MESOZOIC IGNEOUS ROCKS IN SOUTHEASTERN NEW HAMPSHIRE

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INTRODUCTION

The long history of work on post-metamorphic igneous rocks in New England has brought slow but continuing progress in our understanding of the sequence of magma generations and their relation to tectonic events. We have focused recently on the overlapping provinces of Triassic, Jurassic, and Cretaceous intrusions that occur in southeastern New Hampshire (McHone, 1992; Sundeen and Huff, 1992), which follow up on some of our earlier investigations (McHone and Trygstad, 1982; Sundeen, 1971). This field trip is the first to be organized for most of the area's Mesozoic intrusions, outside of the classic Mt. Pawtuckaway complex (Freedman, 1950; Creasy and Eby, 1993).

Dike rocks of the different generations can often be categorized through careful examination of hand samples. Most of the dikes are fine grained but holocrystalline as well as porphyritic, and many have obvious igneous structures such as flow bands. Thin sections are always very useful, and in some cases they are indispensable for characterizing the petrography and classification of the dike rocks. It is important to improve our knowledge of the distribution of Mesozoic intrusions because there appear to be definite boundaries to these igneous provinces in southern New Hampshire. The igneous province boundaries could have tectonic controls such as terrane boundaries and major faults, or specific mantle melt zones may be featured. We will discuss the physical distinctions of these rocks during this trip.

MESOZOIC IGNEOUS PROVINCES IN NEW HAMPSHIRE

Even before the establishment of Mesozoic ages for plutons of the White Mountain magma series (principally by Foland and others, 1971, and Foland and Faul, 1977), many geologists have lumped all post-metamorphic igneous rocks of northern New England into this great province, commonly labeled as WMMS. Because most of the WMMS dikes, stocks, and batholiths display alkalic igneous characteristics (Ti-rich clinopyroxene and alkali amphibole; abundant alkali feldspar; high K, Na and Th contents), it has seemed logical to relate them to differentiation or fractionation of intra-plate mantle or crustal melts that have some common genesis (Creasy and Eby, 1993). Although some examples show hydrothermal alteration and igneous fabrics, the Mesozoic igneous rocks do not have the metamorphic foliations that distinguish the common Paleozoic plutons in New Hampshire. Additional work (McHone, 1984) has reinforced the age divisions of Foland and Faul (1977) into groups near Middle Triassic (220-235 Ma), Early to Middle Jurassic (170-200 Ma) and Early Cretaceous (100-130 Ma), with only a few important exceptions (Belknap Mountain is probably close to 160 Ma). Apparent boundaries for Mesozoic igneous provinces in northern New England are shown in Figure 1 (updated from McHone, 1978).

A major problem remains: Early Jurassic WMMS intrusions apparently include many alkalic diabase and lamprophyre dikes that are very similar to members of the Cretaceous NEQ and the Triassic CNE provinces (described below). To date, however, all such look-alikes are found only in central New Hampshire and western Maine (McHone and Trygstad, 1982; McHone, 1992), a geographic association that makes it easy to call them members of the White Mountain magma series. McHone and Butler (1984) have proposed that the alkalic Early Jurassic plutons and dikes of the WMMS are shown as a cohesive province only in central and northern New Hampshire (into northeasternmost Vermont), and western Maine (at least to the Rattlesnake Mountain pluton of John Creasy, this field guide). We do not know of any Early Jurassic alkalic plutons in southeastern New Hampshire, and so this region is probably outside of the WMMS province. More radiometric work would be helpful in resolving the province boundaries.

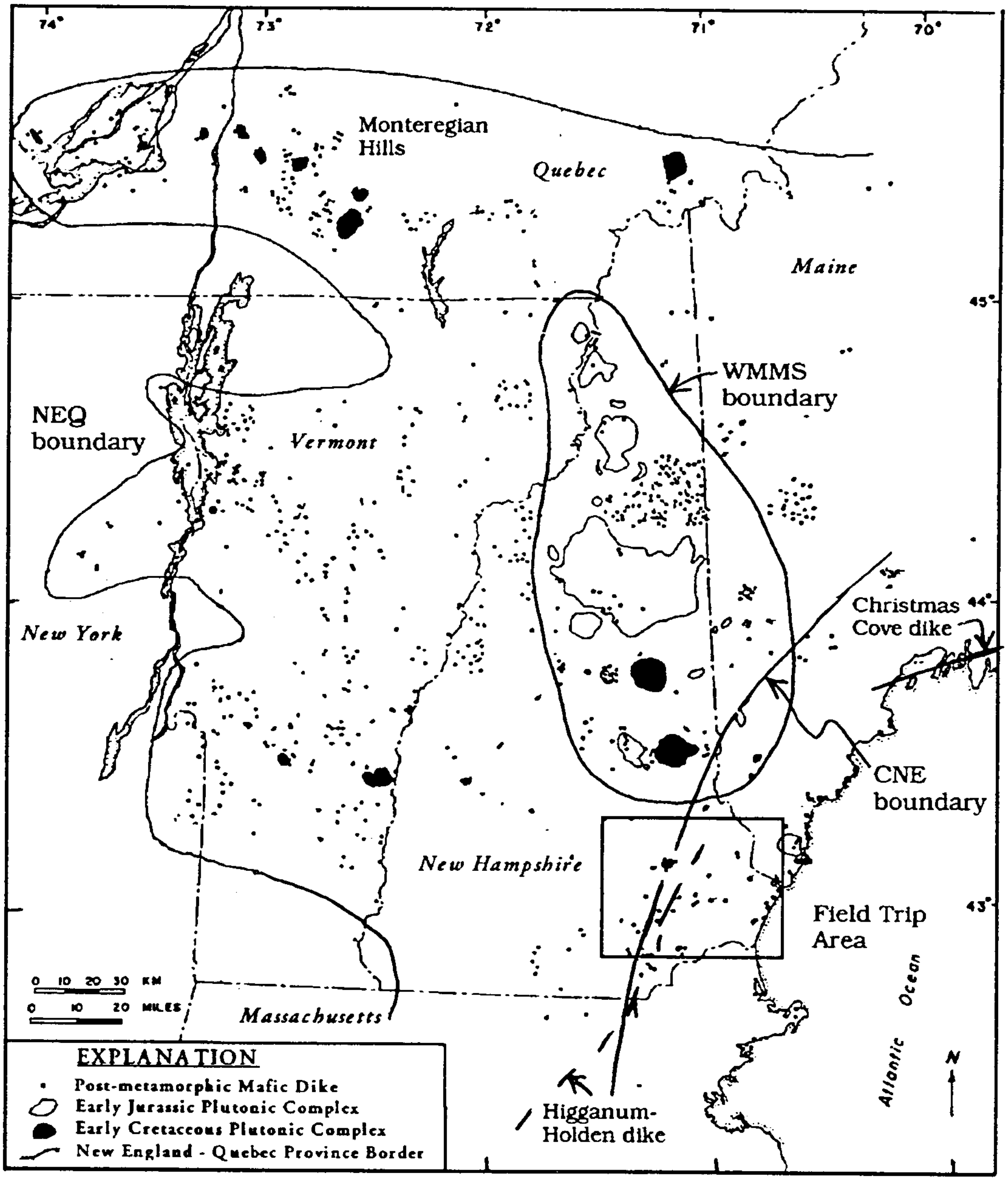

Figure 1. Mesozoic igneous provinces of New England, with boundaries after McHone and Butler (1984).

New England-Quebec (Cretaceous) igneous province

Although magmas of all the Mesozoic divisions overlap in New Hampshire, the Early Cretaceous intrusions range across a wide province that includes the Monteregian Hills of southern Quebec, dense swarms of lamprophyre dikes in western Vermont and eastern New York, and scattered dikes through southeastern Maine (McHone, 1984). Because of their similar ages and petrological characteristics, the Early Cretaceous intrusions were regrouped as the New England-Quebec (NEQ) igneous province by McHone and Butler (1984). NEQ dikes, like the larger Cretaceous plutons, can be found anywhere in New Hampshire but are not concentrated in dense swarms.

Although we know of no Early Cretaceous radiometric dates published for lamprophyre dikes in southeastern New Hampshire, dates of 95 to 110 Ma are measured for several camptonite and monchiquite dikes to the west and east of the region (McHone, 1984). Lamprophyres also crosscut the Early Cretaceous Mt. Pawtuckaway alkaline complex (near Stop 2; also see Roy and Freedman, 1944). Camptonites such as at Stop 4 are distinctively fresh, and we know of no pre-Cretaceous dates for monchiquites in northern New England or Quebec. Therefore, we have some confidence in believing that unaltered alkali lamprophyres without significant amounts of feldspar phenocrysts are of Early Cretaceous generation in southeastern New Hampshire, probably close to the circa-124 Ma age of the Mt. Pawtuckaway complex. Around 20 NEQ lamprophyres are mapped in the region, but more could probably be identified with extra field and lab study.

