Chapter N

Ring Dikes and Plutons: A Deeper View of Calderas as Illustrated by the White Mountain Igneous Province, New Hampshire

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RING DIKES AND PLUTONS: A DEEPER VIEW OF CALDERAS AS ILLUSTRATED BY THE WHITE MOUNTAIN IGNEOUS PROVINCE, NEW HAMPSHIRE

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THE WHITE MOUNTAIN IGNEOUS PROVINCE

The White Mountain igneous province (magma series of Billings, 1934) consists of plutons, ring complexes, and volcanics emplaced along a NNW trend across New England (Figure 1). Four petrographic associations are recognized (Creasy, 1974; Eby, 1987): (1) alkali syenite-quartz syenite-granite; (2) subaluminous biotite granite; (3) gabbro-diorite-monzonite and; (4) syenite-nepheline syenite. The igneous activity is largely confined to two periods, 200-165 Ma and 130-110 Ma (Eby and others, 1992). These two major periods of igneous activity are related by McHone and Butler (1984) to the opening of the North Atlantic Ocean. The reader is referred to Eby (1987) for an overview of the White Mountain igneous province.

The older White Mountain igneous province is dominated by silica-oversaturated subaluminous to peralkaline rocks of association 1, including the White Mountain batholith. Two minor nepheline-bearing intrusions occur at Red Hill, New Hampshire, and Rattlesnake Mountain, Maine. These two occurrences together with nepheline-bearing intrusions of the younger White Mountain province define a narrow zone that strikes at high angle to the NNW trend of the overall province (Figure 1; Creasy, 1989). To the north of this zone are found the large composite plutons and batholith of the older province; to the south only a few small scattered plutons of this age are present. In contrast, nearly all plutons of the younger White Mountain province are found to the south of this zone.

The Monteregian Hills and younger White Mountain igneous provinces represent the last period of igneous activity in New England (130-100 Ma). The bulk of the magmatism occurred *ca.* 125 Ma, but younger ages have been obtained for Little Rattlesnake (114 Ma, Foland and Faul, 1977) and Cuttingsville (100 Ma, Armstrong and Stump, 1971). Plutons emplaced to the west of Logan's line consist largely of mafic alkaline suites, many of which are nepheline normative. To the east of Logan's line, felsic rocks are much more important components of the intrusions and silica-undersaturated rocks are not found. Some of these younger plutons show ring-like structures (Ossipee and Pawtuckaway) while others appear to be small plugs (e.g. Little Rattlesnake, Ascutney, and Tripyramid). In most cases the most evolved rocks are syenites and quartz syenites, but biotite granites are found at Ossipee and Merrymeeting Lake.

This field excursion illustrates two contrasting examples of the White Mountain igneous province. Day 1 and Day 2 are devoted to the **White Mountain batholith** [associations 1 and 2 above] which comprises about 50% of the total areal extent of the older White Mountain igneous province. The **Mount Pawtuckaway** ring dike complex [association 3 above] of the younger White Mountain igneous province is the subject of Day 3.

THE WHITE MOUNTAIN BATHOLITH

INTRODUCTION

The White Mountain batholith (Figure 2; see also Hatch and Moench, 1984) is a composite of several overlapping centers of felsic magmatism. Individual centers are strikingly defined by composite ring dikes of porphyritic quartz syenite. Thick sections of rhyolitic crystal tuffs, breccias, and subvolcanic granite porphyry are partially circumscribed by the ring dikes. A mosaic of subalkaline to peralkaline silica-oversaturated plutons intrude these centers and provide areal continuity to the batholith. Distribution of porphyritic, miarolitic, and aplitic textures indicate that the roofs of several plutons are partially intact.

The geology of the White Mountain batholith is described by Billings (1928), Billings and Williams (1935), Creasy (1974), Davie (1975), Eby and others (1992), Fitzgerald (1986), Henderson and others (1977), Moke (1946), Osberg and others (1978), Parnell (1975), Smith and others (1939), Wilson (1969) and, Wood (1975). Granites, quartz syenites, and syenites account for about 97% of the 1,000 km^2 area of the batholith; volcanic rocks of similar composition account for the remainder. Pink, medium-grained subalkaline biotite granite (the Conway Granite) and a green, medium-grained subalkaline to peralkaline amphibole granite (the Mount Osceola Granite) comprise 80% of the batholith. Medium-grained sub-alkaline to peralkaline amphibole syenites and quartz syenites are widely distributed and are similar in occurrence, texture, and mineralogy to the Mt. Osceola. Distinctive porphyritic quartz syenite occurs in ring dikes in the western (the Mount Garfield) and the eastern (the Albany) halves of the batholith. Fine-grained syenite occurs in isolated outcrops spatially associated with the ring dikes.

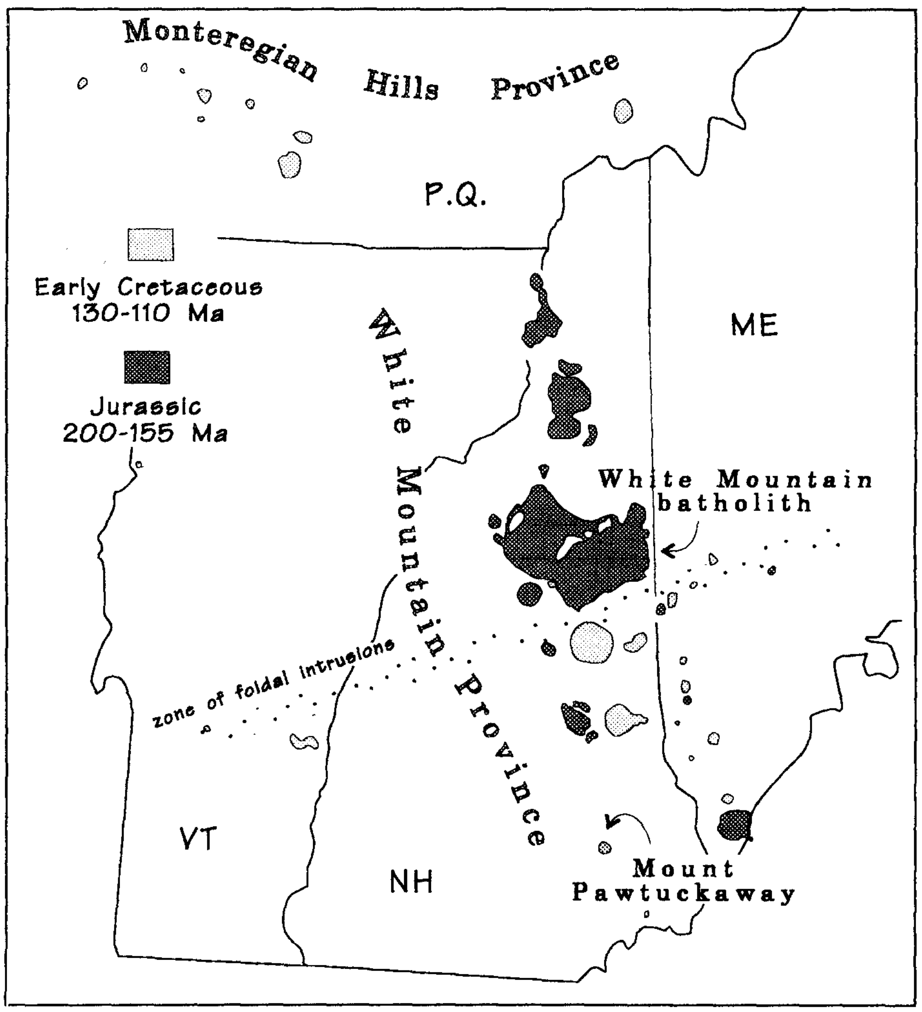

Figure 1. The White Mountain igneous province showing the location of the White Mountain batholith and Mount Pawtuckaway.

Volcanic rocks (the Moat Volcanics), chiefly trachyte, tuff, breccia, and alkali rhyolite and comendite, are found in the eastern portion of the batholith. Only minor occurrences of such lithologies are present within the ring dikes of the western batholith. Several units of granite porphyry (grouped as the Mount Lafayette unit) occurring in the western batholith differ little in texture or mineralogy from the comendites of the eastern batholith. We show these rocks as volcanics (Figure 2) although definitive volcanic textures are generally

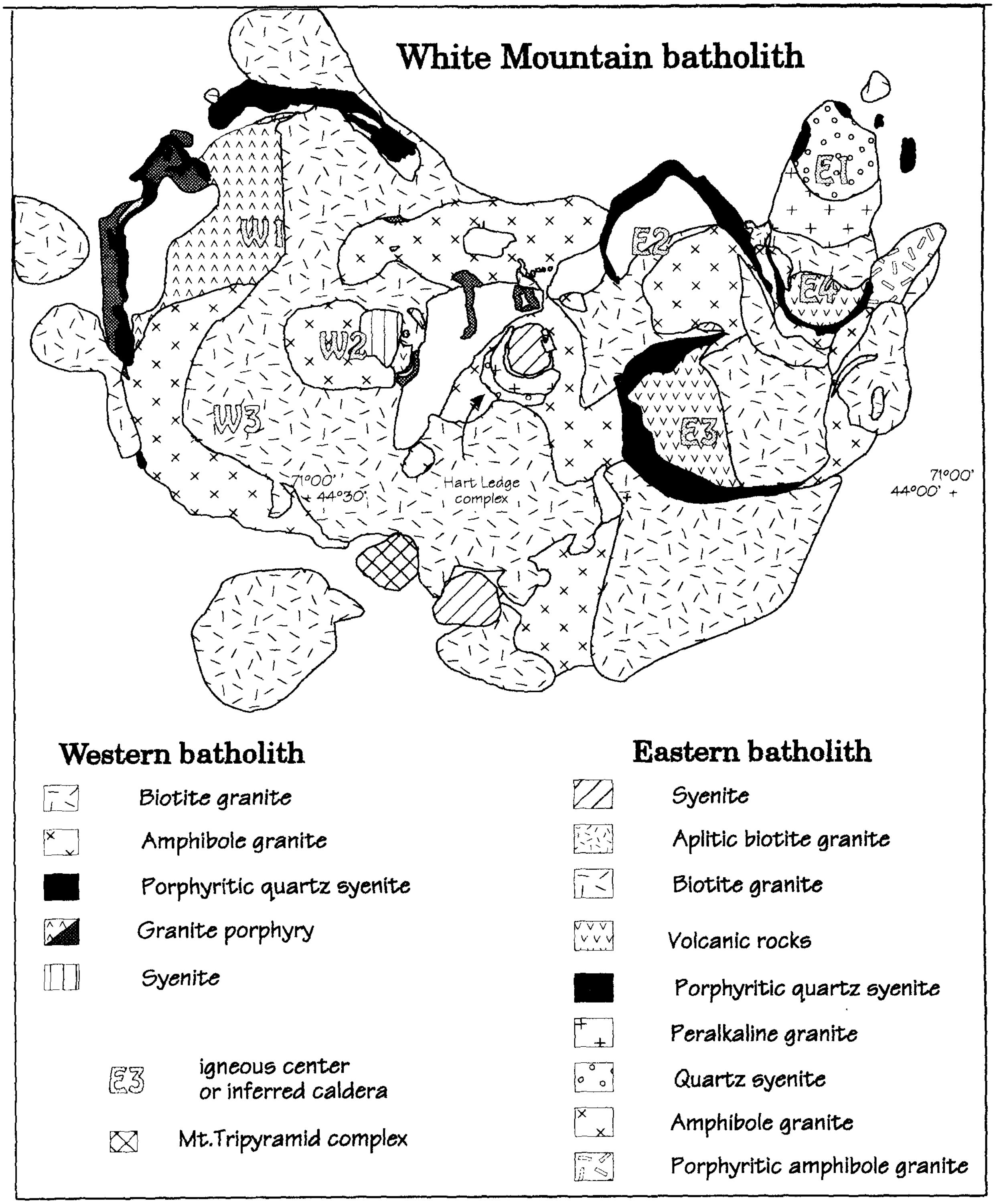

Figure 2. Geologic map of the White Mountain batholith (modified from Creasy, 1974; Osberg and others, 1976).

lacking. Historically, the granite porphyry is treated as intrusive and not included within the Moat Volcanics (Williams and Billings, 1935; Eby and others, 1992).

