TRIP B-3

GEOLOGIC REVIEW OF THE BELKNAP MOUNTAIN COMPLEX

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Introduction

The Belknap Mountain complex of central New Hampshire is one of several classic ring dike complexes identified in New England. The complex is located between the towns of Alton and Gilford, New Hampshire, and lies in close proximity to several other similar and related complexes; as for example, the Ossipee Mountain complex (Kingsley, 1931), Red Hill (Quinn, 1937), and the Merrymeeting stock (Quinn and Stewart, 1941). Each complex contains rocks assigned to the White Mountain Plutonic-Volcanic series (Billings, 1928, Chapman and Williams, 1935). Rocks of this series, originally thought to be of late Paleozoic age (Billings, 1934), have been dated radiometrically between about 100 and 200 m.y., most recently by Foland _et al_. (1971) and Armstrong _et al_. (1971), a mid-Mesozoic age. The Belknap complex lies between these ages with K/Ar dates of 158 and 149 m.y. for diroite and granite, respectively (Foland _et al_., 1971).

Early geologic work in the Belknap Mountains was completed by Pirsson and Washington (1905, 1906) followed by more detailed work by Modell (1936) whose geologic map is reproduced in this field guide (Figure 1). Subsequent geologic work of a mineralogical and geochemical nature in the Belknap Mountains (Gaudette and Bothner, 1969) has contributed to the understanding of the evolution of this central complex of the White Mountain series. In recent years, additional excellent and easily accessible exposures have been made by new highway construction. These new exposures, which change little of Modell's work, do afford a better opportunity for close field examination. The aim of this field trip is, then, to examine critical exposures and to discuss the petrological and geochemical characteristics of the White Mountain rocks in the Belknap complex.

Petrology - Geochemistry

The Belknap complex contains the most complete rock sequence of any complex in the White Mountain series. Rocks range in composition from gabbro to granite and include as well as the typical syenites, vent agglomerates, intrusive breccias, and a screen of the Moat volcanics. The rocks of this complex were emplaced into the Winnipesaukee quartz diorite and Meredith porphyritic granite, both members of the New Hampshire Plutonic Series (Upper Devonian) and the Devonian Littleton Formation (Billings, 1956).

Following the designation of Modell (1936), the rock types in the Belknap Mountains are, in order of apparent increasing age (Moat volcanics excepted).

Trap syenite breccia	tsp
Rowes vent agglomerate	va
Conway granite	cg
Albany porphyritic quartz syenite	aqs
Lake quartz syenite	sqs
Sawyer quartz syenite	pqs
Belknap syenite	s
Gilmanton (augite) monzodiorite	am
Ames monzodiorite	m
Endicott (brecciated) diorite	bd
Gilford gabbro	g
Moat volcanics	mv

The age relationships are based on cross-cutting relations, "the law of decreasing basicity" (Modell, 1936), and in part by radiometric dates (Foland et al., 1971).

The megascopic characteristics of these rocks are discussed in the description of individual stops in the road log. The modal characteristics are, however, summarized as averages in the following table.

AVERAGE MODAL ANALYSES--BELKNAP MOUNTAIN COMPLEX

	g	bd	m	gm	s	sqs	pqs	aqs	cg
Plagioclase	49.8	73.4	49.4	42.1	35.5	29.5*	32.4	22.1	19.0
An Content	64	32	32	28	30	28	28	28	23
K-felspar	-	-	29.3	42.0	51.8	53.6	48.4	54.7	49.5
Quartz	-	3.4	5.3	2.6	4.8	13.8	16.0	13.6	28.2
Biotite	6.9	8.1	6.2	4.3	4.3	9.0	2.0	7.5	2.1
Amphibole	26.4	12.5	7.8	6.9	2.6	1.7	>1.0	1.4	-
Pyroxene	9.8	1.3	1.7	-	-	-	-	-	-
Opaques	6.7	1.2	0.4	2.0	0.9	1.0	1.1	0.3	0.7
Accessories	0.4	0.1	tr	0.1	0.1	0.4	tr	0.4	tr

(600-1200 counts were made for each slide; accessories included: apatite, rutile, allanite, fluorite, sphene and zircon. Occasional opaque sulfides are also present. Modell's modal analyses are not included in this table.)

*A small amount of nepheline was identified on Rattlesnake Island.