In addition to the Mt. Pawtuckaway complex, a small felsic stock or plug occurs in the southern Mt. Pawtuckaway quadrangle called the Little Rattlesnake Hills (Freedman, 1950; Sundeen and Huff, 1992), which has a date of 114 Ma (Foland and Faul, 1977). The intrusion is little studied, but its petrography and association with Mt. Pawtuckaway point to membership in the NEQ province. Sundeen (1971) has mapped a rhyolitic body near the border with Massachusetts at Bugsmouth Hill, which is now dated as 118 +/- 4 Ma (Sundeen and Huff, 1992). This feature is the subject of a stop in this guide.

Eastern North American (Jurassic) dolerite province

The Onway dike of Dye and others (1985) and Sundeen and Huff (1992) is a continuation of the huge Higganum dike of Connecticut (Philpotts and Martello, 1986), which runs northeastward through eastern Massachusetts as the Holden dike (McEnroe, 1989), and is found in southeastern New Hampshire at least as far as Durham. This remarkable intrusion has a distinctive quartz-hypersthene tholeiitic chemistry and petrography, and it is correlated with the Talcott basalt and other "initial flood basalts" of Mesozoic rift basins in eastern North America (Puffer, 1992); this magma is probably close to 196 Ma in age. Except for a shift in orientation, the Higganum-Holden-Onway dike is exactly like the Christmas Cove dike of coastal Maine (McHone and others, 1995) and we closing in on a physical connection that, if we are correct, presents a single dike complex more than 600 km in length. Jelle de Boer (pers. comm. 1995) is studying the magnetic fabric of these dikes (sampled at the drill holes visible at these stops); it is possible that the larger dikes show magnetic flow attitudes that point to their source region.

It is likely that other representatives of ENA magmas also occur as dikes in southeastern New Hampshire. The Buttress-Ware and Bridgeport-Pelham dikes of southern New England (Philpotts and Martello, 1986; McEnroe, 1989) parallel the Higganum-Holden dike to its west and trend toward southern New Hampshire, although they are not mapped to the border. Hale and Friberg (1995?) report a chemical analysis for a small dike in the Peterborough quadrangle that is very similar to the Buttress-Ware magma type, which probably was a feeder for the Holyoke basalt (Philpotts and Martello, 1986). The great Caraquet dike of New Brunswick and central Maine is another example of the B-W magma type that trends toward southern New Hampshire, although it is not yet mapped into southwestern Maine. The slightly younger Bridgeport-Pelham dike (which fed the Hampden basalt) is not yet identified in northern New England. If ENA tholeiites are the only Early Jurassic intrusions in southeastern New Hampshire, we avoid the problem of explaining how these definitely non-alkalic magmas could have been generated in the same time and place as alkalic basaltic dikes of the WMMS proper.

Coastal New England (Triassic) igneous province

The Triassic dikes and larger plutons are apparently common only in eastern New England, from Rhode Island (Hermes and others, 1984), through eastern Massachusetts (Ross, 1992), southeastern New Hampshire (Sundeen and Huff, 1992), and southern Maine (Swanson, 1992). These intrusions share some petrological and physical characteristics, being mainly small alkalic to "transitional" olivine diabase dikes (McHone, 1992); in Maine, they are associated with the Triassic Mt. Agamenticus syenite complex. Some Triassic dikes are true lamprophyres (camptonites and a few spessartites), which may be distinguished by a higher degree of hydrothermal alteration than we see in younger dikes. McHone and Butler (1984) refer to the group of Triassic intrusions as the Coastal New England (CNE) igneous province. Around 100 alkali diabase dikes crop out in this field guide area, and hundreds more appear along the New Hampshire and southern Maine coastlines (Bellini and others, 1982; Swanson, 1992).

PETROGRAPHIC DESCRIPTIONS

Tholeiitic dikes

True tholeiitic dikes in southeastern New Hampshire are best represented (perhaps only represented) by the Early Jurassic Onway-type rock. Phenocrysts are not especially abundant, and are dominated by plagioclase with subordinate hypersthene and clumps of augite. The groundmass usually assumes a subophitic texture in coarser examples, with minor areas of intergrown quartz-feldspar granophyre. Figure 2 illustrates some of these textures.

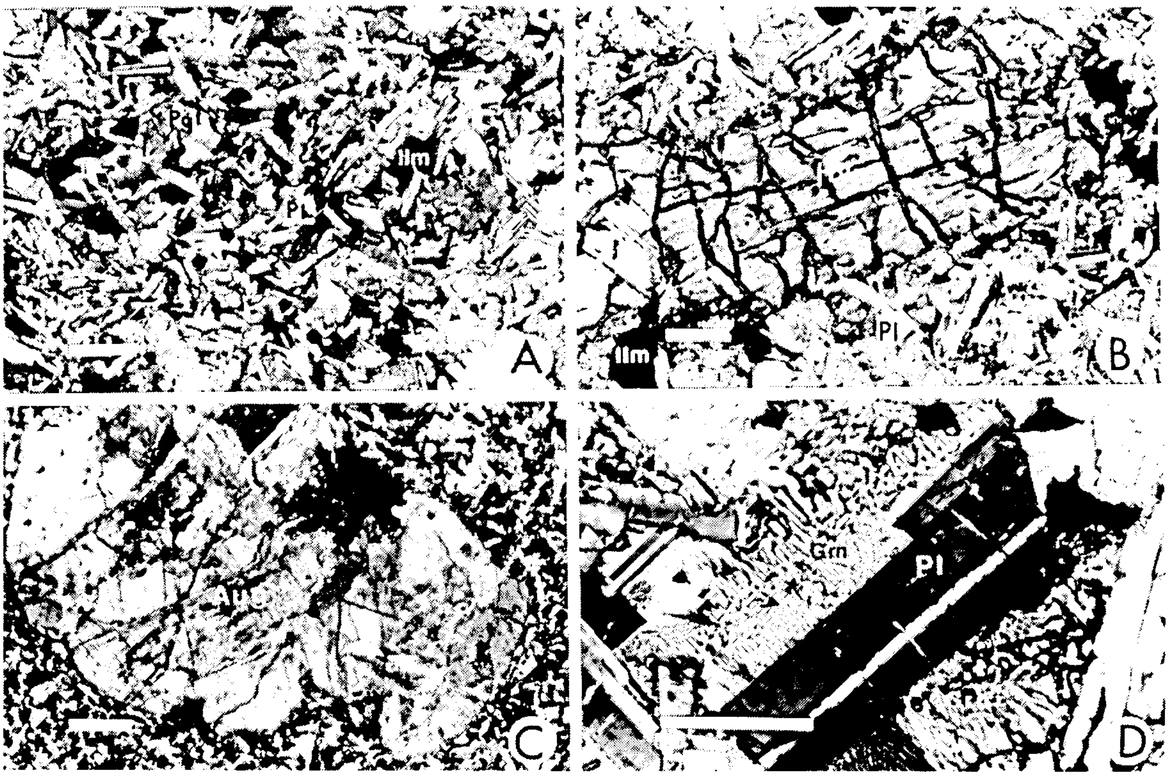

Figure 2 (opposite). Photomicrographs of tholeiitic rocks located in southeastern New Hampshire. Symbols for minerals (after Kretz, R., 1983) are as follows: Aug-augite, Grn-granophyre, Hyp-hypersthene, Ilm-ilmenite, Pgt-pigeonite, Pl-plagioclase (labradorite). Scale bar is 0.25 mm. **Descriptions: A.** aphyric tholeiite displaying typical mineralogy and texture of matrix with intergranular to sub-ophitic texture, labradorite laths surrounding pigeonite, and opaque ilmenite (crossed polars, sample from outcrop 2.5 miles south of STOP #3; see Sundeen and Huff, 1992 for exact location of sample 1006.20); **B.** corroded hypersthene phenocryst with serpentinite in fractures in tholeiitic rock matrix of labradorite, pigeonite and ilmenite (crossed polars, STOP #1, sample 1008M); **C.** partially resorbed, rounded polycrystalline augite phenocryst displaying glomeroporphyritic texture in finegrained matrix of tholeiitic basalt in chill zone on eastern edge of Onway Dike (crossed polars, STOP #3, sample 1003.102); **D.** granophyre surrounding labradorite, sample from center portion of Onway Dike (crossed polars, STOP #3, sample 1003.032).