Gabbro, diorite, and monzonite are present in the Mt. Tripyramid complex (Figure 2), a member of the younger White Mountain igneous province, that is spatially associated with the White Mountain batholith.

EMPLACEMENT OF THE WHITE MOUNTAIN BATHOLITH

Emplacement of the batholith occurred in middle and late Jurassic time, 201-155 Ma (Eby and others, 1992). The western half of the White Mountain batholith, exposed in the Franconia and Crawford Notch 15' quadrangles, contains three igneous centers (W1-3, Figure 2), the largest of which is 20 km in diameter. Igneous activity commenced in the western batholith with emplacement of the porphyritic quartz syenite (201 Ma and 193 Ma) and the quartz porphyry (195 Ma) of center W1 and the syenite and trachyte of center W2 (193 Ma). Subsequent intrusions of amphibole granite (187 Ma) [possible W3 (?)] and biotite granite (181 Ma) were widespread across the entire area of the batholith. Intrusion of peralkaline granite (177 Ma) in the eastern part of the pluton is considered an extension of the amphibole granite (Mount Osceola) event.

The eastern portion of the White Mountain batholith, exposed in the North Conway and Crawford Notch 15' quadrangles, has at least four magmatic centers (Figure 3). Two centers with thick pyroclastic successions are interpreted as calderas (Noble and Billings, 1967; Fitzgerald, 1987; Fitzgerald and Creasy, 1988). Other centers where ring dikes or crescent-shaped intrusions are associated with epizonal plutons define more deeply eroded calderas. Caldera development here post-dates similar events in the western batholith by about 10-20 Ma. Dated units include the ring dike of center E2 (179 Ma); the Moat Mtn volcanic sequence (173-168 Ma) and ring dike (170 Ma) of center E3; and plutons of biotite granite (171 Ma and 155 Ma). We interpret the White Mountain batholith as a sub-horizontal slice through a caldera field cut about 1.5 km thick and 1-2 km below the original landsurface. This excursion illustrates the field characteristics and structural relations of plutons, ring dikes, and volcanics that constitute the eastern half of the White Mountain batholith (Figure 3).

PLUTONS

Rocks forming plutons within the White Mountain batholith (Figures 2 and 3) are divided into two groups: (1) amphibole-bearing granites, quartz syenites and syenites and; (2) biotite granites.

Amphibole-bearing Granites, Quartz Syenites, and Syenites

Mount Osceola Granite. The Mt. Osceola Granite, a green amphibole ± biotite granite, is the *oldest* member of the White Mountain magma series exposed in the North Conway quadrangle (Osberg and others, 1978; Eby and others, 1992). The number and original extent of plutons of the Mt. Osceola Granite within the North Conway quadrangle is not fully certain due to the complexity and abundance of younger rocks. A whole-rock Rb-Sr isochron for samples from both eastern and western portions of the batholith yields an age of 186 m.y. (Eby and others, 1992) and indicates synchronous intrusion over a broad area . [This age places the Mt. Osceola as the *youngest* member associated with the large magmatic center that forms the western portion of the batholith.]

The Mt. Osceola Granite is a medium- to coarse-grained hypersolvus granite that is dark green where fresh. It consists of an interlocking network of anhedral to subhedral microperthite 3-10 mm in diameter enclosing rounded grains of smokey quartz. Ferrohastingsite and locally annite are interstitial, late crystallized minerals. Fayalite (Fa_{95-99}, Creasy, 1974) and sodic ferrohedenbergite (typical analysis $Na_3Ca_{40}Fe_{56}Mg_1$) are frequently present in accessory amounts and encased by reaction rims of ferrohastingsite. Characteristic accessories include allanite, sphene, zircon, fluorite, ilmenite, and monazite. Locally the Mt. Osceola is weakly peralkaline with ferrorichterite or riebeckite rimming ferrohastingsite. Miarolitic cavities may be locally abundant (one percent of outcrop area) and large (six to eight square centimeters). Pegmatite pods five to twenty centimeters across are

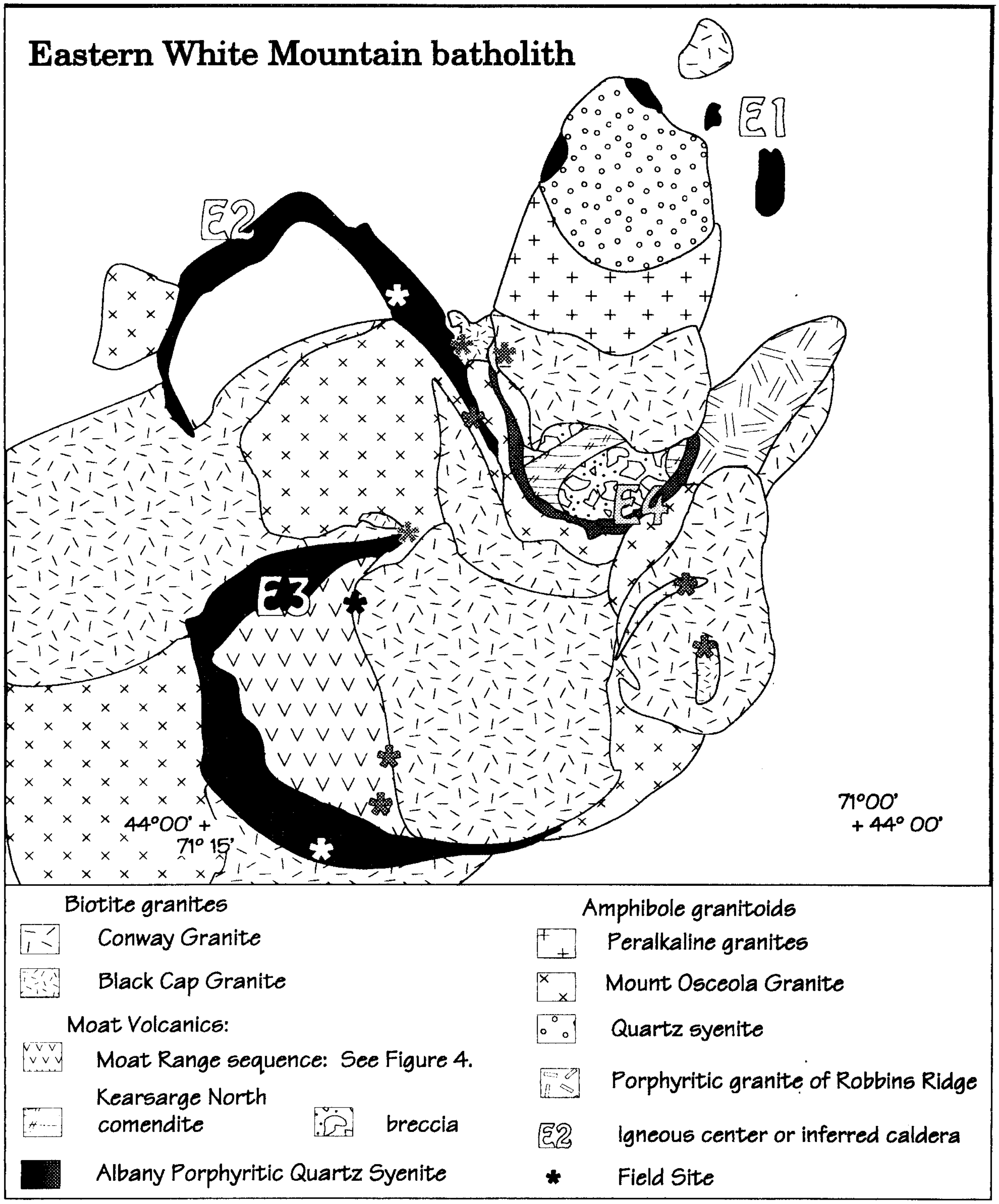

Figure 3. Geologic map of the eastern half of the White Mountain batholith (Billings, 1928, modified by Osberg and others, 1978, Creasy, 1986).

abundant in many exposures of the Mt. Osceola Granite, locally forming up to two to three percent of the outcrop. Aplite dikes, quartz veins, and fractures are abundant in all large exposures of the Mt. Osceola Granite. The aplitic dikes rarely exceed ten centimeters in width although they may be traced continuously for a hundred meters. Veins of quartz range from two to five centimeters in width and commonly have open cores into which project well-formed crystals of quartz.

Protracted crystallization of feldspar progressively depleted the melt in Al and Ca and progressively enriched the melt in volatiles. Temperatures, total pressure, and water contents necessary for the stabilization of hydrous mafic phases were obtained after about 90% solidification. Compositions of interstitial amphiboles range from Al-poor ferrohastingsite → ferrorichterite → riebeckite. The occurrence of several amphiboles within samples deemed in hand specimen to be Mt. Osceola Granite suggest that the degree of fractionation of the crystallizing magma was locally variable. A fluid phase of sufficient volume to produce deuteric alteration and form pegmatitic pods was present during the final stages of crystallization.

Peralkaline Granite. Riebeckite-arfvedsonite granite forms an arcuate dike and small pluton intruding the Conway Granite of the Green Hills pluton. Peralkaline granites also form larger areas of outcrop in the eastern (e.g. on North Doublehead, Parnell, 1975) and central (e.g. Hart Ledge area, Henderson and others, 1977) batholith that appear to be young plutons spatially and genetically associated with Mt. Osceola Granite. Contacts between the peralkaline granites and the Mount Osceola are commonly gradational.

The peralkaline granites are composed of subhedral grains of white microperthite (5-10 mm) and clear quartz (2-6 mm), blocky interstitial grains of riebeckite-arfvedsonite (<10 mm), and flakes and aggregates of interstitial biotite. Characteristic of this rock are abundant radiating arrays of golden colored astrophyllite. Fluorite, ilmenite, sphene, and apatite are common accessory minerals. Near contacts, miarolitic pods and cavities are developed on a cm-scale; here prismatic riebeckite crystals are found up to 5 cm in length. One small body within the Hart Ledge complex (Wood, 1975) contains ferrorichterite (7%) in place of riebeckite-arfvedsonite; fayalite and ferrohedenbergite are accessories.

