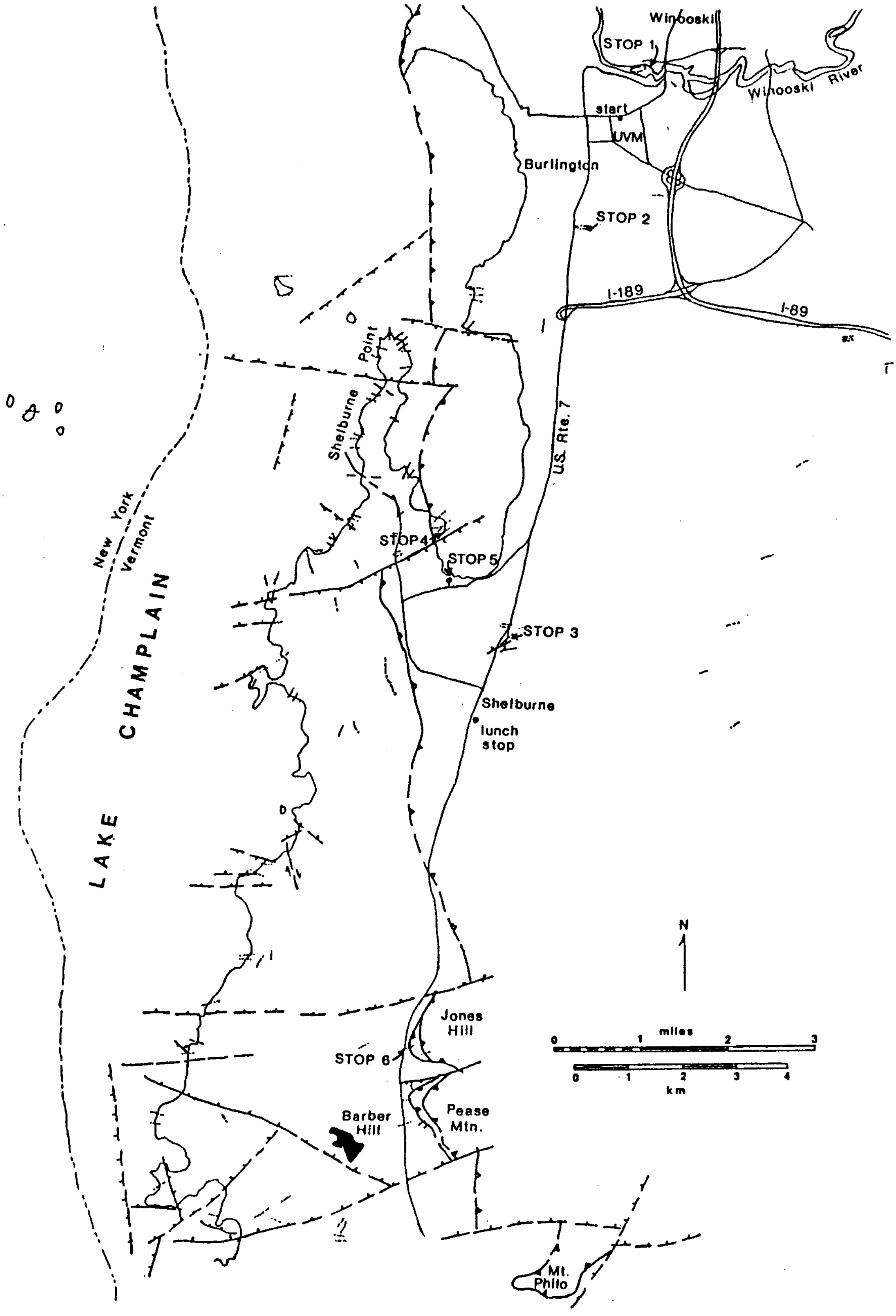

Figure 3. Location map of field stops and dikes in the Burlington - Shelburne area, Vermont (adapted from Welby's 1961 geologic map).