Geochemical data are not reproduced here. However, standard X-ray fluorescence analysis has been made for each major rock type in the Belknap complex (Gaudette and Bothner, 1969). The following elements were determined from whole rock samples: K, Rb, Sr, Ni, Ca, Cr, Si, Ti, and total Fe. Concentration levels of these elements and certain concentration ratios have suggested the presence of two magmatic trends in the evolution of the Belknap complex. The first trend begins with the Gilford gabbro and follows normally through the Gilmanton monzodiorite while the second trend includes the Belknap syenite and continues through the Albany porphyritic quartz syenite and Conway granite. The Moat volcanics occupy a middle position, very closely related to the Belknap syenite.

Geologic Structure of the Belknap Complex

The Belknap complex can be properly termed a composite pluton. Intrusion of some members of the sequence occurred along arcuate fractures related to volcanic activity and cauldron subsidence, while other members, at least from surface form, appear to have been emplaced as small stocks. Ring dikes cross-cut the Winnipesaukee quartz diorite, Meredith porphyritic granite, and Littleton formation and usually maintain steep, nearly vertical contacts from what can be seen from surface exposures. The ring dikes, however, are neither circular nor complete, as they are, for example, in the Ossipee and Red Hill complexes. Rather the dikes are arcs of elliptical rings that were either cut off by subsequent intrusive activity (e.g., aqs, m; Figure 1), or intruded into partial ring fractures (cg) probably representing incomplete cauldron subsidence. Good evidence for movement along arcuate fractures is found in the exposures at Stops 1 and 2, as well as several less accessible areas noted for the southern portion of the Belknap complex in Modell's paper (1936). For a more complete discussion of the structure of the Belknap complex, see Modell (1936).

Summary

The geologic history of the Belknap complex is similar to the histories of other ring complexes in New Hampshire, Scotland and elsewhere. Each involves successive periods of intrusion and associated extrusion in a relatively small area with rather definite changes in chemistry and rock type. Intrusion occurs along well defined arcuate fractures formed by cauldron subsidence.

In the Belknap complex, the earlier intrusions were emplaced as small stocks (gabbro and diorite), later followed by ring fracturing and successive intrusion of monzodiorites, syenite, and quartz syenites. These intrusive events were followed by a second period of ring fracturing, somewhat offset from the first, (Figure 1), and the emplacement of the Albany porphyritic quartz syenite. Conway granite was then intruded forcefully into the diorite, into a thin ring fracture on the southeast and northwest sides, and into the center of the complex as a central stock. A final period of volcanic activity is recorded in the

Rowes vent agglomerate (Modell, 1936).

Geochemical and mineralogical data from each major rock unit indicate that the White Mountain series in the Belknap complex evolved through fractional crystallization processes. Two fractional crystallization trends are suggested by the distribution of major and minor element concentrations. Geochemically, the Moat volcanics are closely associated with the Belknap syenite and thus do not represent the earliest, but rather an intermediate stage of development of White Mountain series rocks in the Belknap Complex.