Alkali feldspar Quartz Syenite. Quartz syenite forms a small pluton within magmatic center E1 (Figure 2) and two arcuate bodies associated with the Hart Ledge complex of the central batholith (Figure 2; Henderson and others, 1977). The Hart Ledge complex is the youngest igneous activity in the central portion of the batholith, 169-162 Ma (Eby and others, 1992).

The quartz syenite is composed of tabular subhedral crystals of microperthite (1-4 mm) Anhedral quartz (< 2 mm) is interstitial to and never included within these crystals of microperthite. Rounded grains of sodic ferrohedenbergite averaging 0.5 mm are present in all specimens though in variable amounts; commonly, these grains are enclosed within the microperthite. Ferrorichterite, the most abundant mafic mineral, forms interstitial grains and reaction rims on sodic ferrohedenbergite. That a vapor phase may have formed is suggested by the occurrence of riebeckite. Riebeckite forms very thin rims on ferrorichterite, coats fractures within the ferrorichterite and penetrates pyroxene within. Further, tufts of acicular needles of riebeckite grown on a substrate of ferrorichterite project into grains of quartz. These needles commonly less than one micron in diameter seems to dictate growth from a vapor phase. Ilmenite, allanite, zircon, and sphene are common accessories.

Alkali-feldspar Syenite. Syenite is an uncommon plutonic member of the White Mountain magma series; only two are described from the White Mountain batholith. The syenite occurring in the central portion of the batholith (Figure 2; Wood, 1977; Henderson and others, 1977)) is part of the Hart Ledge complex. The syenite is a coarse rock, dark green where fresh; blocky microperthite and ferrohastingsite (about 10%) account for ninety-five percent of the hand specimen; fayalite and ferrohedenbergite are minor accessories. The syenite contains miarolitic pods of coarse prismatic ferrohastingsite and irregularly-shaped quartz.

The syenite is of interest because of the spatial and genetic relationship to the widespread Mt. Osceola Granite and to the peralkaline granites and quartz syenite. Significantly, REE data for the Hart Ledge complex (Creasy and others, 1979; Eby and others, 1992) show a positive europium anomaly for the syenite, but substantial negative anomalies for the quartz syenites and peralkaline granites. The syenite may represent the cumulus feldspar and the peralkaline granites may represent residual liquids derived from the crystallization of a Mount Osceola-type parental magma. No other analyzed rocks from the batholith show negative Europium anomalies.

The variation in composition of these amphiboles, consistent with principles of crystal fractionation, suggests the riebeckite granite is more strongly fractionated than the other two units. The Mt. Osceola Granite, the quartz syenite of Mt. Tremont, and the riebeckite granite, respectively, were derived from the same or similar magmas that had undergone increasingly greater degrees of crystal fractionation. The apparent variation in degree of fractionation may reflect the sequential evolution of a single parent magma or may result from the exposure, at current levels of erosion, similar magmas that had fractionated to differing degrees.

Biotite Granites

Conway Granite. This pink sub-aluminous biotite granite is the most extensive unit in the North Conway quadrangle. Billings (1928) showed the Conway Granite as a single irregularly shaped pluton and as the youngest of the White Mountain magma series. More detailed mapping (Osberg and others, 1978) has recognized several distinct plutons of biotite granite on the basis of texture and outcrop geometry (Figure 3). Absolute ages for plutons in the North Conway quadrangle are within the range of 183-155 Ma (Eby and others, 1992). Field relations suggest that emplacement of these plutons was not synchronous across the quadrangle but related to individual magmatic centers. The Birch Hill pluton (Osberg and others, 1978) is the largest pluton. The Conway Granite of this pluton becomes finer grained, porphyritic, and miarolitic where it intrudes the Moat Volcanics. The Gardiner Brook pluton (Osberg and others, 1978) intrudes Moat Volcanics on Mount Kearsarge and is associated with the magmatic center defined by ring IV (Figure 3). The Conway Granite of this pluton shatters Silurian metasedimentary rocks (Hatch and others, 1984) along the East Branch of the Saco River. A third pluton underlies most the Green Hills, the prominent north-south oriented ridge forming the east side of Mt. Washington Valley; this pluton is well exposed on Black Cap mountain.

The Conway Granite is a medium- to coarse-grained pink biotite two-feldspar granite. Values of microperthite:oligoclase range from 2:1 to 10:1 and average 4-5:1 (Creasy, 1974). Annite (Ann_{90}) forms anhedral interstitial grains up to 5 mm in size. In contrast with other members of the White Mountain magma series, fayalite and ferrohedenbergite are absent. Subordinate amphibole is present in some samples. Zircon, allanite, apatite, sphene, and fluorite are common accessories. Near intrusive contacts, the Conway Granite shows a variety of textures that may grade into each other on the outcrop scale: porphyritic, aplitic, miarolitic, and pegmatitic. Miarolitic cavities are typically of mm-scale and bounded by euhedral crystals of quartz and feldspar. A zone of miarolitic cavities ranging up to several meters is present within the Conway Granite adjacent to the Moat volcanics on the east side of the Moat Range. This and similar occurrences of miarolitic cavities in the eastern batholith have produced many beautiful smokey quartz crystals. Weakly developed banding on the cm- to dm-scale resulting from variations in grain size and/or mineral concentrations is developed near some contacts. Lithic fragments of any type are sparse in the Conway Granite.

Black Cap Granite. The Black Cap Granite (Billings, 1928) is a fine-grained pink aplitic biotite granite that outcrops in two small areas in the North Conway quadrangle. It is composed of quartz, microperthite, subordinate oligoclase, and chloritized biotite. Accessories include zircon, magnetite, apatite, and fluorite. The Black Cap Granite is shattered and intruded by the Conway Granite (Green Hills pluton) on the flanks of Black Cap. Billings considered this rock an early lithologically distinct 'phase' of the Conway Granite. Osberg and others (1978) suggest that the Black Cap granite to be coeval with and a roof facies of the Conway Granite.

Table 1. Modes from the eastern portion of the White Mountain batholith (Billings, 1928; Osberg and others, 1978; and Davie, 1975).

Stop No.	#1a	#1b	#2a	#2b	#2c
Quartz	35	22	10	16	20
Alkali feldspar	49	72	79	70	68
Plagioclase	14	3	0	0	0
Biotite	2	tr	1	0	tr
Amphibole	0	1	8	9	
Ferrohedenbergite	0	tr	8	2	1
Fayalite	0	2	1	tr	tr
Accessories	tr	tr	3	3	3

Stop No.	#5	#6	#7	#8	#9
Quartz	13	29	33	39	28
Alkali feldspar	74	48	49	54	47
Plagioclase	0	17	16	0	18
Biotite	1	6	2	1	7
Amphibole	12	0	0	5	0
Ferrohedenbergite	0	0	0	0	0
Fayalite	0	0	0	0	0
Accessories	tr	tr	tr	1	1

1a Conway Granite, Birch Hill pluton, Hurricane Mtn Road.
1b Mt. Osceola Granite, Rattlesnake Mtn, Redstone area.
2a,b,c Albany Porphyritic Quartz Syenite, three distinct types present within ring dike E3, Little Attitash Mtn.
5 Albany Porphyritic Quartz Syenite, Jackson Falls.
6 Black Cap Granite, Thorn Mtn.
7 Conway Granite, Gardiner Brook pluton, Burnt Knoll Brook.
8 riebeckite granite, North Doublehead.
9 Conway Granite, Green Hills pluton, Black Cap mountain.

RING DIKES

Ring dikes of the eastern White Mountain batholith consist of porphyritic quartz syenite and subordinate porphyritic syenite. The porphyritic quartz syenite is similar in appearance across the batholith but occurrences in the eastern and western parts of the batholith are distinguished as the Albany and the Mount Garfield, respectively. Ring dikes define at least four magmatic centers in the eastern batholith (Figure 3). Ring dikes of centers E2 and E3 yield Rb/Sr ages of 179 and 170 Ma, respectively (Eby and others, 1992). These ring dikes are outwardly dipping at 40°- 80° with well developed chill margins adjacent to older rocks. The ring dikes are not seen to cut each other but relationships to other units indicate their emplacement was not simultaneous. Although similar in mineralogy, the ring dikes of different centers are distinctive in mineral chemistry and in texture.

In fine structure individual ring dikes are themselves multiple intrusions. For example, at least four separate intrusions of porphyritic quartz syenite and syenite occur in ring E3 (Table 1; Figure 3). The increasing abundance of feldspar phenocrysts and of total quartz content with decreasing age suggests (Davie, 1975) successive differentiates of a subjacent magma body. Inclusions present in ring E2 document a similar structural relationship.

Albany Porphyritic Quartz Syenite

The Albany Porphyritic Quartz Syenite contains phenocrysts of microperthite (5-10 mm) and subordinate quartz (2-4 mm); minor phenocryst phases include ferrohedenbergite ($Ca_{45}Fe_{45-40}Mg_{10-15}$), fayalite ($Fa_{90-94}$) and ilmenite (Creasy, 1974). Variation of total phenocryst abundance (10-60%) and phenocrystic feldspar:quartz (5-10:1) is noted both within a ring dike (e.g. #2a, b, c of Table 1; Davie, 1975) and among different ring dikes. Quartz phenocrysts are subangular in chilled border zones but are rounded with seriate margins in coarser varieties.

The groundmass is uniform in grain size (<2-3 mm) within an intrusion (except near contacts) but shows variation among different intrusions. Minerals of the groundmass are anhedral quartz, alkali feldspar, subordinate oligoclase, and minor ferrohastingsite and annite. Ferrohastingsite occurs as anhedral interstitial grains and as rims on the ferrohedenbergite and fayalite. In both occurrences it may poikilitically enclose small quartz grains. Grunerite is found as reaction rims on fayalite and is surrounded by ferrohastingsite. Accessories include allanite, sphene, zircon, and fluorite. Secondary sericite, biotite and chlorite are commonly present.

The mineralogic transition from the anhydrous phenocryst (intratelluric) assemblage to the hydrous groundmass (emplacement) assemblage is written as a simplified end-member reaction (Creasy, 1974):

$$Fe_2SiO_4 + 2CaFeSi_2O_6 + FeTiO_3 + [NaAlSi_3O_8 + H_2O] \rightarrow NaCa_2Fe^{2+}Fe^{3+}Si_6(Al,Ti)_2O_{22}(OH)_2 + [2SiO_2]$$

fayalite + 2 ferrohedenbergite + ilmenite + albite = ferrohastingsite + quartz,

where [ ] indicates probable melt components. The stabilization of the hydrous phase, ferrohastingsite, relative to fayalite and ferrohedenbergite requires a reduction in temperature or a combined reduction in temperature and total pressure. The textural and physicochemical changes coincide with emplacement of the ring dikes.

Porphyritic Syenite.