Mileage Total	by Point	Description
0.0	0.0	Starting from parking lot behind Perkins Hall (Department of Geology) at UVM, turn right (east) onto Colchester Avenue. Street will curve to the north and descend a hill.
0.8	0.8	Bridge over Winooski River. Colchester Avenue becomes Main Street in Winooski.
0.9	0.1	Turn left (west) at light onto West Canal Street, just past bridge.
1.1	0.2	Park along street near the Woolen Mill. Walk west through the parking lot, around the fence and follow path SE down to the river (about 300 m).

STOP 1. The Cambrian Winooski dolostone at this location shows well-developed fractures that intersect a camptonite dike, near the end of the Winooski River gorge called Salmon Hole. The cliff face follows joints trending between N15W and N25W, about the same trend as the vertical dike present at the cliff base. Three small-displacement, N-S faults are mapped in the area (Stanley, 1980, fig. 7). A N50E joint set crosses both the dike and dolostone. N30E and N5W fractures are more common in the dolostone than in the dike, and many of these joints appear only on the east wall above and up to the dike, but not crossing it.

The dike is a dense and fine-grained augite camptonite, with many small blue (chalcedony?) amygdules. The dike pinches out or is truncated under sand near the river to the south, although a thin dike stringer is present into the water. The main dike extends with some pinch and swell for over 75 m NNW to its cover near some mill turbine ruins, and is 74 to 79 cm wide. A similar dike appears on line with the trend at Schamska Park about 1/2 mile to the SSE and may be connected.

At least three offsets are exposed. The southernmost shows right-lateral offset of 64 cm where a N28E fracture is exposed in the dolostone wall. The dike is 48 cm wide in the offset, and the rock is foliated or sheared parallel to the fracture. The fracture does not appear to extend into the dolostone west of the dike, and is interpreted as a syn-intrusional feature in which slip occurred only on the eastern side shortly after or while the magma conduit opened.

The middle offset is along a fault oriented N2W, 55W that Stanley (1980, p.26) calls a normal fault of minor displacement, possibly related to the longitudinal St. George fault system along the eastern Champlain Valley. Stanley (1980, p.26) states that the fault predates the dike, but about 22 cm of poorly-exposed left-lateral offset can be observed, with the fault continuing in the dolostone south of the dike. In addition, the dike is strongly and closely fractured at this offset.

A third small, right-lateral offset farther north appears to be another syn-intrusional feature, with a small dike stringer extending through the fracture opposite the main dike. The fracture is about N70E, 87SE and does not extend past the dike to the west.

Return on the same streets past the Geology Department and UVM (do not follow Route 7 along the river road).

2.3	1.2	Colchester becomes Pearl Street.
2.5	0.2	Turn left (south) onto South Willard Street (reconnect with Route 7).
3.8	1.3	Roundabout at foot of hill past Dunkin Donuts. Continue south (Route 7).
4.0	0.2	Turn left (east) onto Hoover Street. Up short hill, park in quarry (not on grass).

STOP 2. Redstone Quarry. 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 quarry, 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. The southernmost is 110 cm wide, N85E, 85S, and shows its vertical dimension well along the wall of the quarry. This dike has small nodules of granite, metagabbro and gneiss carried up from Grenvillian basement some distance (several thousand feet?) below, plus several larger dolostone slabs. This is the "Willard's Ledge" dike mentioned by Thompson (1860, p. 580), which he believed to be exposed again "a few rods to the east". 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 an essential part of the camptonite definition. This variety of camptonite has since been shown to be common.

The northern dike in the quarry is also augite camptonite, N86W, 81N, and 66 cm wide. The middle dike is a narrow stringer of glassy augite camptonite about 10 m to the south. It is only about 10 m long, pinching out at both ends with a maximum width of 12 cm. It curves from N80W (thicker part) to N55W (thinner).