Alkalic diabase and lamprophyre dikes

The alkalic diabase and lamprophyre dikes lack orthopyroxene but often show kaersutite (Ti-rich basaltic hornblende) in the groundmass. Lamprophyres may also have kaersutite but little feldspar as phenocrysts; what we call alkali diabase generally has plagioclase, and lesser augite and olivine as phenocrysts. Figure 3 illustrates some typical microscopic textures, some of which is apparent in the field with a good hand lens.

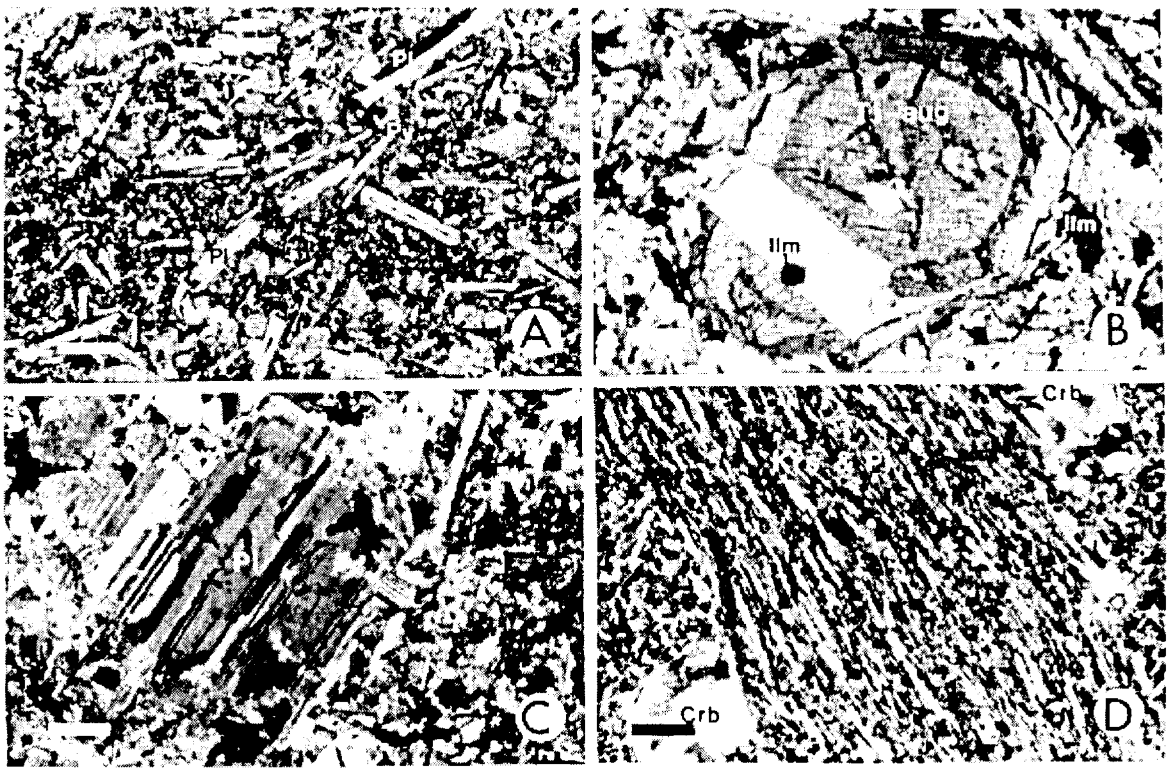

Figure 4. Photomicrographs of alkali diabase and lamprophyre in southeastern New Hampshire. Symbols for minerals (modified after Kretz, R., 1983) are as follows: Anl-analcime, Ap-apatite, Bt-biotite, Cal-calcite, Crbcarbonate, Chl-chlorite, Ilm-ilmenite, Krs-kaersutite, Ol-olivine, Pl-plagioclase, Py-pyrite, Qtz-quartz, Ti-aug=titanaugite. Scale bar is 0.25 mm. **Descriptions: A.** alkali basalt displaying typical mineralogy and texture

of subparallel oriented plagioclase laths in a matrix of plagioclase microlites, altered olivine (?), clinopyroxene, ilmenite and pyrite (crossed polars, Site 4/5 at 54.3 miles, sample 1001.2S, Fig. 5); **B.** twinned and zoned titanaugite phenocrysts in matrix of kaersutite, plagioclase, and ilmenite and leucoxene (crossed polars, sample 34; **C.** phenocryst displaying twinning and oscillatory zoning in a groundmass of altered plagioclase, chlorite, pyrite and ilmenite and leucoxene (crossed polars, site 4/5 at 54.3 miles, sample 1001.5S); **D.** flow texture displayed by parallel alignment of swarm of kaersutite and plagioclase laths, with ocelli of carbonate in matrix of plagioclase, kaersutite and ilmenite (crossed polars, STOP #4, sample 1007).

Felsic dikes

The Mesozoic felsic igneous rocks of southeastern New Hampshire are sometimes shown on maps as "volcanics" (Freedman, 1950), which is a clue about their field appearances. The rhyolite dikes at Stop 5 have a more porphyritic texture but a similar mineralogy to the larger stocks or laccoliths of Little Rattlesnake Hill and Bugsmouth Hill (Stop 7). Figure 4 illustrates this petrography.