The porphyritic syenite is the oldest and least evolved lithology present within ring dikes. In contrast to the porphyritic quartz syenite, total phenocryst abundance is commonly less than fifteen percent, reaction rims of ferrohastingsite are minor or lacking, and alkali feldspar lacks exsolution textures. A two-pyroxene assemblage proxies for the ferrohedenbergite typical of the Albany:

inverted ferropigeonite ($Ca_8Fe_{70-82}Mg_{22}$) + *ferroaugite* ($Ca_{40-37}Fe_{48-48}Mg_{25-18}$) $\rightarrow$
[porphyritic syenite]

ferrohedenbergite + fayalite + quartz.
[porphyritic quartz syenite]

This reaction marks the boundary of the pyroxene 'forbidden zone' and bulk grain compositions cited above yield T = 825°C (Lindsley, 1983). Compositions of orthopyroxene host and ferroaugite lamellae of the inverted ferropigeonite give temperatures of about 700-750°C.

VOLCANIC ROCKS

The Moat Volcanics (Billings, 1928) are exposed in the Moat Range to the west of North Conway (E3, Figure 3; Figure 4); a second major occurrence is on Kearsarge North (E4, Figure 3). The Moat Range sequence shows pronounced and laterally persistent layering (Billings, 1928; Noble and Billings, 1967) striking northwest and dipping 30°-40° to the northeast. Billings (1928) interpreted these exposures as an originally flat-lying sequence that subsided and rotated along a ring fracture (now the ring dike). Noble and Billings (1967) suggest syn- or post-subsidence accumulation of the sequence within a caldera. An intra-caldera setting is supported by the detailed mapping of Fitzgerald (1987; Figure 4). The original extent of the volcanics outside the caldera is a major question. The isotopic systematics (Eby and others, 1992) indicate that fractional crystallization of quartz syenitic magma with minor amounts of crustal contamination can produce the comendites of the Moat Range sequence.

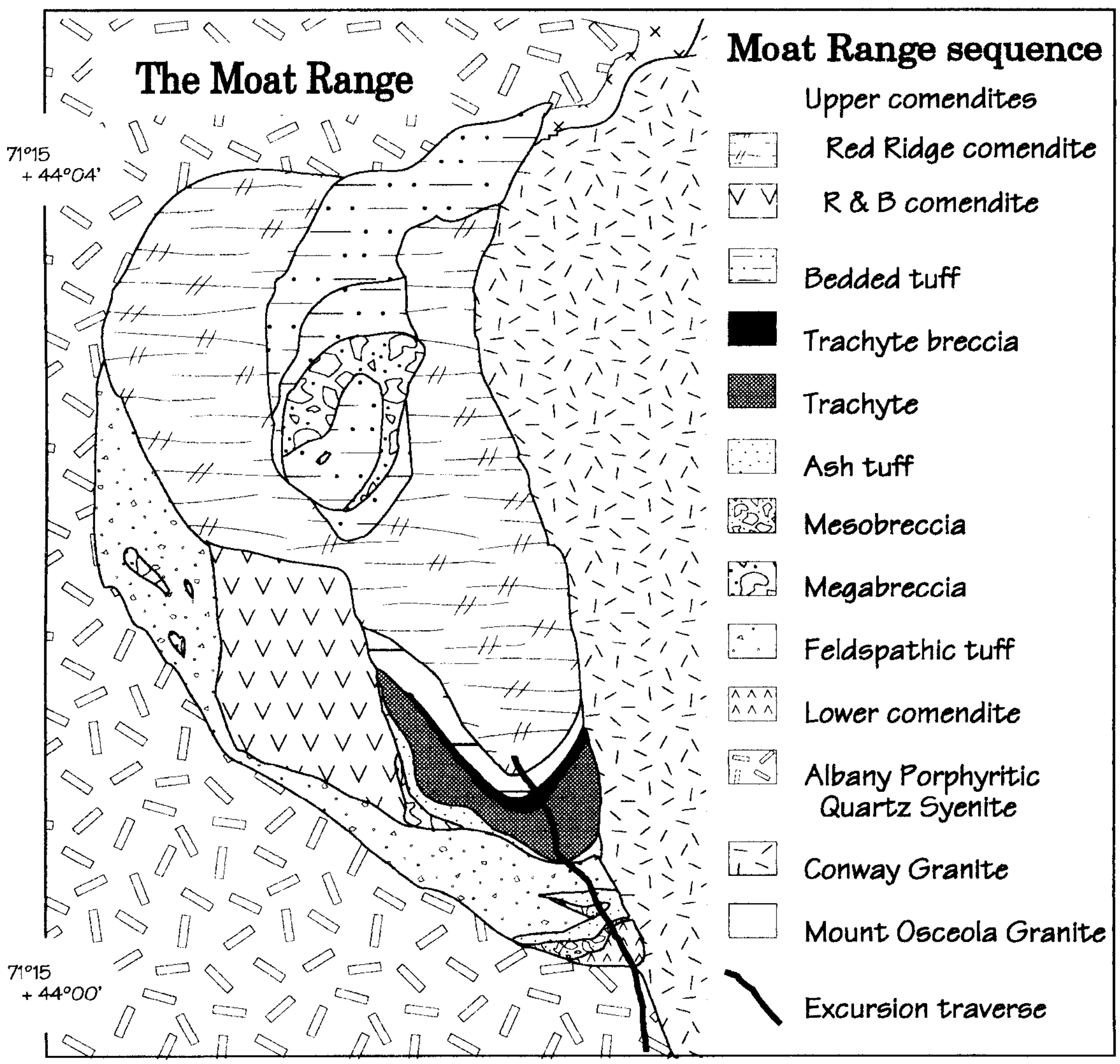

Figure 4. Geologic map of the Moat Range (Billings, 1928; Fitzgerald, 1987).

Five crystal-rich units dominate the 3.6 km of volcanic stratigraphy of the southern Moat Range (Fitzgerald and Creasy, 1988; Figure 4). These are (base to top): lower comendite (380 m), feldspathic welded tuff (425 m), the R & B comendite (1070 m), trachyte and trachyte breccia (300 m), and Red Ridge comendite (>1050 m).

The lower comendite contains interbeds of polymict lapilli tuff and breccia that are thickest and coarsest adjacent to the enclosing ring dike. Internal structures (fiamme, oriented lithic clasts) developed within the lower two units but are lacking in the upper comendites. Several thin but persistent horizons of bedded ash tuff, lapilli tuff, and mesobreccia and megabreccia lie above and below the trachyte. Bedding generally parallels the surrounding ring dike (E3) and dips radially inward at 20°-40°.

The northern Moat Range is dominated by the upper comendite units which are generally homogeneous but show variation of abundance and proportion of phenocrysts and lithic fragments. Bedded tuffs here are quite similar to the comendites but exhibit bedding (averaging 2 m), eutaxitic textures, and are more lithic-rich. A section of chaotic megabreccia (60 m thick, clasts up to 4 m) within the bedded tuffs is interpreted as a lahar or debris flow (Fitzgerald, 1987). A polymict clast-supported mesobreccia is present on the summit of North Moat Mtn (3196'), highest point of the Moat Range.

Kearsarge North (E4, Figure 3) exposes a mix of comendite, feldspathic tuff, and meso- and megabreccias (Billings, 1928) similar to those found on North Moat. The comendites lie topographically below the more extensive breccias and are lithic-rich. As in the Moat Range sequence, the breccias on Kearsarge North are polymict (although in any horizon one or another clast lithology may predominate) and the matrix:clast ratio varies greatly.

The comendites are blue-gray to pink rocks contain variably abundant phenocrysts (1-3 mm) of quartz and microperthite and rare phenocrysts of biotite, ferrohastingsite, ferrohedenbergite, and riebeckite set in a matrix of quartz and alkali feldspar. Accessories include apatite, fluorite, zircon, and magnetite. Lithic fragments (mm- and cm-scale) constitute 1-5% of most comendite samples. Lithic types include hornfels, cogenetic volcanic rocks, porphyritic quartz syenite, and rarely cogenetic plutonic rocks. The trachyte consists of phenocrysts (2-3 mm) of pink alkali feldspar set in a dense (<0.1 mm) groundmass of alkali feldspar. Accessories include abundant hematite and minor zircon, magnetite, epidote and clinozoisite. The breccias contains angular to subrounded blocks ranging from a few centimeters to a meter in size. Lithic fragments include a variety of metamorphic rock lithologies, Paleozoic intrusive rocks, and cogenetic volcanic and hypabyssal rocks.

ITINERARY FOR DAY 1 AND DAY 2

All stops are located in the U.S.G.S. North Conway and Crawford Notch 15' Quadrangles. Access to Stops 2 and 3 is through the Ossipee Lake 15' Quadrangle. All excursion stops are located on the U.S.G.S. 7.5' topographic base in Figures 5 - 11.

STOP 1A. CONWAY GRANITE AT THE REDSTONE PINK QUARRY (45 MINUTES) (North Conway West Quadrangle). The coarse pink Conway Granite (Table 1, #1a) of the Birch Hill pluton is homogeneous in grain size and texture and was quarried extensively for building stone (Dale, 1923). Sparse inclusions, chiefly of porphyritic granite, are present locally. A few thin (3 cm) dikes of aplitic granite are seen on the main bench of the quarry. Samples from here have been used in numerous studies related to the high concentrations of U (20 ppm) and Th (70 ppm) in the Conway Granite (e.g. Adams and others, 1962; Birch and others, 1968; Osberg and others, 1978).

Exit the clearing adjacent to columnar pieces of granite. Follow path .1 mi to small quarry with derricks.

STOP 1B. MT. OSCEOLA GRANITE AT THE REDSTONE GREEN QUARRY (30 MINUTES) (North Conway West Quadrangle). The Mt. Osceola Granite (Table 1, #1b) was quarried here. The contact between this green ferrohastingsite granite and the Conway Granite of Stop 1a is reached by traversing around the east and north (top) sides of the quarry along a narrow foot trail. The Conway Granite is distinctly finer grained at the contact.

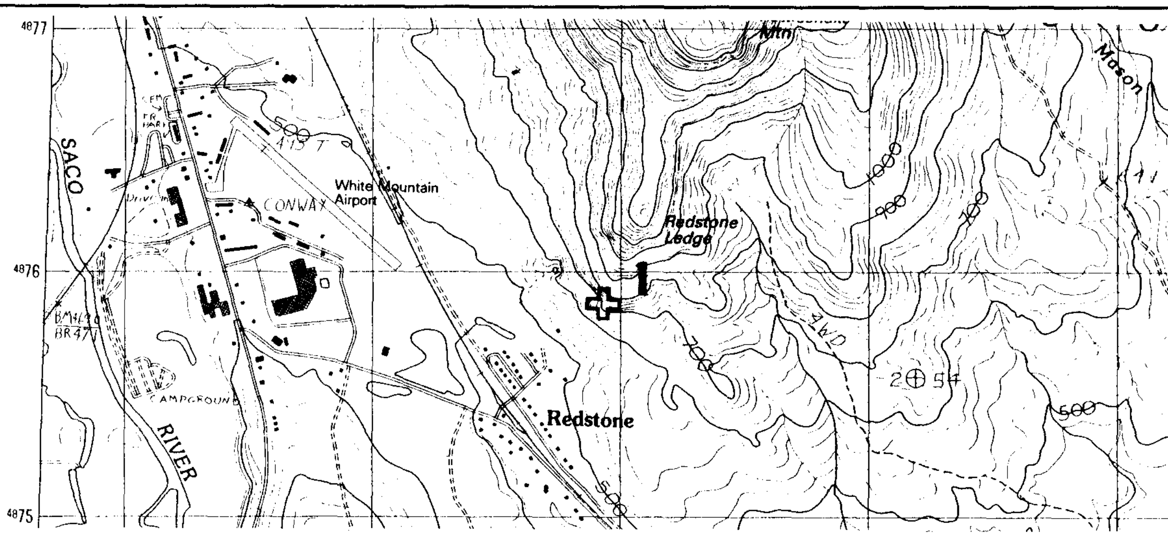

Figure 5. Location of **STOP 1** (North Conway West Quadrangle). Grid spacing is 1 km.