Joint patterns in the quarry have not been carefully examined for this report, but an E-W set can be seen, as well as some curving joints like the fracture filled by the stringer dike. We will note a few of the orientations, but watch out for radiating fractures around blasting holes. The continuation of the southern dike eastward into the quarry wall is not clear, and needs examination.

Return to Route 7 down Hoover Street.

4.5	0.5	Turn left (south) onto Route 7. Be careful! If traffic is too heavy, turn right and go around the roundabout.
5.4	0.9	Pass under I-189 exchange, continuing S.
8.9	4.4	Through light at Jelly Mill Common.

9.3	0.4	Turn left (southeast) at intersection curve past Dutch Mill. Watch traffic!
9.4	0.1	Turn left, park in First Baptist Church lot. Walk across road, through parking lot adjacent to hill, right along Route 7 highway cut. Stay off the pavement (no need to cross the highway).

STOP 3. S9 roadcut. This cut is dominated by one large and several smaller cross faults, and was described by Stanley and Sarkesian (1972). The exposed surface of the footwall on the major fault is oriented N70E, 75NW, along which Winooski dolostone has dropped against Monkton quartzite. At least eight smaller NE and N-S-trending faults are exposed as well, and slickensides indicate mostly dip movement (near-vertical maximum compression). Gouge is common, and with the slickensides indicate a brittle environment of faulting. Stanley and Sarkesian (1972, p. 132) reported that quartz lamellae at this site indicate NE-SW compression, interpreted as preceding the final fault movement.

About 25 m north of the major fault, a narrow (4 to 12 cm wide) green-colored trachyte dike has intruded a small fault, oriented N54E, 85 SE in the Winooski dolostone. Please do not sample any of this dike...it is unique! The pale grass-green color has not been observed elsewhere, but is believed to be caused by an unknown reaction of the magma with the dolostone. The dike is silicified but preserves altered alkali feldpar phenocrysts. A strange texture of frothy brown bubbles is observed in thin section, along with much dolostone microbreccia incorporated by the dike. An x-ray diffraction pattern of the rock identified alpha quartz, clay minerals, and smaller peaks of unknown cause.

In times of light traffic, two N85E monchiquite dikes can be visited just north of the driveway across the highway at the northwestern end of the roadcut. The southernmost is very weathered to a light-brown color close to that of some trachyte dikes. A large group should not try to cross this busy road.

Return to Route 7.

9.6	0.2	Turn left (south) CAREFULLY onto Route 7.
10.4	0.8	Through stop light, Shelburne Village.
10.7	0.3	Turn left into parking lot at Harrington's, home of the "world's best ham sandwich", for lunch stop. A rest room is available upon polite request. A gas station is nearby. Also, Cafe' Shelburne for the elite eater. Please limit lunchtime to 45 minutes or less.
		Return north on Route 7 to Village.
11.0	0.3	Turn left (west) at stoplight in Shelburne Village.
11.1	0.1	Cross railroad track.
11.7	0.6	Road curves right (north).

12.6	0.9	Stop sign. Continue straight north toward Shelburne Point.
13.4	0.8	Turn right (east) into parking lot south of large brown barn. Parking by permission only, do not block driveway (boat repair shop).

Walk east across field toward southern side of hill on the lake above Shelburne Bay. This is private property of Mr. Thomas Cabot, and access permission is for this trip only. Walk though the woods, down the hill toward the lake. Assuming normal low Fall lake levels, we will walk along the shore northward along the hillside. If high water, stay well above the lake, and travel around the eastern hillside through the woods, where thick float can be seen.

STOP 4. Shelburne Point intrusive breccia. At least four trachyte (bostonite) dikes are found around the eastern side of this point, three of which contain abundant xenoliths of many Paleozoic and Proterozoic rocks that underlie the region. The intrusive breccias have 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 sidewise 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 Williams, 1985).

Return the same route back to cars, and turn left (south).