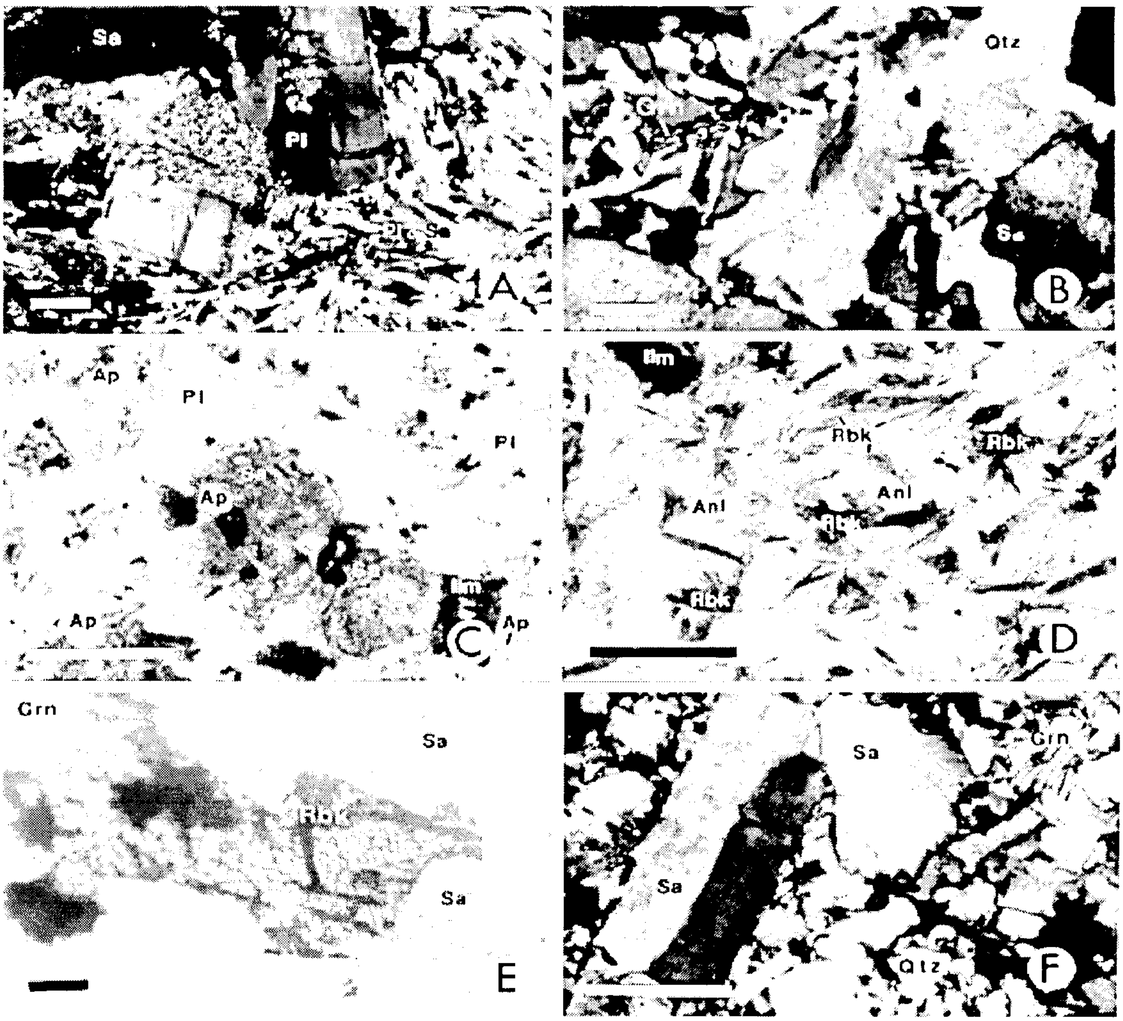

Figure 4 (opposite). Photomicrographs of felsitic rocks located in southeastern New Hampshire. Symbols for minerals (modified after Kretz, R., 1983) are as follows: Anl-analcime, Ap-apatite, Crs-cristobalite, Grn-granophyre, Ilm-ilmenite, Pl-plagioclase, Qtz-quartz, Rbk-riebeckite, Sa-sanidine. Scale bar is 0.25 mm unless otherwise indicated. **Descriptions: A.** Rhyolite with slightly altered cluster of sanidine and plagioclase phenocrysts in a groundmass of plagioclase and sanidine (crossed polars, sample 457, see Sundeen and Huff, 1992, for location); **B**. granophyre in rhyolite with quartz and sanidine (crossed polars, scale bar is 50 microns, STOP #7, location 104); **C.** basal sections of euhedral apatite in rhyolite composed of plagioclase, sanidine, and ilmenite (plane polarized light, STOP #5, location 1004A); **D.** bluish-green riebeckite prisms in andesite matrix of analcime, and altered ilmenite (plane polarized light, STOP #5, location 1004Y); **E.** Bluish-green to yellow riebeckite basal section in rhyolite surrounded by sanidine and granophyre (plane polarized light, scale bar = 25 microns, STOP #7, location 104); **F.** Rhyolite with sanidine phenocrysts surrounded by quartz, alkali feldspars, and granophyre (crossed polars, STOP #7, location 104).

CHEMICAL CORRELATIONS

There are a few scattered rock and mineral analyses for dikes of southern New Hampshire in older literature (see the compilation of Billings and Wilson, 1964) and in some unpublished master's theses (especially Bieler, 1973 and Trygstad, 1979). Earlier dike studies by McHone (1978a and 1978b) include few specific examples from southeastern New Hampshire, but chemical analyses for the Seabrook CNE dike swarm are listed in later work by McHone (1992; analyses by Jean Bedard) and Pe-Piper and others (1992); both use samples described by Bellini and others (1982). More recent work by Sundeen and Huff (1992) and Hale and Friberg (1995) provide chemical analyses for many of the important dike types of southeastern New Hampshire.

Whole rock major-element dike analyses for several of the stops of this field guide are listed in Table 1. Although CNE alkali diabase and lamprophyre dikes often show hydrothermal alteration and volatiles are abundant, modern analytical techniques often list only anhydrous compositions. "Loss on ignition" (mostly H2O and CO2) values typically range from 3 to 5 weight percent (McHone, 1978a) for alkali diabases and lamprophyres, and some of that is actually primary to the magma, as shown by igneous amphiboles, discrete carbonates, and crystalline zeolites. Tholeiites such as at sites 1 and 3 are much dryer and usually show only minor biotite and clay products.

CNE alkali diabases such as at site 4/5 (Table 1) commonly show SiO2 values between 46 and 50 weight percent, TiO2 above 2 weight percent, and K2O above 1 weight percent. NEQ lamprophyres (as at site 4) have similar high Ti and alkalies but lower SiO2, usually 39 to 45 weight percent. The quartz tholeiite (sites 1 and 3) types have SiO2 around 50 to 53 weight percent, TiO2 near 1.0 to 1.3 weight percent, and K2O around 0.4 to 0.7 weight percent. These compositions are well reflected by the presence and abundances of kaersutite, olivine (usually as replaced relict crystals) and plagioclase, among other minerals. We have found CIPW normative calculations to be of limited value in that they usually show what is already obvious from the mineralogy and chemistry of these rocks. Norms are used in some of our terminology, such "quartz tholeiite." The felsic dikes are harder to characterize by their chemistry, but they are less common and usually can be associated with particular dated plutonic complexes.

ACKNOWLEDGEMENTS

We are grateful for help from Wallace Bothner on the logistics of this trip and for background on the geology of Adams Point. Nelson Eby supplied information about the stop at Mt. Pawtuckaway, and Jeffrey Hale provided data from his recent M.Sc. work on dikes to the west of this field area. Jelle de Boer has offered much-needed support for field visits and sample analyses. Nancy McHone has been an able field assistant with J. G. McHone; Carol Dye and Marilyn C. Thoroman Huff have worked on aspects of these intrusions with D. A. Sundeen. Although they predated our present understanding of the magma generations, discussions by Joyce Trygstad Nelson with J. G. McHone in the late 1970's were critical to identifying these petrographic problems.

TABLE 1. WHOLE ROCK MAJOR ELEMENT ANALYSES OF FIELD TRIP DIKES

STOP	1	3	4A	4B	4/5	5	7
SiO2	51.44	52.23	41.4	43.96	47.92	62.58	64.19
TiO2	1.11	1.22	3.24	3.82	2.78	0.26	0.26
Al2O3	13.45	14.58	12.0	14.16	14.26	20.32	20.80
FeO*	10.02	10.18	13.6	12.41	13.78	2.83	3.41
MnO	0.20	0.21	0.20	0.20	0.21	0.31	0.43
MgO	8.14	7.22	9.02	8.24	8.04	0.23	0.26
CaO	11.44	10.71	9.55	9.64	8.76	1.17	0.71
Na2O	. 1.66	1.93	2.58	2.91	2.72	4.97	3.10
K2O	0.49	0.68	1.72	1.79	0.97	5.29	4.21
P2O5	0.12	0.14	0.79	0.64	0.28	0.01	0.00
LOI			5.10				
Total	98.07	99.10	99.17	97.77	99.72	97.97	97.37

*Total iron as FeO

Analyses are of dikes at stops as numbered in this field guide, except: 4/5 is from the non-stop site along Rte. 101 between stops 4 and 5 (see trip log). All analyses are from Sundeen and Huff (1992) except for stop 4A (camptonite dike at Stop 4) which is from Table 6 of Hale and Friberg (1995). Sample 4B is the same dike as analyzed by Sundeen and Huff (1992, sample 1007).

ROAD LOG

Several of our field stops are along major highways. Safety is a major consideration, and we may skip stops if required by traffic conditions and the number of participants. Please park along shoulders well off the pavement, and stay alert for traffic. On secondary roads, do not park on both sides or make any hazardous obstacles for local traffic. All of our stops are on public lands, but please be courteous to local land owners whom we may surprise.

This road log takes us through the Dover West, Barrington, Mt. Pawtuckaway, Candia, Epping, Exeter, Newmarket , and Portsmouth 7 1/2 minute USGS quadrangles. We also use the New Hampshire Atlas and Gazeteer, published by DeLorme and Co. The New Hampshire State Highway Map can save time because it emphasizes the best roads; Figure 5 locates stops on that highway map.

The trip log starts from Lot A on the west side of the University of New Hampshire campus. For participants who are driving from Maine, we recommend following I-95 south to Portsmouth, New Hampshire, and then taking U.S. Rte. 4 northwest to Durham. From Rte. 4, Lot A is most easily reached by exiting on the west side of town onto Old Rte. 4 (becomes Main Street), then east 1.2 miles to the entrance road just west of the greenhouses. Park behind the white UNH Parking and Transit Building. The trip ends at this lot as well, so please combine into a few vehicles as possible. We intend to start promptly at 9 AM.