STOPS 2A, B, C. ALBANY PORPHYRITIC QUARTZ SYENITE OF RING DIKE E3 (1 HOUR) (Silver Lake Quadrangle). The Kancamagus Highway (and adjacent Swift River) crosses ring dike E3 (Figure 3) at a low angle providing excellent outcrops of the Albany Porphyritic Quartz Syenite and the Porphyritic Syenite within the composite ring dike E3. This stop illustrates at least three Albany-type lithologies (Table 1, #2a, b, c) distinguished by the abundance and proportion of quartz and feldspar phenocrysts. Davie (1975) demonstrated the composite nature of this ring dike on the north margin (Attitash Ski Area, North Conway West Quadrangle) which provides excellent but less accessible exposures.

STOP 3. ALBANY PORPHYRITIC QUARTZ SYENITE AT TYPE LOCALITY (20 MINUTES) (North Conway West Quadrangle). This is the probable type locality for the Albany porphyritic quartz syenite (Hitchcock, 1877) and a calendar-quality photo op of the Albany covered bridge.

STOP 4. TRAVERSE OF MOAT RANGE VOLCANIC SEQUENCE, SOUTH MOAT MTN (4 HOURS) (North Conway West Quadrangle). The purpose of Stop 4 is to illustrate the varied lithologies of the Moat Range sequence. This involves a traverse of about 3.5 miles and 1200 vertical feet (up going, down returning) along and adjacent to the South Moat Trail. The traverse is shown on Figure 4.

STOP 5. U.S.F.S. SMOKEY QUARTZ COLLECTING AREA (30 MINUTES) (North Conway West Quadrangle). This is an accumulation of boulders of the miarolitic contact facies of the Conway Granite; bedrock is not exposed.

STOP 6. CATHEDRAL LEDGE (20 MINUTES) (North Conway West Quadrangle). The Conway Granite of the Birch Hill pluton is beautifully exposed on the summit of Cathedral Ledge (New Hampshire's Half Dome!). The excellent views of the Saco River and Mt. Washington Valley make this a convenient location for geologic orientation.

STOP 7. CONTACT OF MOAT VOLCANICS AND CONWAY GRANITE IN LUCY BROOK (2 HOURS) (North Conway West Quadrangle). At Diana's Baths (0.4 mi) the coarse Conway Granite becomes porphyritic and contains large (up to 3 m) segregations of dark material that Billings (1928) interpreted as partially assimilated inclusions. NO HAMMERS PLEASE! From here, follow the Moat Mtn Trail (1.4 mi) to the first trailside ledges (Moat Volcanics), then cut over to Lucy Brook (100 ft). The contact between the Moat Volcanics (upstream) and the Conway Granite (downstream) is very well exposed in the Brook. In the lowest stream exposures, the coarse Conway Granite grades into medium-grained porphyritic contact facies characterized

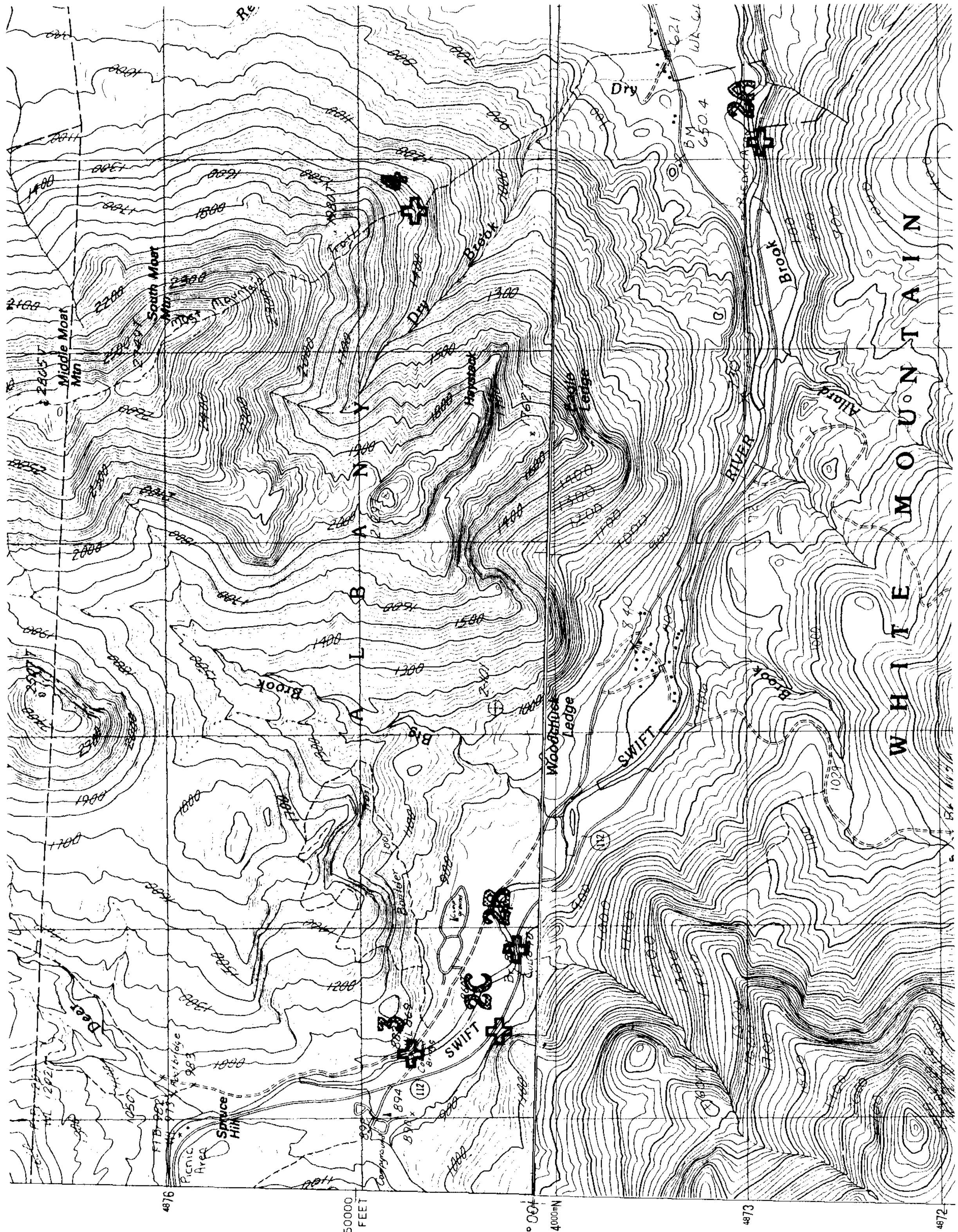

Figure 6. Location of **STOPS 2, 3,** and **4** (North Conway West Quadrangle). Grid spacing is 1 km.

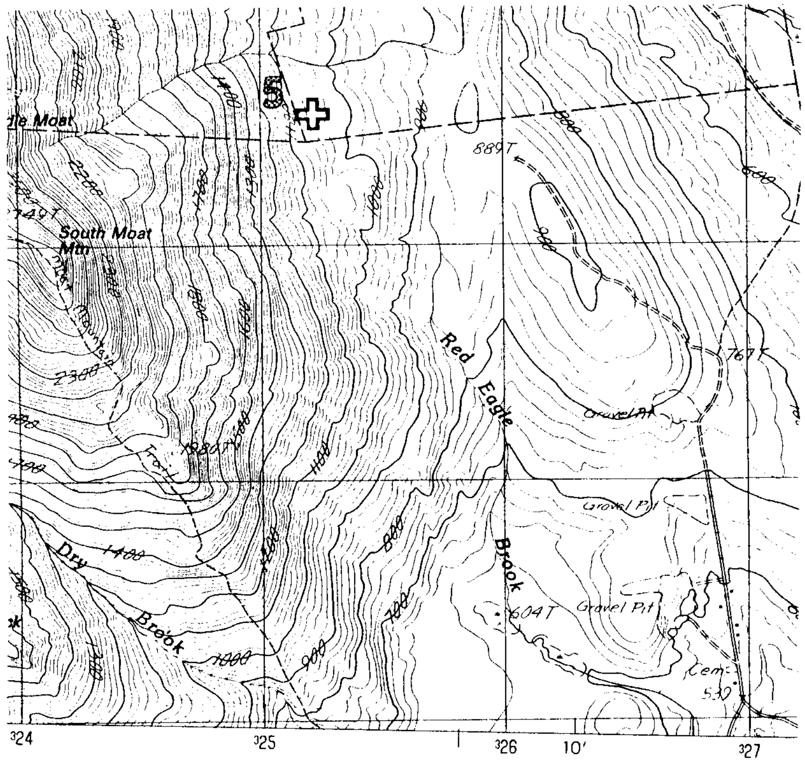

Figure 7. Location of **STOP 5** (North Conway West Quadrangle). Grid spacing is 1 km.

by a heterogeneous and miarolitic texture. Large rounded inclusions of fine-grained biotite granite are included in the Conway Granite, perhaps representing an older contact facies. Blue-gray comendite of the Moat Volcanics is bleached and pink where cut by numerous fractures and thin (<2 cm) quartz veins. Eutaxitic texture is not well developed here; the rocks resemble quartz porphyry.

STOP 8. MOUNT OSCEOLA GRANITE AT HUMPHREY'S LEDGE (20 MINUTES) (North Conway West Quadrangle). The Mount Osceola Granite is exposed at the north end of Humphrey's Ledge. This is an excellent locality for collecting samples that contain fayalite and ferrohedenbergite.

STOP 9. ALBANY PORPHYRITIC QUARTZ SYENITE OF RING DIKE E2 (1 HOUR) (Jackson Quadrangle). Park on wide right (east) shoulder at Jackson Falls picnic area. Walk to broad exposures in Wildcat Brook. NO HAMMERS PLEASE! The Albany Porphyritic Quartz Syenite in composite ring dike E3. This is one of the best (and most scenic) localities to examine the Albany--about 2000 ft of continuous exposure is present between here and Jackson along Wildcat Brook. Just downstream of the iron bridge a screen of Siluro-Devonian gneisses and granite 110 ft wide is intruded by the Albany. Downstream from this screen, the Albany is relatively uniform in mineralogy and texture and contains a few small (2-5 cm) inclusions. Upstream, large (up to 1 m) inclusions of feldspar-poorer porphyritic syenite are enclosed by the Albany.