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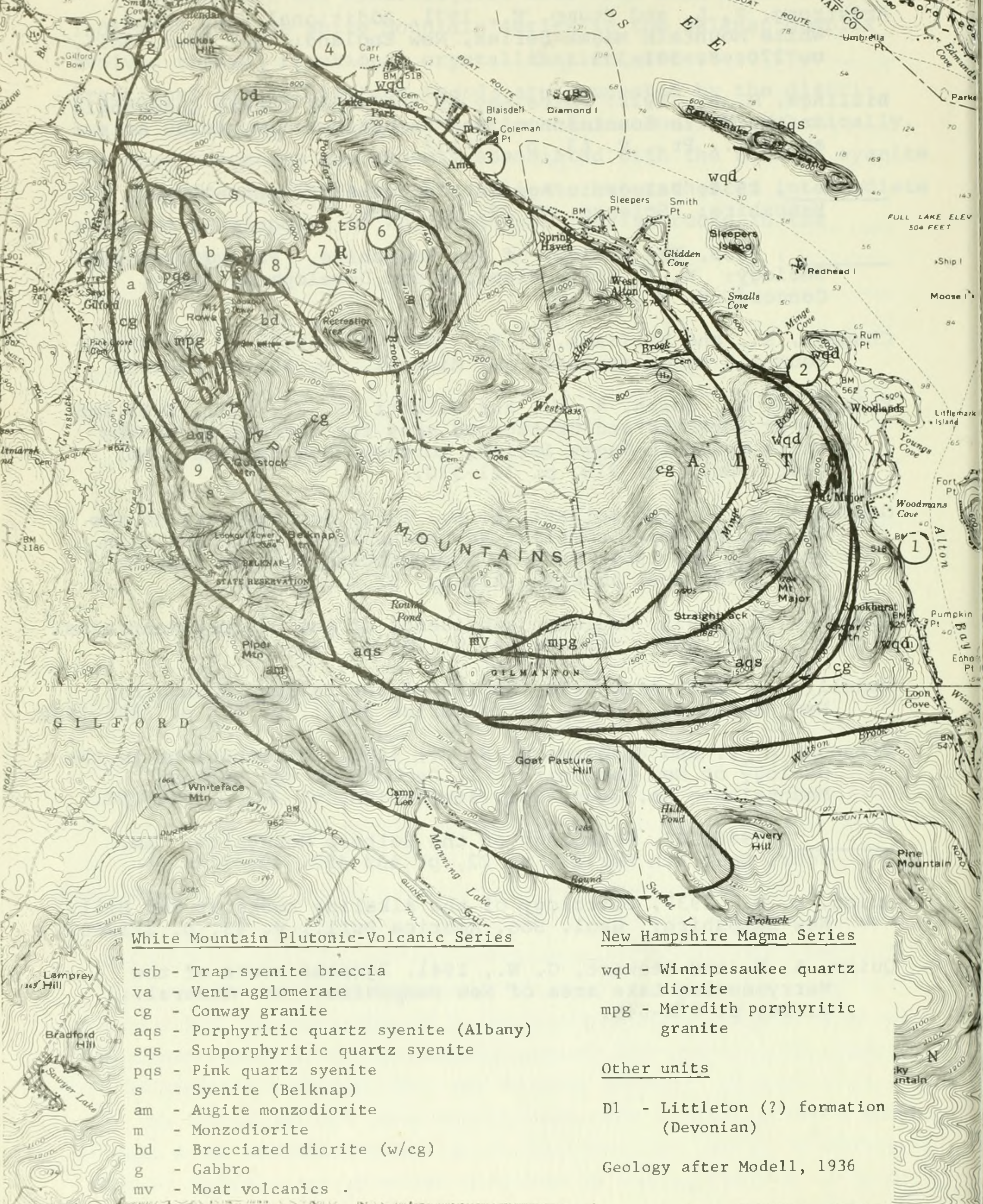
GEOLOGIC MAP OF THE BELKNAP MOUNTAIN COMPLEX

FIGURE 1.



ROAD LOG FOR TRIP B-3

Participants will meet at Alton Bay, N. H. at 9 AM, Sunday morning in the large parking lot between the old Alton Bay railroad station and Victoria Pier on Route 11. The easiest route from Concord to Alton Bay is: U.S. Route 202/4 east from Concord to N.H. Route 28 (about 19 miles), Route 28 to Alton, (30 miles), and finally Route 11 to Alton Bay (2 miles). An alternate route would be Interstate 93 north to Tilton (Exit 20, 30 miles), U.S. Route 3 to the intersection of Route 11 (21 miles), and Route 11 southeast to Alton Bay (about 16 miles).

Mileage

0.0 Alton Bay railroad station.

3.1 Winnipesaukee quartz diorite (wqd) is exposed on the southwest side of the Rt. 11. Both coarse- and fine-grained phases are present in this outcrop. The coarse-grained phase contains porphyroblasts of feldspar in excess of 6 cm in length. Both are cross-cut by small felsic dikes.

3.5 STOP 1 Park in "Scenic View Area". The view to north and east consists of the upper end of Alton Bay, a large portion of Lake Winnipesaukee, the Ossipee Mountain ring complex, and finally the White Mountains in the far background. Rattlesnake Island composed of subporphyritic quartz syenite can also be seen due north in the Lake.

In the large cliff face opposite the parking area, Winnipesaukee quartz diorite is well exposed. Both coarse- and fine-grained varieties are present. The coarse-grained porphyritic wqd has large (up to 8 cm) aligned K-feldspar porphyroblasts. The country rock is cut by numerous dikes, two of which are related to the White Mountain series and were not reported by Modell. Smaller dikes are composed of diabase, granite, and granite pegmatite.

The dike on the right is a 20-foot thick green-gray quartz syenite dike trending N85W and vertically dipping. The contact with wqd is sharp with a very thin chill margin and no apparent reaction with wqd. Small phenocrysts of feldspar and round quartz grains are apparent in fresh exposure and are more visible in thin section.