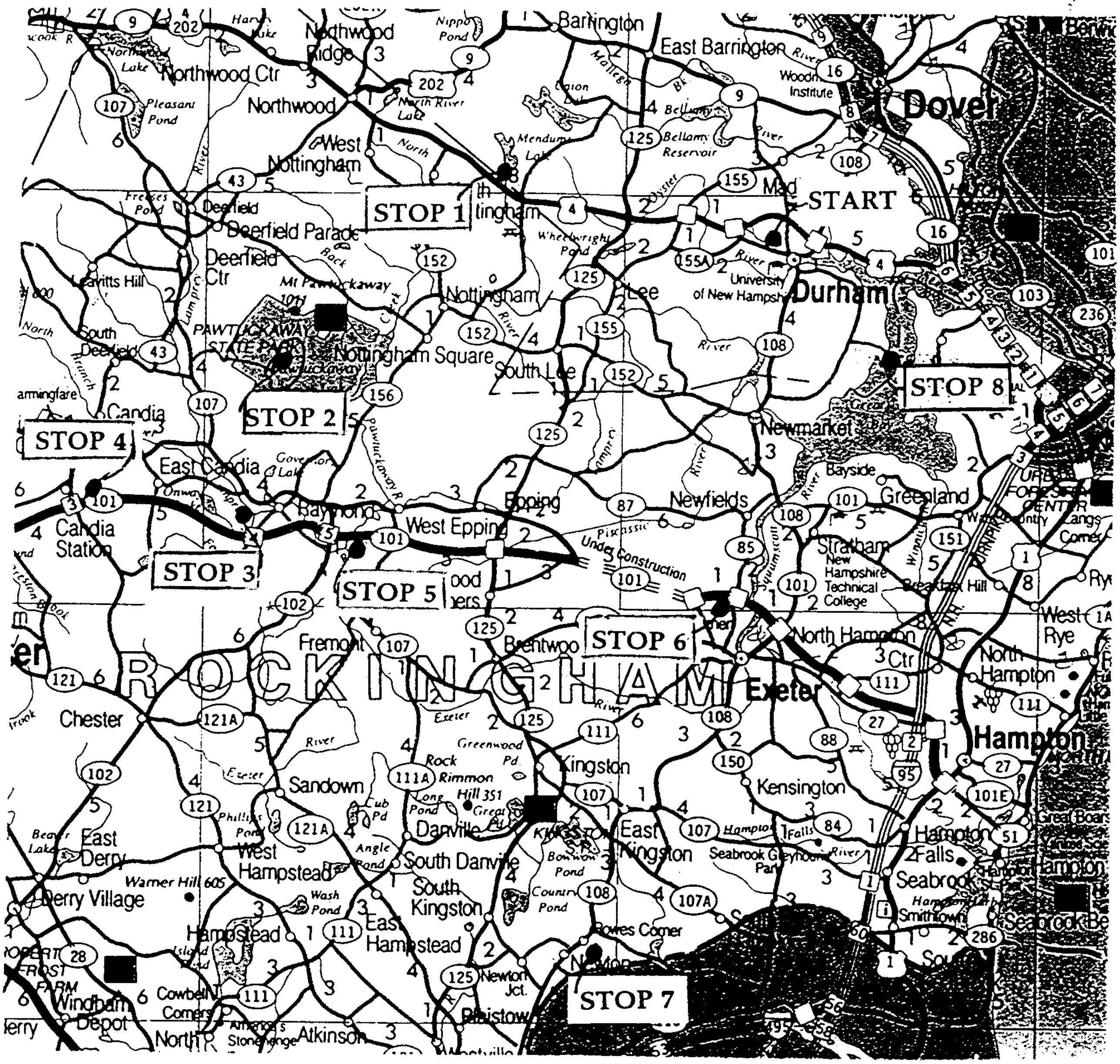

Figure 5. Section of the New Hampshire State Highway Map showing the field area, with stops (solid dots).

Mileage

0.0 Assemble at Parking Lot A, University of New Hampshire campus, Durham, NH. before 9 AM. Proceed northwest on Old Rte. 4 to intersection with new U.S. Rte. 4.

1.2 Turn left (west) onto U.S. Rte. 4

3.8 Cross intersection with SR 125.

7.2 Park on the right shoulder of the westbound lane off the pavement, just past the roadcut. WATCH FOR TRAFFIC!

STOP 1. ENA tholeiite - the Onway dike at Rte. 4. Barrington quadrangle (20 minutes). A large dolerite dike is partially exposed on both sides of the road. The SE contact is clear, yielding a N37E strike and vertical dip. In detail the contact is irregular, but a reasonable strike can be obtained by sighting across the road along this margin. About 18 m of the dolerite is exposed, but other locations of this dike show thicknesses between 20 and 40 m. The NW contact is buried, but notice the gneiss that appears above what should be the center of the dike. Either this the dike splits around a large inclusion, or the dike takes a great deviation from vertical on its NW side. Both possibilities have been observed in similar dikes at other locations.

This is the northernmost known exposure of the great Early Jurassic Higganum-Holden-Onway dike, which runs at least 180 km from here to the southwest across eastern Massachusetts and Connecticut, and on under western Long Island Sound. There is also some possibility that it can be traced northeastward into southern Maine, where it would turn to the east to link with the Christmas Cove dike, mapped by Art Hussey (1971) eastward from the Portland area. We will see this dike better exposed at Stop 3 (Onway Lake). The fresh and weathered surfaces show its medium to fine-grained tholeiitic texture of plagioclase and augite in a subophitic matrix, with scattered larger crystals of plagioclase and hypersthene. The medium gray fresh color is also characteristic, and we suggest that you carry a small sample for comparison with other mafic dikes during the trip.

Continue west on Rte. 4 toward Northwood. Watch for road signs; our turn onto Rte. 43 will be just before the intersection with Rte. 9 and it is easy to miss.

12.0 Turn left (southwest) onto C.R. Rte. 43.

17.8 Turn left (south) onto Rte. 107 (joins 43).

19.4 Rte. 107 splits from Rte. 43; stay left on Rte. 107.

20.0 Turn left (east) into entrance road to Pawtuckaway Mountains and fire tower. The entrance is marked by a small brown sign on the east side of Rte. 107. We intend to follow the loop road around the interior of the park, which can be narrow and rough. Drive slowly and try not to straddle large rocks that may damageyour vehicle.

21.2 Bear right onto the tower road.

22.0 Past old Meloon cemetery on the right (in woods). Gabbro is exposed along the far side of Meloon Hill above this area, but we do not have time to explore that far.

22.3 Turn left onto the western part of the loop road.

22.9 Park along right shoulder near and past an old logging road on the right. Walk about 50 m along the road, bearing right into the woods before the hill gets steep. The Middle Mountain quarry (long aban doned) is cut into the hillside and provides good exposures.

STOP 2. Middle Mountain quarry - NEQ Diorite. Mt. Pawtuckaway quadrangle (25 minutes). Hornblende diorite is intruded by fine grained monzodiorite. Details of the petrography of these rocks are found in the field guide of Creasy and Eby (1993). We are near the center of this plug-shaped pluton, which was dated by Foland and Faul (1977) at 124 +/- 2 Ma (biotite K-Ar, corrected to newer constants). The pluton is roughly circular, with outer ring dikes of gabbro and coarse monzonite intruded by central diorite. The granites of some of the other New Hampshire alkaline complexes are not present. This quarry is near the contact between a large central section of diorite and a smaller core zone of fine monzonite (Fig. 6).

Although all units of the Mt. Pawtuckaway complex are crosscut by mafic (lamprophyric) dikes, a mafic magma similar to lamprophyre (camptonite) is also a likely parent to the rock types present in the pluton. The older gabbro and pyroxenite have cumulate characteristics (Creasy and Eby, 1993), while crystal fractionation produced the younger diorite, monzonite, and syenite. Regionally, NEQ dikes are mostly camptonite and less-abundant monchiquite, but some trachyte (rhyolite) dikes occur near plutonic complexes. Dikes of Cretaceous monzonite and diorite are found only within or very close to differentiated plutons like this one.