STOP 10. INTRUSIVE RELATIONS AT THORN MTN (1 HOUR) (Jackson Quadrangle). A 1 mi loop at traverses ski trails to and from the summit of Thorn Mtn. The ski trails on the north slope of Thorn Mtn expose pavement outcrops of the fine-grained and homogeneous Black Cap biotite granite (Table 1, #6). Just below (north of) the summit, the Black Cap intrudes a screen of country rocks consisting of Silurian meta-

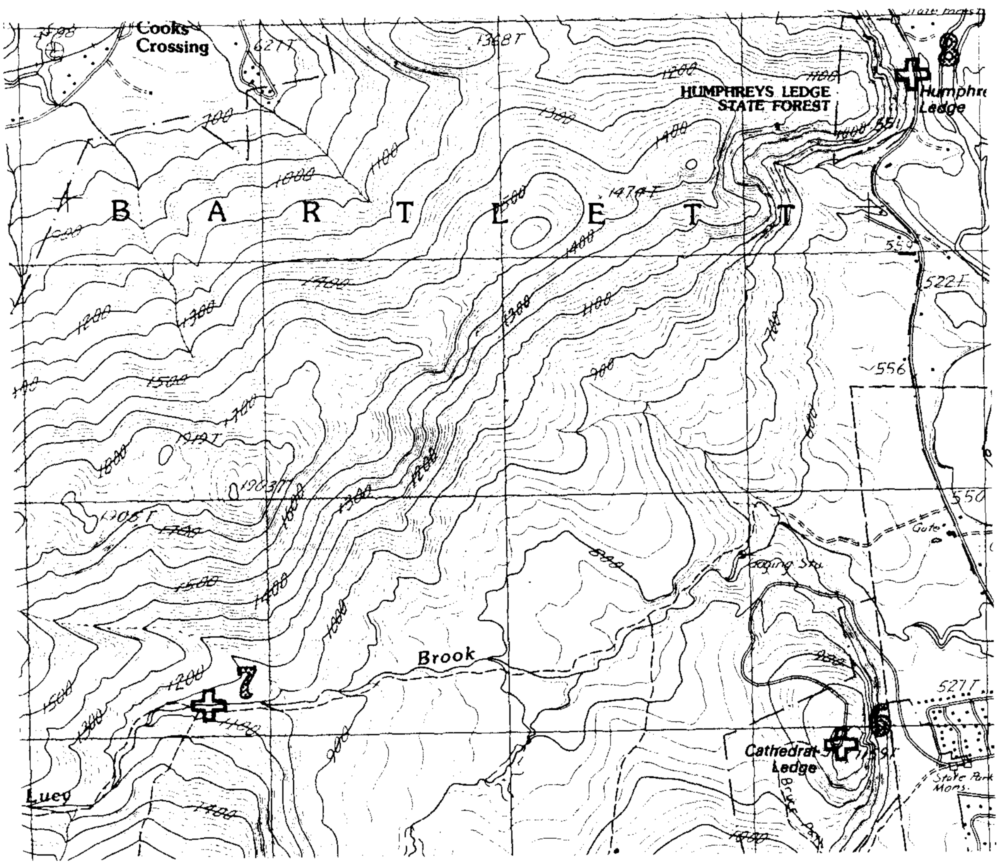

Figure 8. Location of **STOPS 6**, **7**, and **8** (North Conway West Quadrangle). Grid spacing is 1 km.

morphic rocks and Devonian (?) granites and pegmatites. The south margin of the screen is shattered and intruded by a chill facies of Albany Porphyritic Quartz Syenite. At and south of the summit the Albany Porphyritic Quartz Syenite has coarser grained groundmass and may be a separate intrusion. The screen is cut out to the east; the Black Cap Granite is in contact with the chilled Albany but age relations are not evident here.

STOP 11A. INCLUSIONS WITHIN RING DIKE E4 (20 MINUTES) (North Conway West Quadrangle). The purpose of Stop 11 in total is to examine the internal and marginal aspects of the Albany Porphyritic Quartz Syenite within ring dike E4 exposed within the East Branch of the Saco River. Stop 11A is within the interior of the ring dike. Notable here are abundant small inclusions. The average azimuth of inclusions does not parallel the northwesterly trending contact of the Albany with the younger Conway Granite. They may parallel the original contact of the Albany with the country rock; subsequent intrusion of the Conway Granite resulted in a different orientation of the contact.

STOP 11B. CHILL MARGIN OF RING DIKE E4 (1 HOUR) (North Conway West Quadrangle). The Albany is here chilled against a screen of schists, grading over a distance of twenty feet from typical Albany to a dense brown porphyry through a reduction in grain size of the groundmass. The percentage of quartz phenocrysts increases (from 5 TO 15%) and their average size decreases towards the margin.

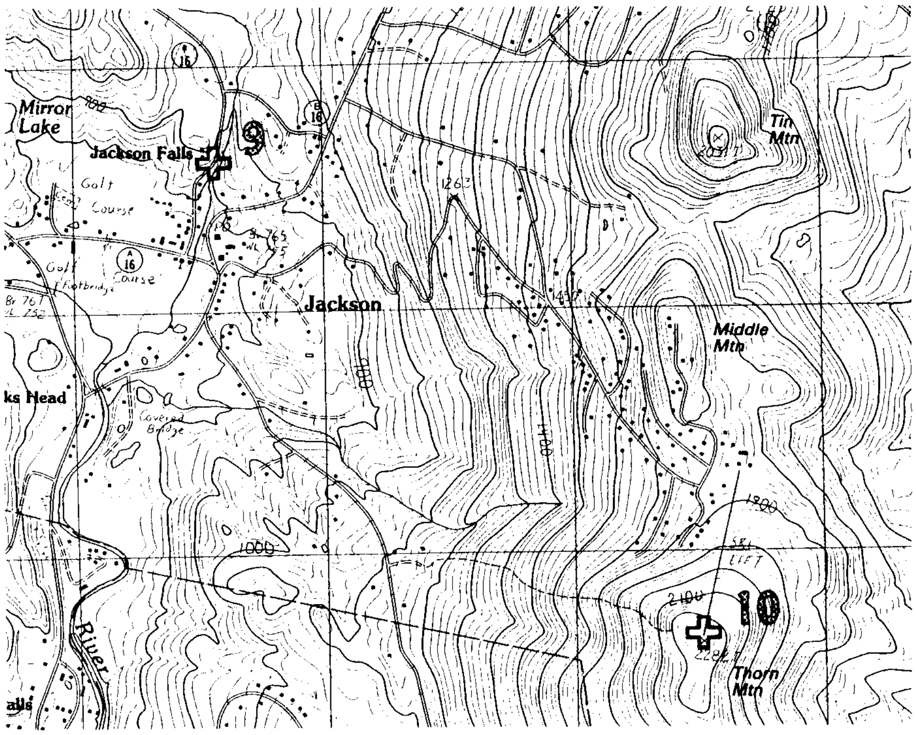

Figure 9. Location of **STOPS 9** and **10** (Jackson Quadrangle). Grid spacing is 1 km.

STOP 12. CONTACT OF THE GARDINER BROOK PLUTON. (30 MINUTES) (North Conway West Quadrangle). Park on south side of bridge and cross bridge to outcrop on northeast side of road. The coarse-grained Conway Granite of the Gardiner Brook pluton (Table 1, #7) exposed at the north end of the long outcrop becomes porphyritic towards the Silurian schists and gneisses which occur downstream of the bridge (and to Stop 11B!). These country rocks are shattered and intruded by a fine-grained biotite granite (Black Cap Granite ?) which is intruded by the porphyritic Conway Granite.

STOP 13. PERALKALINE GRANITE ON HURRICANE MTN (1 HOUR) (North Conway East Quadrangle). Follow woods road to a point where a trail leaves left (about .25 mi); ascend via trail to open south-facing ledges (.15 mi) that expose riebeckite-arfvedsonite granite. Conway Granite is exposed around the rest of the mountain. Abundant miarolitic pods and cavities notable for their large prismatic crystals of riebeckite-arfvedsonite--check blast debris! This miarolitic contact facies is probably the top or margin of a larger subjacent pluton of peralkaline granite (c.f. South Doublehead Mtn). Exposures near the summit of Hurricane Mtn lack biotite and contain only scattered miarolitic pods and may lie below this contact zone. Astrophyllite is a characteristic accessory mineral in this granite.

STOP 14: BLACK CAP GRANITE AND GREEN HILLS PLUTON (1.5 HOURS) (North Conway East Quadrangle). The purpose of this traverse (about 2 miles, 600' of relief--up going, down returning) is to examine the relationship between the Black Cap and Conway granites. The medium-grained Conway Granite of the Green Hills pluton (Table 1, #9) is well exposed in the ledges as the trail ascends the north slope of Black Cap from the Hurricane Mtn road. Near and south of the summit, the Conway locally becomes sub-porphyritic. About .25 mi southeast of the summit (no trail) the exposure geometry of the fine-grained Black Cap Granite suggests it forms a sub-horizontal sheet--probably the roof facies of the pluton. The Black Cap Granite is shattered and intruded by the main intrusive pulse of the Conway Granite.

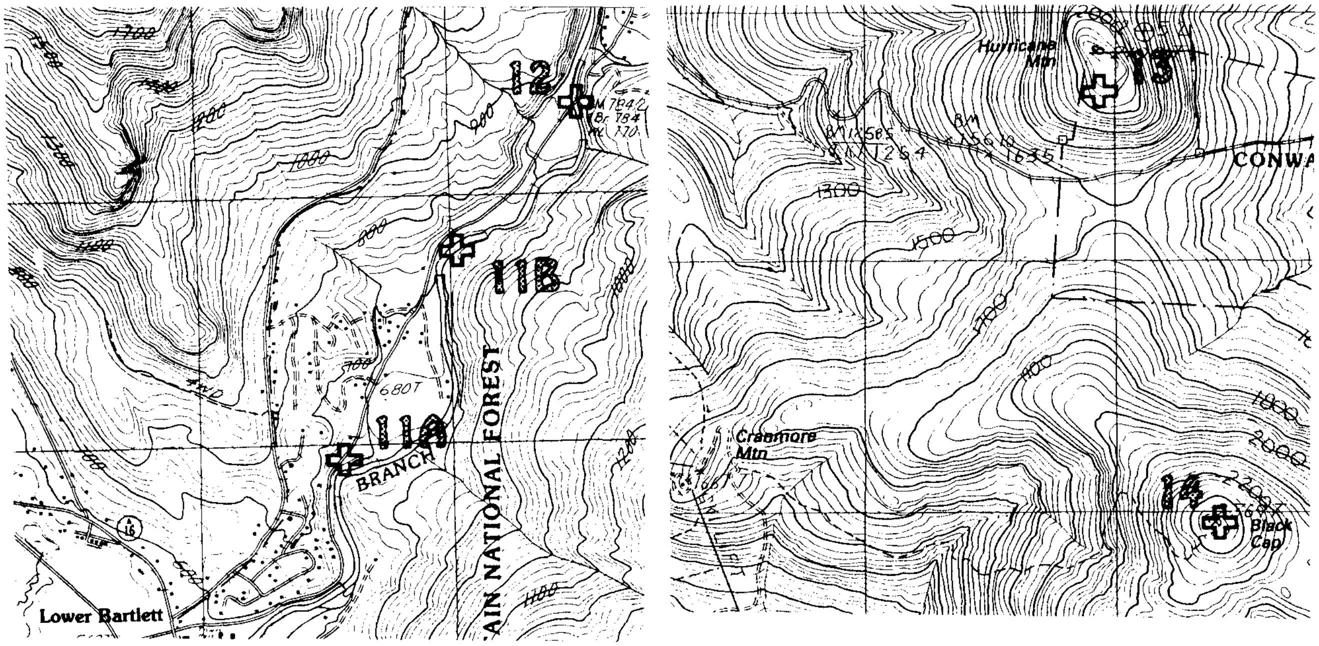

Figure 10. (Left) Location of **STOPS 11** and **12** (North Conway West Quadrangle). (Right) Location of **STOPS 13** and **14**. Grid spacing is 1 km.