The dike on the left is a strongly laminated (foliated) pink to gray syenite dike approximately 10 feet thick at road level. It trends N35E and dips about 50 SE. The contact with wqd is sharp, cataclastic, and in part mylonitic. K-feldspar clasts are often broken and rotated. Some are zoned. Quartz can be seen, particularly in the finer grained lamellae, as subround grains about 5 cm in diameter. The lamination is found only near the contacts; the center is coarser grained and more granular in appearance with occasional thicker lamellae of dense fine-grained syenite.

3.9 Mt. Major trail. Parking area on west side of Route 11. Small exposure of fine-grained wqd is exposed near the trail head.

4.5 In road cuts to the west, close-spaced exfoliation is seen in wqd. View of the Ossipee Mountains to the west.

4.9 Exposures of wqd.

5.3 STOP 2 Pull far off Route 11 in breakdown lane. Exposures on both sides of road of porphyritic quartz syenite (Albany) cross-cutting wqd. The porphyritic quartz syenite dike is part of a partial ring dike mapped by Modell (aqs). Here, in fresh exposure, it is typically pink, coarse-grained and porphyritic. K-feldspar phenocrysts are very apparent and show some zoning in hand specimen.

The contact between aqs and wqd varies in thickness from several centimeters to 2 meters. It is characterized by a black aphanitic zone some of which has been sheared to form bands of varying color and composition. The ring dike contains occasional xenoliths (wqd, diabase?) a few of which show development of K-feldspar grains. K-feldspar in aqs at the contact is set in an aphanitic matrix which grades rapidly into an equigranular center.

Several diabase and granitic dikes cross-cut wqd at this locality. The diabase has occasional irregular contacts, but contains no apparent evidence of reaction with country rock. Granitic, pegmatitic, and diabase dikes are widespread in wqd.

5.4 Intersection with Route 110.

5.5 Winnipesaukee quartz diorite exposures; rejoin old Rt. 11.

6.1 Enter West Alton, N. H.; wqd boulders.

6.4 Intersection with Rt. 11A. Small exposures along highway for the next several miles are of brecciated diorite invaded by Conway granite.

8.9 Ames Farm.

9.3 STOP 3 Ames monzodiorite (m) is exposed on the top of a small knoll very close to the road. Pull ahead of the exposure and park in the small parking area on the right, or on the small side road also on the right.

The small glacially smoothed ledge of monzodiorite is exposed on the east side of Rt. 11. Beneath the thin buff-gray weathered zone, coarse-grained medium gray monzodiorite is exposed. The fresh rock contains euhedral to subhedral plagioclase to 1 cm in length. Some of the grains have a bluish reflectance and are occasionally rimmed with K-feldspar. Some feldspar, very minor quartz, and commonly hornblende are rimmed with biotite.

Numerous small (3-4 cm) inclusions of wqd and probable metasedimentary rocks are present with thin fine-grained borders. Reaction between melt and xenolith is suggested in many places.

This unit has been mapped to the shore of Lake Winnipesaukee and appears to be continuous with quartz syenite dikes on Diamond and Rattlesnake Islands. The unit, however, is sufficiently different from sqs to warrant a separate designation.

10.5 Continue to left on new Route 11 up hill.

10.6 Small turn off on west side of road. Brecciated Endicott diorite is exposed here. Do not park here, proceed to larger turn off area and scenic area 0.5 miles ahead.

11.1 STOP 4 Scenic View area. Spectacular view of the Ossipee Mountains across Lake Winnipesaukee. Mt. Chocorua is seen to the north against a backdrop of the White Mountains.

CROSS ROAD CAREFULLY!

Brecciated Endicott diorite (bd) is well exposed in a number of outcrops along Rt. 11. The rock is characterized by abundant angular to subrounded blocks of diorite, occasional Winnipesaukee quartz diorite and probable Littleton formation. The blocks are of highly variable size, often rotated, and are separated by Conway granite (cg). The amount of cg varies considerably in short distances although there is no place along Rt. 11 where it is the dominant phase. The invaded blocks show varying degrees of reaction with the granite. Some are mere ghosts in the host granite, some have seriate edges but otherwise show no internal alteration, while others have a sharp completely unaltered character. Both fine- and coarse-grained varieties of diorite are present, some with K-feldspar phenocrysts developed within the block.

The granite is generally medium-grained, but varies depending on width of exposure. It invaded the brecciated diorite on more than one occasion, evidenced by the cross-cutting relations of granitic dikes.

12.3 Glendale, N. H. Exposures on both sides of the road approaching Glendale are of Meredith porphyritic granite (mpg). The granite here is gray, medium-grained and strongly exfoliated. It contains occasional feldspar phenocrysts and numerous inclusions.