14.2	0.8	Intersection near Shelburne Farms. Turn left (east).
14.9	0.7	Turn left (north) into large parking area of Shelburne Bay Access. Walk out onto rocky peninsula.

STOP 5. Shelburne Bay Access. Joints and small-displacment faults are well exposed at this classic teaching site, described by Stanley (1974). North-south and east-west faults show both dip and strike-slip offsets of less than 30 cm. Some E-W fractures are extensional and are filled with quartz. Careful analysis of the fractures by Stanley (1974) and his students has shown that an early set developed with generally E-W principle compressive stress, followed by a second set with roughly N-S compression. Low confining stress

conditions indicate shallow depths (less than 2 km) during deformation. Although Stanley (1974) originally related the Shelburne Access fracturing to Acadian (Devonian) tectonism, a Mesozoic time of deformation is also reasonable for at least some of these features. Stanley (1974) especially pointed out the proximity to the major Shelburne Point cross fault near to the previous stop (and almost visible from the access rocks).

Return back the same way (turn right from the parking lot)

15.6	0.7	Back at intersection near Shelburne Farms, turn left (south). Continue back (SE) to Shelburne.
17.2	1.6	Turn right (south) onto Route 7 at stop light, Shelburne Village.
18.0	0.8	Through blinking yellow light.
18.2	0.2	Gecewicz Farms fruit stand on left.
20.9	2.7	Good view of Champlain Valley.
21.7	0.8	Jones Hill on left, Barber Hill is low hill in valley about one mile directly ahead.
22.2	0.5	Intersection with F-5 (Charlotte). Turn around by turning left into gas station, return north on Route 7 so that we can park on the east side of the highway.
22.7	0.5	Park off pavement along east side of Route 7.

STOP 6. Jones Hill dike. This dike was exposed by highway construction in the late 1960's. The Champlain thrust fault has capped this hill and Pease Mountain to the south, as well as Mt. Philo and others of the "Red Sandrock Range", with durable Monkton Quartzite. According to Welby (1961), younger cross faults cut the Champlain thrust, contributing to erosion that has isolated these hills from one another. As at the Pease Mountain roadcut farther south on Route 7, the Iberville shale is highly contorted and folded. The offset visible in this camptonite dike partly follows shaley cleavage, but it is clear that the dike crosscuts most of the deformation. Although generally covered by rubble, the southern end of the offset is a sharp break. However, the dike along the offset is fine-grained like the chill margin, so it may an intrusional 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 samples shows that the dike magma was typical basanite, except for its high volatile content.

Trachyte dikes are exposed in the Pease Mountain hillside and roadcut to the south, and they trend toward Barber Hill, the top of a small (?) syenitic stock nearby to the west of Pease Mountain. Ambitious geologists might also attempt to visit other offset dikes listed in Table 1, some of which lack serious study.

End of trip. Return north to I-189 for easy access to I-89 and Montpelier.

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

SAMPLE	A	B	C	D	E		B	D
Ti-augite	18.9	23.0	21.6	25.8	17.1	SiO2	43.9	44.57
Alt. cpx	2.3	tr.	tr.	tr.	tr.	TiO2	2.31	2.16
Kaersutite	8.7	27.1	25.7	31.2	17.2	Al2O3	14.6	13.71
Plagioclase	7.5	25.0	25.1	22.2	15.8	Fe2O3	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.	Na2O	3.68	2.94
Serpentine*	tr.	tr.	2.1	1.0	tr.	K2O	2.30	2.67
						P2O5	0.85	0.55
						H2O+	1.81	0.90
						CO2	3.49	3.41
						H2O-	0.63	0.25
						Total	99.47	99.52
						ppm Rb	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
						Sr87/Sr86	0.7046	n.a.

*mostly replacing oliving phenocrysts
** total iron as FeO
***mostly devitrified glass, incl. microlites of plag., kaers., opaques, analcime, & apatite
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 dissertation by McHone.