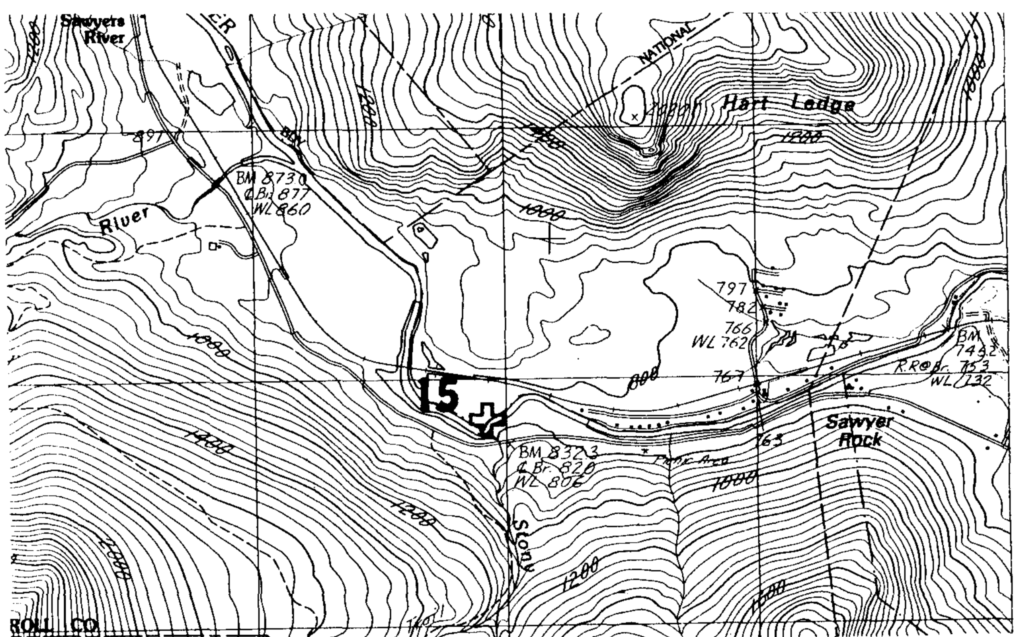

Figure 11. Location of **STOP 15** (Bartlett Quandrangle. Grid spacing is 1 km.

STOP 15: SYENITE OF THE HART LEDGE COMPLEX. (30 MINUTES) (Bartlett Quadrangle). Coarse syenite of the Hart Ledge body is found at the juncture of Stony Brook and the Saco River. Samples from this locality have a negative Europium anomaly (Creasy and others, 1979), most unusual among felsic rocks of the White Mountain batholith. The purpose of this stop is to evaluate possible field evidence for a cumulus origin. A vague cm-scale mineral layering is present but is it convincing? The miarolitic cavities or pegmatitic clots dimpling the surface of this outcrop contain large crystals of ferrohastingsite and quartz. Abundant dikes of syenite pegmatite and aplite, many of them compound, are well exposed.

MOUNT PAWTUCKAWAY

INTRODUCTION

Mount Pawtuckaway, a member of the younger White Mountain igneous province, is located in Rockingham County, New Hampshire. The complex is centrally located on the 15' Mt. Pawtuckaway quadrangle and falls within the boundaries of Pawtuckaway State Park. The complex has a surface exposure of approximately 8 km^2, is roughly circular in outline, and the maximum relief is on the order of 200 m. The mafic rocks, which are easily eroded, underlie the lowlands while the more resistant monzonites and syenites form ridges. The low ridge along the southern edge of the complex is underlain by gabbros and troctolites. The Pawtuckaway magmas were intruded into the Precambrian Massabesic Gneiss Complex.

The earliest studies of the Mount Pawtuckaway complex described the rocks as largely syenites and camptonites. Roy and Freedman (1944) were the first to completely map the complex and a further modification of the geology is found in Freedman (1950). Shearer (1976) did a geochemical study of the major units and Richards (1990) undertook a structural, petrographic and geophysical study. A series of senior projects (J. Dadoly, M. Kick, M. Lambert, and J. Plunkett) conducted at the University of Massachusetts, Lowell, have dealt with various aspects of the geology and geochemistry of the complex. The data of all these investigators has been used to construct the current version of the Mount Pawtuckaway geologic map (Figure 5).

GENERAL GEOLOGY

Modeling of geophysical data (Richards, 1990) indicates that the pluton is a plug-like structure extending to a depth of approximately 3 km. The units have steep contacts, and a body of high magnetic susceptibility occurs at depth. Field relations indicate that the mafic rocks were emplaced prior to the felsic rocks (see Figure 5 for the locations of the various units). Based on apatite fission-track data Doherty and Lyons (1980) estimated that the rocks currently exposed at the surface were originally at a depth 3.0 to 3.6 km. A K-Ar biotite age of 124 ± 2 Ma (corrected to new decay constants) has been determined for the coarse-grained monzonite (Foland and others, 1971).

The earliest mafic rocks are pyroxenites which are preserved as blocks in the foliated diorite and medium-grained monzonite. Given the large size of some of these blocks, it is unlikely that they have undergone any significant upward transport, and they most likely occur close to their original level of emplacement. An arcuate body of gabbro occurs along the southern margin of the complex. This unit is distinguished by the anorthite content of its plagioclases (An_{60} to An_{46}), the essential absence of apatite (which is a common accessory in the other mafic units), and its distinctive trace element geochemistry. Troctolites occur within this unit. Locally the gabbro does show a foliation dipping inward at about 50°. The position of the gabbro in the sequence of mafic rock emplacement is ambiguous since it is not intruded by any of the other units. Several varieties of diorite are found: coarse-grained hornblende diorite, medium-grained foliated diorite and fine-grained diorite. The coarse-grained hornblende diorite is largely confined to the western portion of the complex. Locally this unit does show

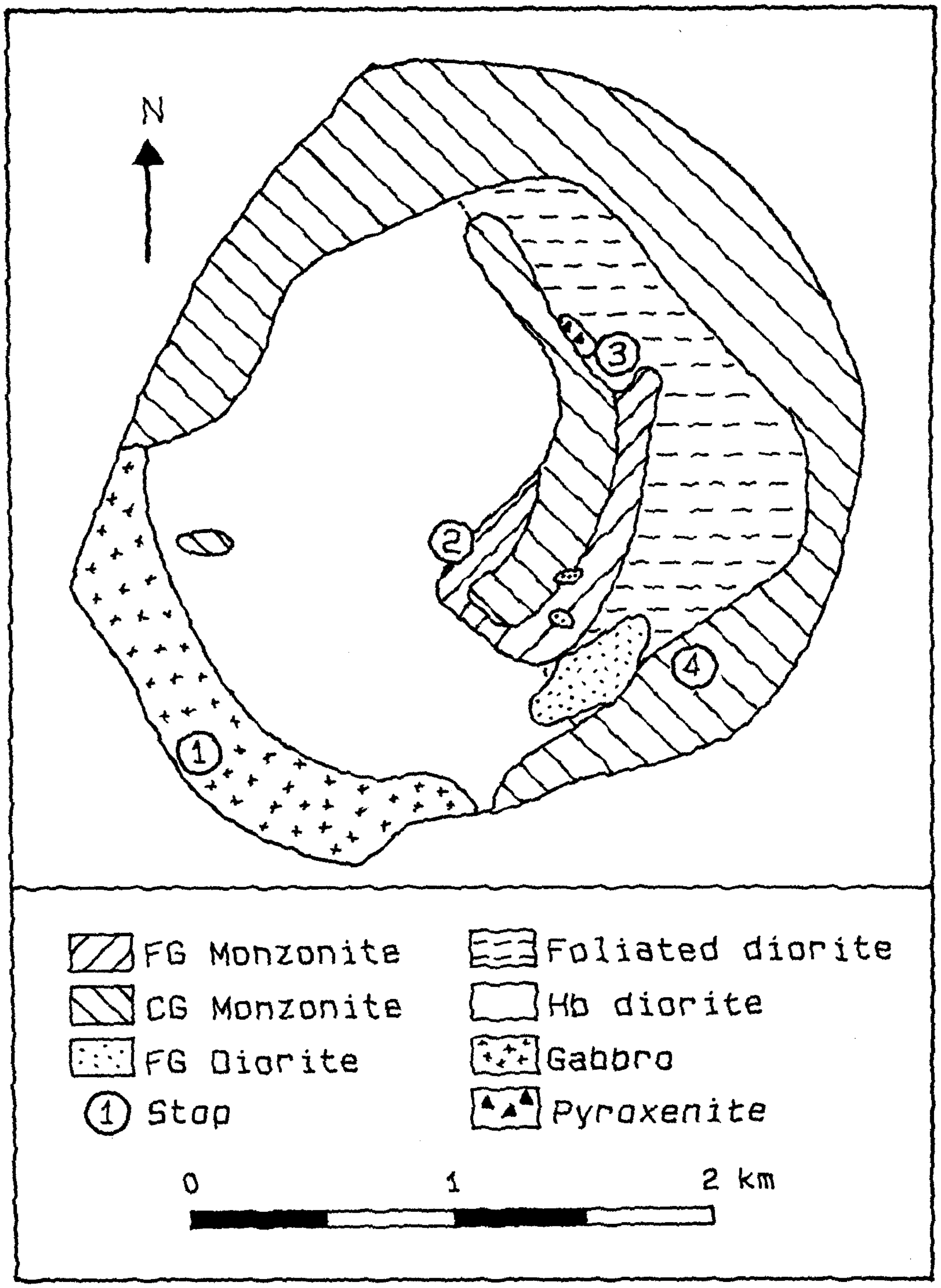

Figure 12. Geologic map of Mount Pawtuckaway from Roy and Freedman (1944), modified on the basis of *additional mapping by Richards (1990), Kick (1992, unpublished), and Eby (1993, unpublished).*

a weak foliation. The medium-gained foliated diorite is differentiated on the basis of its generally higher pyroxene/amphibole ratio and the presence of foliation due to the alignment of plagioclase laths. These rocks are largely confined to the eastern portion of the complex. The fine-grained diorite is a distinctive unit texturally and shows no foliation. Because of the absence of foliation it is inferred to be the last mafic unit emplaced in the complex.