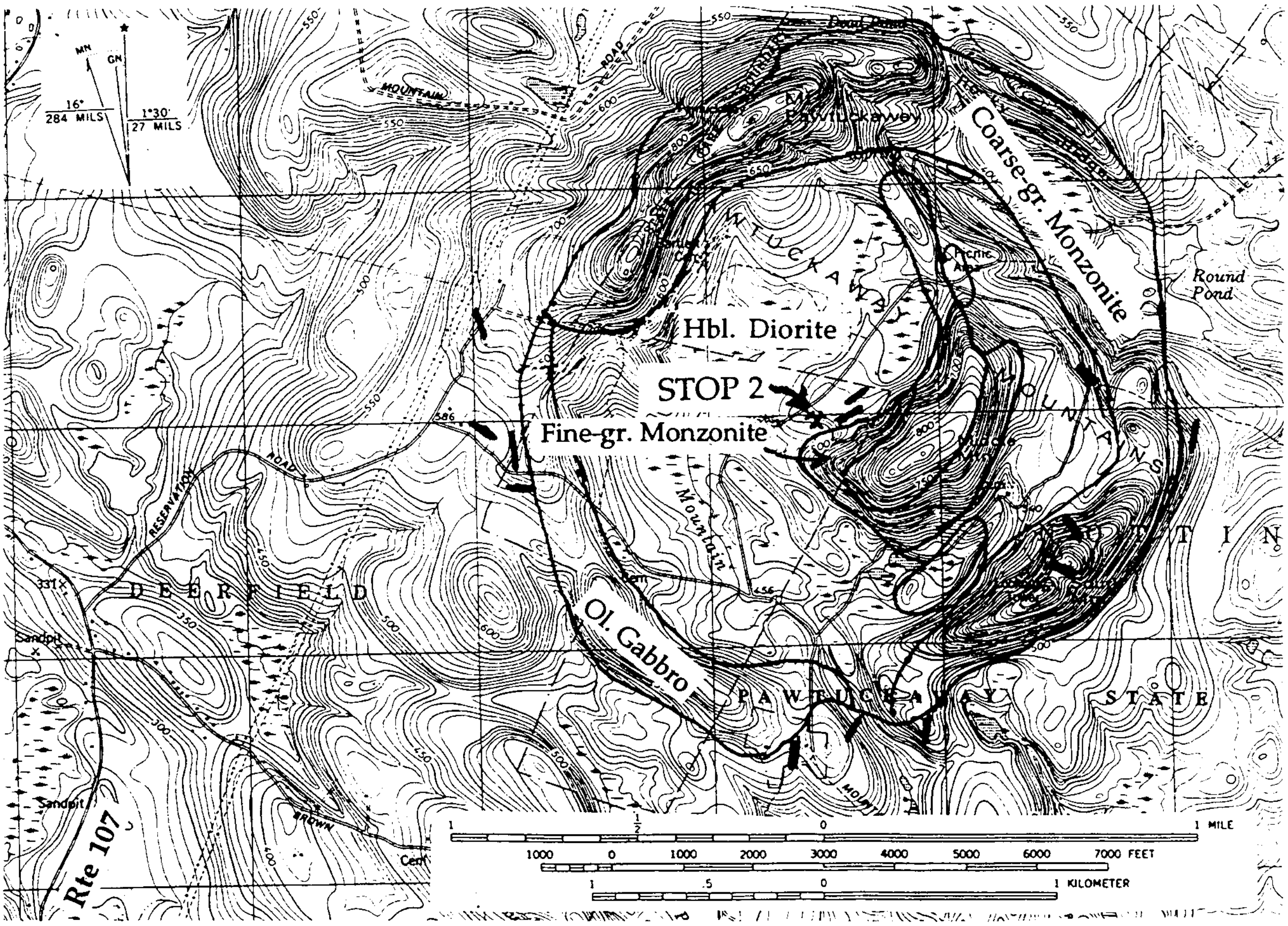

Figure 6. Mt. Pawtuckaway area of Stop 2 (Rte. 107 lower left). Plutonic boundaries loosely adapted from Creasy and Eby (1993). Short, dark line segments represent mafic dikes (Roy and Freedman, 1944).

24.3 Parking area for the fire tower trail up South Mountain. If you are here when there is time to hike, there are good exposures of monzonite on South Mountain, and several mafic dikes (lamprophyres) are present near the fire tower. Continue back along the Reservation Road to Rte 107.

27.6 Turn left (south) onto Rte. 107.

29.0 Outcrops of Massabesic Gneiss with a narrow brown mafic dike, unstudied.

30.7 Turn left (east) onto old Rte 101 (Business 101), combined with 27 and 107.

35.6 To the right (west) take a sharp turn onto the bridge over Lamprey River on Langford Road.

36.4 Sharp left (southeast) onto Onway Lake Road; Onway Lake is to your right.

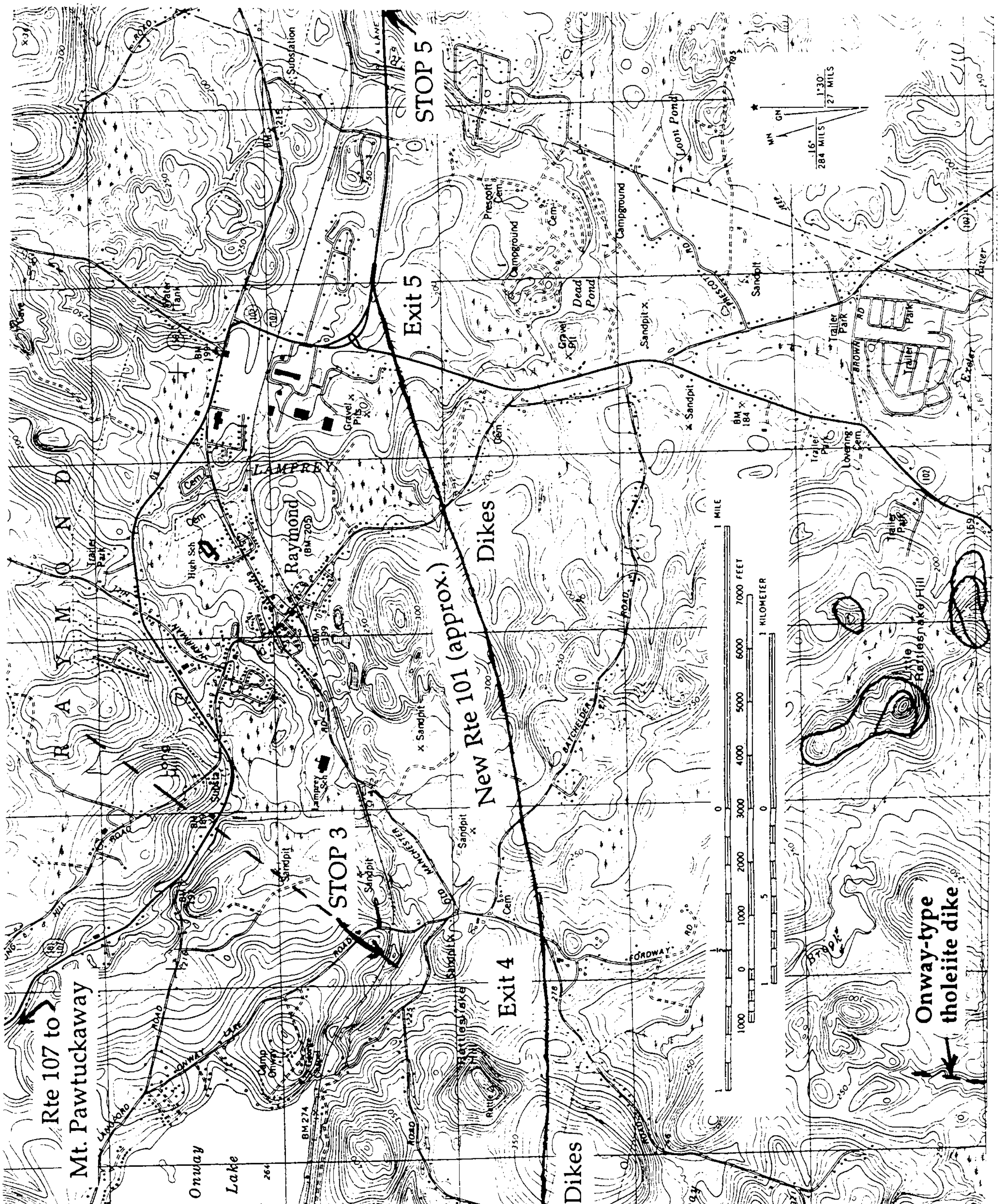

Figure 7. Stops near Raymond, New Hampshire. The Onway dike trend toward Stop 1 is shown as a dashed line.

37.5 Pull into the town park road on the left and park on its shoulder. Cars can also park along the left road shoulder before the overpass over the abandoned Boston and Maine track. Walk down into the RR cut to the right (west).

STOP 3. ENA Tholeiite - The Onway dike. Mt. Pawtuckaway quadrangle (25 minutes). Walk westward along the abandoned railroad bed for about 100 m. Outcrops of dark gray Eliot formation, a quartz biotite schist, hosts the tholeiitic Onway Dike (Dye and others, 1985; Sundeen and Huff, 1992). The dike is massive, bluish-gray, slightly porphyritic, dips steeply to the west, and measures over 30 m thick. Notice the smaller dike SW of the main one in the S side of the cut; we have only seen pegmatite on the opposite side, which exemplifies the abrupt geometric changes possible in these dikes. The main dike is very hard, and the exact contact with the schist is indistinct. Despite the large mass of hot magma, thermal metamorphic effects in the schist appear in thin-section to be minor.