12.9 STOP 5 Park behind the Toyota Garage on the left. Walk several hundred yards to the southwest to Lockes Hill. Gilford gabbro is poorly exposed in the pine stand and occasionally as small cliffs on the west and southwest sides of Lockes Hill. The gabbro is weathered dark gray to black in outcrop; fresh, it has a gray medium-grained character with clots of black spheroids. As Modell (1936) pointed out, this unusual gabbro contains spheroids that are composed of poikilitic brown hornblende and stand out in relief, as well as labradorite, augite, and a second green hornblende.

Contacts between the Gilford gabbro and other units are not exposed.

13.2 Junction of Rts. 11 and 11B, turn left at lights.

13.4 Turn left at Rt. 11B south, continue on Rt. 11B following the Gunstock River.

14.9 Junction with Rt. 11A, bear left.

16.3 Mt. Rowe entrance on right.

OPTIONAL STOP 6 Just beyond Mt. Rowe entrance, take left into Gunstock Acres. Be sure VISITOR CARD is visible. Drive to top of steep hill, keep to left at top (please do not sample near chalets).

Exposure of Belknap syenite and spectacular view of Presidential Range to northeast.

Belknap syenite is a coarse-grained gray syenite which weathers to a light gray to pinkish color. The exposures at the top are glacially smoothed. Good samples of this rock can be obtained in several localities in small road cuts near the stop area.

Return to Mt. Rowe entrance, park along entrance road.

16.3 STOP 7 Mt. Rowe entrance. Trap syenite breccia (tsp) exposed in stream bed of Poorfarm Brook from the bridge on Rt. 11 and downstream. This is a small probable vent area as mapped by Modell, containing fine-grained glassy "trap" (trachyte) with abundant fragments of brecciated Belknap syenite. Fragments are blocky to rounded with little apparent reaction with liquid. Plagioclase phenocrysts are common in the "trap". Petrographic character of groundmass is very similar to the coarser-grained syenite.

16.6 OPTIONAL STOP At the base lift station at the Mt. Rowe ski area, new fresh exposures of Belknap syenite have been uncovered. Fresh unaltered samples can be easily obtained at this point.

16.7 STOP 8 Rowes vent agglomerate and Belknap syenite are well exposed in an abandoned quarry just beyond the fence separating the Mt. Rowe ski area and the Gunstock recreation area. The syenite here is cross-cut by a number of dikes related to the vent agglomerate. The syenite is typically coarse-grained and contains perthitic K-feldspar up to 2 cm in length, biotite and little quartz. It is very deeply weathered and probably represents a pocket of preglacial weathered rock.

The agglomerate is quite variable in character and although it is related closely to tsp (Stop 7) it contains fewer xenoliths. Those that are present, however, are clearly defined and are occasionally quite large (2-4 m.), mostly Belknap syenite. Smaller and less frequent xenoliths of Sawyer quartz syenite (pqs), Albany porphyritic quartz syenite (aqs) and Conway granite (cg) are found. Associated dikes are dark gray, aphanitic, and contain only occasional phenocrysts and xenoliths.

17.4 Gunstock Ski Area parking lot. Assemble at the base of the chair lift and ride to the top of Gunstock Mountain (elev. 2140).

STOP 9 will consist of a geologic traverse beneath the chairlift down the mountain. The traverse starts in the Belknap syenite, crosses the Albany porphyritic quartz syenite, the Sawyer pink quartz syenite, the Conway granite and finally brecciated diorite. No unequivocal contacts between units are seen. Best exposures are of bs, cg, and bd. Sawyer and Albany quartz syenites are less well exposed.

ADDITIONAL OPTIONAL STOPS

a. Conway granite is exposed just off Potter Hill Road to the right and behind the Zimmermann Chalet in an abandoned quarry. Permission should be obtained before crossing property. The granite is fresh, pink, coarse-grained and contains quartz, plagioclase and K-feldspar, biotite, and some hornblende.

b. Rowes Vent agglomerate and Belknap syenite are very well exposed on new development roads. The roads are occasionally very steep but are passable. Take the first right on Rt. 11A from the intersection of Rt. 11B and 11A and the first right again on the graveled portion of this road; drive to the top. Outcrops are only recently exhumed by bulldozer activity.

c. Conway granite is exposed in small ledges on the left hand side of Grant Road, the second right beyond the entrance to the Gunstock Ski Area (opposite the Alberg Ski Shop and Restaurant).