The felsic rocks are monzonites and syenites. The outer ring of coarse-grained monzonite grades inward to coarse-grained syenite. An arcuate unit of coarse- to medium-grained monzonite occurs within the complex. The fine-grained monzonite partially surrounds this arcuate structure and is found as inclusions in the coarser-grained monzonite. Dikes of what appear petrographically to be fine-grained monzonite cut the outer coarse-grained monzonite. Most of these units are cut by mafic and felsic dikes which represent the last stages of igneous activity at Mount Pawtuckaway.

The pyroxenites are apparently the earliest rocks to be emplaced at Mount Pawtuckaway. The arcuate gabbro which outcrops at the southern edge of the complex may be related to the pyroxenite. In terms of both texture and geochemistry, the pyroxenite and gabbro can be interpreted as cumulus rocks. The initial phase of magmatic activity at Mount Pawtuckaway, therefore, may have consisted of the precipitation, from the wall inward, of minerals from a convecting mafic magma. The coarse- and medium-grained diorites were the next units to be emplaced. The foliation in these units dips towards the center of the complex and the dip increases as one moves inward (Kick, 1992, unpublished data), suggesting a funnel-shaped intrusion. The fine-grained diorite does not show any foliation, and does occur as inclusions in the medium-grained monzonite, thus it must be the last of the mafic units emplaced, but must predate at least some of the felsic units. The fine-grained monzonite occurs as inclusions in the medium- to coarse-grained monzonite of the central arcuate unit. If the fine-grained monzonite dikes in the outer coarse-grained monzonite are related to the central fine-grained monzonite then there are at least two periods of coarse-grained monzonite emplacement.

The sequence of events as deduced from the field relations indicate that a number of different magmas must have been involved in the formation of the Mount Pawtuckaway intrusion. The initial magmas were mafic. Later magmas were more felsic in composition. All of the felsic rocks are broadly similar in chemical composition, and their textural differences may be due to the water pressure at the time of crystallization. There is also evidence for several periods of subsidence. The first formed the outer ring of coarse-grained monzonite. This was followed by the emplacement of the fine-grained monzonite which, on textural grounds, may represent a magma which vented to the surface. Subsequently the central arcuate coarse- to medium-grained monzonite was emplaced. The last period of igneous activity is represented by the emplacement of mafic and felsic dikes which cut all of the other units.

PETROGRAPHY

Mafic Units

Pyroxenite. The pyroxenites are coarse-grained and largely composed of cumulus olivine and augite with interstitial labradorite and opaque minerals. The augites show a pink tint and are spotted and rimmed by red-brown amphibole. The augites contain minute opaque inclusions which are oriented parallel to crystallographic directions. The opaques are titano-magnetite intergrown with hercynite. Apatite occurs in trace amounts.

Gabbro. The gabbros are medium- to coarse-grained and locally show a well-developed foliation due to the alignment of plagioclase laths. Plagioclase (An_{60} to An_{46}) and a light pink augite are the major minerals. Olivine is locally abundant. The augites contain oriented minute opaque inclusions and are rimmed and spotted by red-brown amphibole.

Hornblende diorite. The grain size is variable from medium-fine-grained to coarse-grained, and locally foliation can be found. The plagioclase is generally andesine, but can be zoned to oligoclase. The pyroxenes are generally light green, but pink cores are not uncommon. The pyroxenes are often extensively replaced by reddish-brown hornblende and green hastingsite. Red-brown biotite occurs both as separate grains and replacing pyroxene and amphibole. Apatite is a common accessory ranging in modal abundance from 1.6 to 3.5%. Olivine, extensively altered, is occasionally found.

Foliated diorite. The grain size is variable from fine- to coarse-grained, and most specimens show a foliation due to the alignment of plagioclase grains. The plagioclase is generally andesine, but may be zoned to oligoclase and occasionally labradorite cores are found. The pyroxenes are light pink and light green in color, and where the two varieties occur together the light pink pyroxene constitutes the core. The pyroxenes are invariably partly replaced by red-brown to green amphiboles. The pyroxenes contain oriented minute opaque inclusions, and the preservation of these inclusions in the amphiboles indicates the prior existence of pyroxene. Olivine is found in most specimens and locally is an important accessory. The biotites are straw brown to red brown and generally occur as large flakes. Apatite is an important accessory ranging in modal abundance from 1.0 to 2.6%.

Fine-grained diorite. The rock consists of a felted matrix of plagioclase (An_{41} to An_{26}), hornblende, minor biotite and trace apatite and opaques with minor small phenocrysts. The phenocrysts are plagioclase, some with alkali feldspar overgrowths, and hornblende. Aphanitic dark gray blebs of mafic minerals are also found.

Table 1. Representative Modes for the Mafic Rocks

	Pyroxenite	Gabbro		Hb diorite		Foliated diorite		Fine-gr. diorite
	MP73	MP81	MP83	MP1	MP50	MP9	MP75	K22
Plag	8	61	67	46	64	45	63	57
Oliv	18	5	21	-	-	7	1	<1
Pyroxene	51	10	<1	16	1	11	6	10
Amphibole	18	19	6	20	25	24	20	15
Bio	-	-	-	9	1	2	4	15
Opaques	5	5	6	6	5	8	4	2
Apatite	<1	-	<1	3	4	3	2	<1

Felsic Units

Coarse-grained Monzonite and Syenite. The grain size varies from medium-to coarse-grained, and the monzonites and syenites are gradational into each other with changes in the K-feldspar/plagioclase ratio. The plagioclase is generally oligoclase and the alkali feldspars are microperthitic. The plagioclases are often rimmed by perthite. The pyroxenes are colorless to light green and are partly replaced by red-brown and dark green amphiboles. The biotites are reddish brown to straw brown and replace both pyroxene and amphibole. Quartz is interstitial, and some sections contain fayalitic olivine.

Fine-grained monzonite. The grain size varies from fine-grained to very-fine-grained. Some sections have phenocrysts of biotite and hornblende. The major minerals are oligoclase and microperthite. Quartz is a minor phase. The amphiboles are green to dark green and the biotites are reddish brown to straw brown. Pyrrhotite and apatite occur as accessories.

Table 2. Representative Modes for the Felsic Rocks

	Coarse-grained monzonites & syenites				Fine-grained monzonite
	MP8	MP12	MP15	MP49	R&F[1]
Plag	19	31	24	8	40
K-feldspar	46	34	54	84	35
Quartz	-	<1	2	3	2
Olivine	1	1	-	-	-
Pyroxene	12	14	4	<1	4
Amphibole	<1	6	11	3	7
Biotite	15	8	4	-	9
Opaque	5	5	1	2	3
Apatite	1	1	-	-	-

[1]Roy and Freedman (1944)

ROAD LOG

Mileage

0.0 Entrance road to Pawtuckaway Mountains and fire tower. The entrance is marked by a small brown sign on the east side of NH Route 107, 3.2 miles north of the juncture of Routes 107 and 27.

2.0 Park by small farm cemetery on south side of road.

STOP 1. GABBRO AT MELOON HILL (1 HOUR) (Mt. Pawtuckaway Quadrangle). Follow logging road departing from west side of cemetery 300 feet to large flat outcrops of gabbro. Take left hand fork and continue another 1000 feet and then proceed southwesterly to SW side of Meloon Hill. Outcrop is essentially continuous along this side of the hill. The gabbro is medium-grained and locally shows a well-developed foliation. The foliation strikes parallel to the contact and dips steeply towards the center of the intrusion. This unit is cut by several fine-grained mafic dikes. Return to vehicles.

2.3 Turn left onto loop road.

2.9 Walk east 200 feet along logging road. Small quarry located just to the north of the road.

STOP 2. MIDDLE MOUNTAIN TRAVERSE (2 HOUR) (Mt. Pawtuckaway Quadrangle). At the western end of the quarry hornblende diorite has been engulfed by fine-grained bluish-gray monzodiorite. Isolated outcrops of this monzodiorite are found in the immediate area. Proceeding eastward in the quarry outcrops of hornblende diorite are observed. These outcrops are cut by both felsite and fine-grained monzonite dikes.

Proceed southeastward from the quarry up Middle Mountain. A series of outcrops provide almost 100% exposure of the fine-grained monzonite. **CAUTION:** This rock is very brittle and fragments come off the outcrop like shrapnel. Do not wound yourself or a fellow geologist. There are slight variations in grain size throughout this unit, but they do not appear to be correlated with distance from the contact. At the top of Middle Mountain outcrops of coarse-grained monzonite are found. Proceed a short distance eastward through this unit. In this area the outcrops are deeply weathered and fresh pieces are difficult to obtain. Inclusions of fine-grained monzonite are found in some outcrops of coarse-grained monzonite. Return to vehicles.

3.6 Park at the intersection of the loop road and Round Pond road. During times of heavy rainfall the road may not be passable between Stop 2 and Stop 3.

STOP 3. ROUND POND ROAD TRAVERSE (2 HOUR) (Mt. Pawtuckaway Quadrangle). Walk back (west) along the road several hundred feet to a road leading north into a primitive picnic area. Outcrops of coarse-grained monzonite are found on either side of the road. Diorite and fine-grained monzonite inclusions are found in the coarse-grained monzonite. On the east side of the road are several outcrops of fine-grained monzonite which contain blebs of coarse-grained monzonite. In thin section no sharp boundaries are observed between the two types of monzonite.

Return to the intersection and continue on the Round Pond road in an easterly direction. Outcrops of pyroxenite are found along the road approximately 400 feet from the intersection. Follow the ridge line northward about 300 feet to an outcrop of large pyroxenite blocks in medium-grained monzonite.

Return to Round Pond road and continue eastward onto an abandoned road. Outcrops of foliated diorite are found in and on both sides of the road. Both fine- and medium-grained varieties of the foliated diorite are observed. Where the two varieties are in contact, the fine-grained diorite appears to intrude the medium-grained diorite.

Continue eastward to Round Pond. Outcrops of coarse-grained monzonite north of the road and just west of the brook carry inclusions of fine-grained diorite. A mafic dike cutting the monzonite is exposed in the stream bed. Return to vehicles.

4.5 Continue southward on loop road to parking area for fire tower trail.

STOP 4. SOUTH MOUNTAIN TRAVERSE (2 HOUR) (Mt. Pawtuckaway Quadrangle). Proceed up trail to top of South Mountain. Excellent exposures of the coarse-grained monzonite are found along the upper portion of the trail. Several fine-grained monzonite dikes cut this unit. A number of mafic dikes are exposed in the immediate area of the fire tower. On a trail going southward from the fire tower is an exposure showing mixing between felsic and mafic magmas. Return to vehicles. Continue on loop road to juncture. Turn right and proceed back to Route 107.

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