As noted previously, the Onway is the northern part of the Higganum-Holden dike (or, dike system). The dolerite is a high-titanium quartz-normative tholeiite, noted for its phenocrysts of orthopyroxene (usually, hypersthene or bronzite). This is the Initial Pangaean Rift magma of Puffer (1992), which extruded simultaneously from Virginia to Nova Scotia, and in northwestern Africa as well (pre-Atlantic). McHone and others (1995) are studying this same dike material along the coast of Maine. The composition (Table 1) is remarkably uniform everywhere the basalt or dolerite is found. This initial rift basalt is dated elswehere between 195 and 200 Ma, but probably all of theJurassic tholeeiitic basalts of northeastern North America formed during one brief magmatic episode near the beginning of the Jurassic period (Hettangian). We regard the K-Ar age by Sundeen and Huff (1992) of 177 +/-4 to be low from Ar loss, a common problem in dating these basaltic dikes.

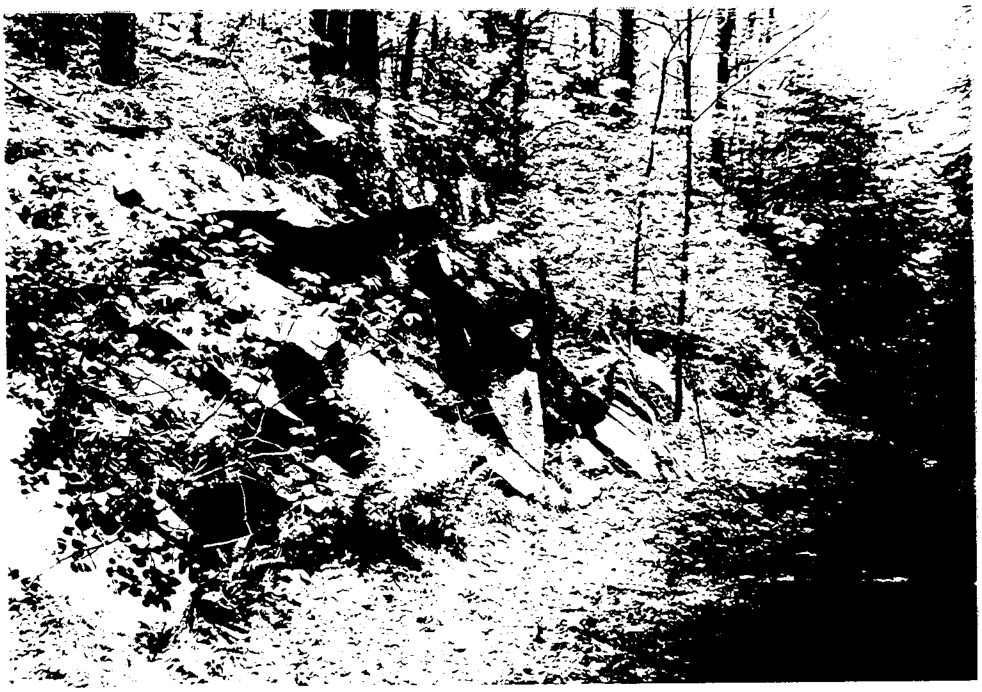

Figure 8. Photograph showing a portion of the 33-m thick Onway Dike, a massive tholeiite exposed in an abandoned railroad cut east of Onway Lake in Raymond (Stop 3). View is to the west.

Although exit 4 of new Rte 101 is down the hill and near to the south (right), we will go back to old Rte. 101 (107) to make our lunch stop. If you are with a small group, an alternate lunch spot is the Long Branch Restaurant in "downtown" Raymond, which you can reach by continuing down the hill and turning left.

39.4 Turn right (east) back onto Old Rte. 101 (and Rte. 107).

39.5 On the left is "The Pines" seafood restaurant, an informal eat in/take out place that is popular with the local people (usually a good sign). We plan to stop here for lunch. Please be ready to leave in 30 minutes or less. Then, continue east on old Rte. 101 (107).

41.6 Turn right (south) toward new Rte. 101.

42.2 Turn onto Rte. 101 West (exit 5 interchange). Unfortunately, the present edition of the Mt. Pawtuckaway quadrangle map does not have new Rte. 101 west from this interchange.

43.2 Past roadcut with a mafic dike, probably a Triassic CNE alkali diabase (not a stop). The dike is rusty brown, very solid; strike N61E, dip 86 SE, 87 cm wide.

Figure 9. Photograph of multiple alkali basalt (camptonite) dikes (dark bands) in 7-m high south-facing vertical exposure of Massabesic Gneiss on NH Route 101, 2.4 miles west of the Raymond-Candia townline in the Candia 7.5' quadrangle (Stop 3; sample 1007 of Sundeen and Huff, 1992). Note: a. change in dip direction (enhanced by superposed parallel black lines), b. rock hammer for scale (arrow).

43.8 Past Exit 4 (near Stop 3).

45.7 Past roadcut with several mafic dikes, most of which appear to be CNE alkali diabases. One diabase resembles the Onway dolerite although it is only 3.5 m wide. The new construction for Rte. 101 has exposed many mafic and several felsic dikes; we believe that all of the Mesozoic magma groups are represented, but most of these dikes have not yet been carefully studied.

49.4 Large roadcut; pull off onto the shoulder about 1/2 way down, near irregular mafic dikes.

43.2 Past roadcut with a mafic dike, probably a Triassic CNE alkali diabase (not a stop). The dike is rusty brown, very solid; strike N61E, dip 86 SE, 87 cm wide.

43.8 Past Exit 4 (near Stop 3).

45.7 Past roadcut with several mafic dikes, most of which appear to be CNE alkali diabases. One diabase resembles the Onway dolerite although it is only 3.5 m wide. The new construction for Rte. 101 has exposed many mafic and several felsic dikes; we believe that all of the Mesozoic magma groups are represented, but most of these dikes have not yet been carefully studied.

STOP 4. NEQ camptonite dike. Candia quadrangle (20 minutes). This is a good example of the Early Cretaceous lamprophyres associated with the Mt. Pawtuckaway and Little Rattlesnake Hill magmas. This is Dike 9 of Hale and Friberg (1995) and Sample 1007 of Sundeen and Huff (1992), with both sources providing a chemical analysis (Table 1). Notice the well developed flow texture and the abundant phenocrysts and megacrysts of kaersutite, an amphibole also found in mantle xenoliths. The irregular form is probably a function of low viscosity, which is due to the high alkali and volatile content as well as low silica. The type camptonite at Campton, New Hampshire shows a thin glassy margin (selvage) much like in this dike. Strike is variable but mainly NNE, and widths of the dike branches vary from zero to 11 cm, and 61 cm.

49.8 Start of ramp to Exit 3; get off here to turn back onto Rte 101 to head back (east). A rather long access road will be encountered, and a U-turn is needed.

50.9 Re-enter Rte. 101 east-bound.

53.4 Mafic dike in cut on south side.

54.3 Series of alkali diabase dikes (CNE?) in the roadcut (not a stop)...same dikes as noted earlier. Sundeen and Huff (1992) report two chemical analyses of dikes from this site (also see Table 1, stop 4/5). They can be traced across the divider, with at least five dikes in a 100 m span varying in thickness from 0.1 to 2.0 meters. The dikes strike parallel to the foliation of the schistose metamorphic host rock (Berwick formation ?). We will visit similar dikes in later stops so we can avoid an extra stop on this busy road.

56.1 Past Exit 4

57.7 Past Exit 5

58.9 Just east of the Lamprey River, pull off onto the shoulder along a large roadcut to the right (south).

STOP 5. NEQ rhyolite dikes. Epping quadrangle (20 minutes). On the south side of the road the outcrop contains two grayish-tan rhyolite dikes. Both nearly parallel the roadcut, providing good lateral exposure. The dikes are about 1 m thick and dip 45 S. Although coarser and more porphyritic (alkali feldspar phenocrysts), the mineralogy and chemistry of these dikes is similar to the Bugsmouth Hill rhyolite described in a later section. We are also not far from the Little Rattlesnake Hill pluton, in which the felsic rocks are mapped as "volcanic" by Freedman (1950).

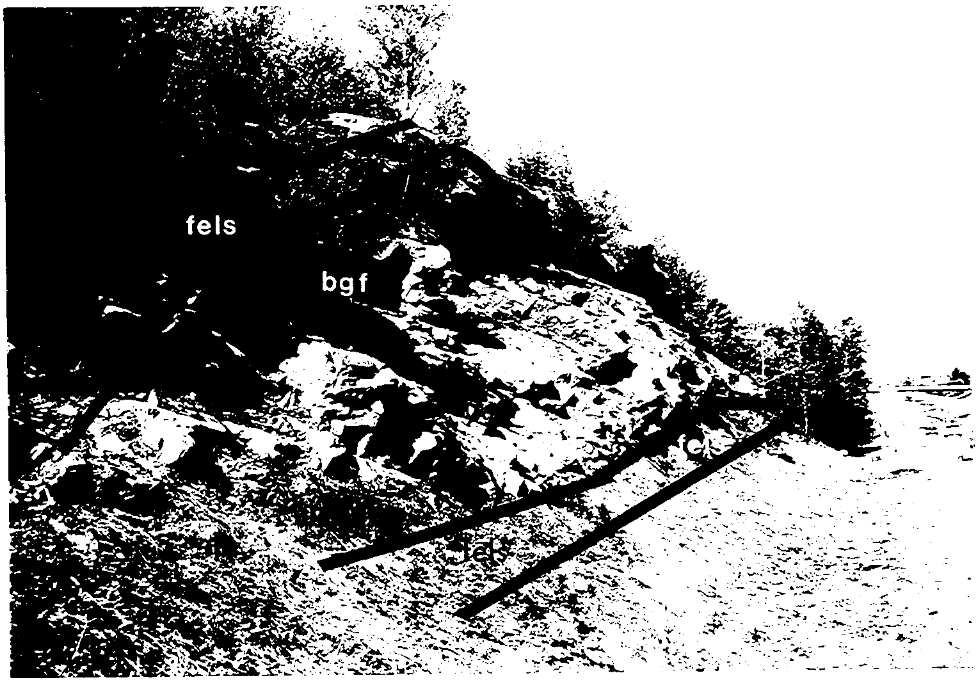

Figure 10. Enhanced photograph of two felsite dikes (fels) in a northfacing outcrop of foliated granite in western Epping on NH Route 101, 1.2 miles east of Exit 5 (Stop 5, location 460, 1004 of Sundeen and Huff, 1992).

Continue eastward on Rte. 101.

60.5 Outcrop on right (south) has an altered mafic (?) dike sub-parallel with the rock face, similar to the rhyolite dikes at Stop 5. New construction immediately ahead will probably remove this cut.

63.6 Past Rte. 125 (Epping exit)

70.4 Pull off onto exit ramp of Rte. 85, which also goes to Exeter (home of Philips Exeter Academy and nameplace of the famous UFO abduction book called "Incident at Exeter"). Park along the shoulder near the road cut on the right (south).

STOP 6. CNE alkali diabase - the Exeter dike. Exeter quadrangle (15 minutes). This is a good place to observe the differences between a mafic dike in a fresh cut versus one in an older, more weathered exposure. There is a CNE-type alkali diabase across the median and this exit cut, although you may have to look carefully to distinquish the dike contacts in the new southern exposure. The same dike in the older road cut to the north is much rustier, and therefore stands out with higher contrast. Our measurement in the northern cut is N46E, 71NW; width 95 cm. Phenocrysts of weathered plagioclase (heavily sericitized; 0.5-2 mm) make up about 25% of the rock, and another 25% is matrix plagioclase, where it looks fresher (zoned subhedral prisms c. An-45-50). The alkaline character of the CNE Exeter dike shows in its matrix, with 15 % lilac-pink augite (0.17-0.2 mm) and 8% slender light-brown prisms of kaersutite. Accessories include trace apatite, 6% Ti-magnetite or ilmenite - some altered to leucoxene - and anhedral clots of pyrite (1%; 0.1-0.3 mm). The rest of the rock is mainly chlorite (some probably replacing olivine) and biotite. Compare this with the Onway tholeiite and the Candia camptonite.

Continue across Rte 85 to return to Rte. 101 east.

71.5 Exit to SR Rte. 108.

If there is time and interest, we would like to include a side-trip south to the little-known Bugsmouth Hill rhyolite body. Otherwise, we will turn north to the last stop on Great Bay. The following are non-logged directions to Bugsmouth Hill (approx. 10 miles each way). The log will continue upon our return with mileage from this same 101-108 interchange.

Proceed south on Rte. 108 through Exeter, past Rtes. 107 and 107A, into Newton. About 1.4 miles past 107A, turn east (left) onto Gale Village Road. Proceed 0.8 miles southeast to a 4-way junction (a divided cross road), and continue through the junction on the unpaved Currierville Road. Proceed about 0.5 miles, park along the road across from woods roads behind some stone walls to your left (east).

Figure 11. Photograph of north-facing exposure of intensely jointed Bugsmouth Hill granophyric rhyolite, located in the southeastern corner of the Haverhill quadrangle (Stop 7, location #104).

The rhyolite is very fine grained, tan in color, and weakly porphyritic with small alkali feldspars. It appears to be uniform over several acres of this hill. The rock is apparently volcanic, but it does not show extrusive structures such as welded glass fragments, vesicles, or flow bands. More likely, it has a hypabyssal form such as a lacolith, perhaps like the Cannon Point bostonite sill at Essex, New York. A good project area for a student to adopt.

OPTIONAL STOP 7. NEQ rhyolite - Bugsmouth Hill. Exeter quadrangle (35 minutes). Walk along woods roads, used by the public for recreation and horseback riding, up the hill to the southeast. Note rhyolite float in the steeper areas. After crossing the top of the hill, there are steep cliffs and talus on the eastern side of he hill, which looks like a quarry but could also be a plucked glacial feature. It is a tricky scramble to get below the cliffs - please stay away from the loose rocks of high areas. Sundeen and Huff (1992) report a K-Ar whole rock date of 118 Ma from this site, which makes Bugsmouth Hill the most southeastern surface member of the NEQ province. Very similar dike or sill rock has been logged in a deep well about 17 km to the south, and also dated as 118 Ma (Simmons and others, 1991). .

Retrace the route back up Rte. 108 to the intersection with Rte. 101.

71.5 Intersection of Rte 108 with Rte. 101. Head north on 108 to Newmarket.

78.7 Cross the good old Lamprey River in Newmarket and turn right onto Bay Road (just past the mills). This road loops towards Great Bay and becomes Durham Point Road

82.6 Right onto Adams Point Road, marked by a gate and mailbox for the Jackson Lab.

83.4 Park in the area to the left, just before the public boat launch.

STOP 8. Adams Point CNE alkali diabase dikes. Newmarket quadrangle(25 minutes). Refer to the geological map of Adams Point by Fargo and Bothner in this guidebook. This point has public trails that make it ideal for student mapping exercises. Several dikes are exposed along the shore to the southeast of this parking lot, including a very large dike that Bothner shows to be offset in a right-lateral sense along a NW fault. The shoreline dikes are most accessible when the tide is not high.

Figure 12. Weathered plagioclase phenocrysts in alkali diabase dike, Adams Point, Durham, STOP #8.

Four rusty-brown dikes stand out of the argillitic country rocks within 100 m of the boat launch, with northeasterly strikes and widths of a few cm to a meter or so. As far as we know, they are all good examples of CNE alkali diabase dikes, with plagioclase phenocrysts and minor brown amphiboles, as well as pinkish augite. As is common in CNE dikes, the feldspar is variably altered to clay minerals. The dike below the boat launch is N32E, 80 NW, 108 cm wide, but you will notice variable orientations among these examples. Our attention is drawn to the very large dike about 150 m from the parking area, which shows at least 5 or 6 internal chill zones (a multiple intrusion) over its 23 m width. The dike contact is about N56E, 76 NW but at least one internal contact is closer to N23E. The plagioclase phenocrysts that mark this (and other) CNE dikes weather to off-white but are dark on fresh surfaces. It might be possible to trace this large dike by magnetometer, but exposures are absent for long distances outside of Adams Point. Sundeen and Huff (1992) describe several wide (to 30.5 m) alkali diabase dikes to the southwest (Derry quadrangle).

Return along Adams Point Road to Durham Point Road and turn right (northwest).

89.0 Turn right (north) on Rte. 108 toward Durham.

89.5 Intersect Rte. 155A in Durham (also Old Rte. 4 and Main Street). Turn left, follow jogs to the west to return to Lot A.

END OF TRIP

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