THE OSSIPEE RING COMPLEX

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THE OSSIPEE RING COMPLEX, NEW HAMPSHIRE

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INTRODUCTION

The White Mountain igneous province of New Hampshire is part of the New England-Quebec province of McHone and Butler (1984). In New England this province is represented by two periods of igneous activity: the older between 220-155 Ma and the younger between 130-100 Ma (Fig. 1). Plutons of the older White Mountain series are largely composed of alkali syenites, quartz syenites, and metaluminous and peralkaline granites. Silica-undersaturated rocks (nepheline syenites) have only been found at two localities; Rattlesnake Mountain in Maine and the Red Hill complex in New Hampshire. With the exception of the Belknaps, mafic igneous rocks are conspicuously absent. The largest intrusive complex is the White Mountain batholith which consists of multiple ring dikes intruded into and by composite plutons of metaluminous to peralkaline granite. Peralkaline rhyolites are preserved in several localities.

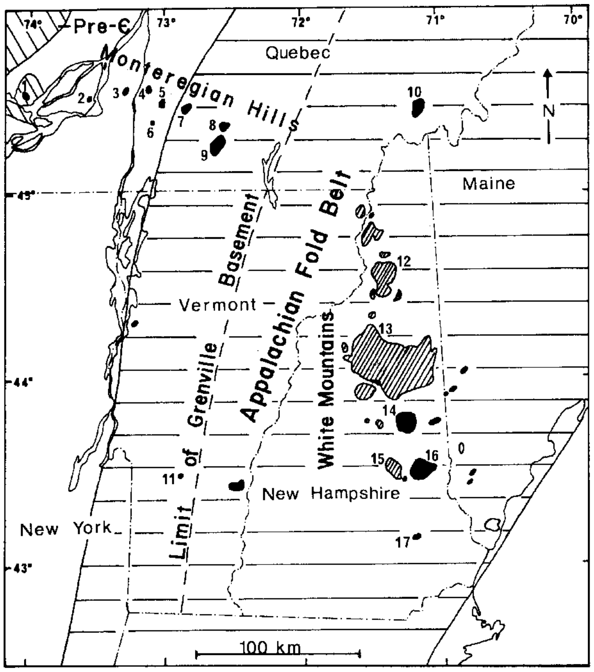

Figure 1. White Mountain and Monteregian Hills igneous provinces. Unfilled plutons emplaced between 220 and 200 Ma; diagonally ruled plutons emplaced between 200 and 155 Ma; filled plutons emplaced between 130 and 100 Ma. Numbered plutons: 1 - Oka, 2 - Mount Royal, 3 - Mount Saint Bruno, 4 - Mount Saint Hilaire, 5 - Mount Rougemont, 6 - Mount Johnson, 7 - Mount Yamaska, 8 - Mount Shefford, 9 - Mount Brome, 10 - Mount Megantic, 11 - Pliny Range, 12 - White Mountain batholith, 13 - Red Hill, 14 - Ossipee, 15 - Cuttingsville, 16 - Belknaps, 17 - Merrymeeting Lake, 18 - Mount Pawtuckaway. LGB - limit of Grenville basement. From Eby (1987).

The Monteregian Hills and younger White Mountain igneous provinces represent the younger period of igneous activity. 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 (which roughly parallels the New Hampshire-Vermont border) 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). Generally the most evolved rocks are syenites and quartz syenites, but biotite granite (Conway) is found at Ossipee and Merrymeeting Lake. An overview of both provinces can be found in Eby (1987).

The White Mountain igneous province is a classic example of A-type magmatism. Chemically the granitoids plot in the A_1 field of Eby (1992). While mafic rocks are scarce in the older White Mountain series, they are relatively abundant in the younger White Mountain series. Mafic volcanics (basalts and andesites) are exposed in the Ossipee complex and mafic plutonics ranging from pyroxenites to diorites are found at Mount Pawtuckaway. Given the presence of the mafic end members, evolutionary models which yield evolved felsic liquids by differentiation of mafic magmas have proven successful. Particularly in the case of Mount Pawtuckaway, low initial $^{87}Sr/^{86}Sr$ ratios indicate that the magmas were emplaced with little contamination by crustal material.

OSSIPEE RING-DIKE COMPLEX

Introduction

The Ossipee ring-dike complex of central New Hampshire is a member of the younger White Mountain igneous province. The topography is shown on the 7.5' Tamworth, Ossipee Lake, Melvin Village, and Tuftonboro quadrangles. The complex is circular in plan view and has a diameter of 14 km (Fig. 2). The almost complete outer ring-dike forms a ridge around the inner basin on the eastern side and forms the outer slopes of the high hills in the western part of the complex. The western third of the complex has a rugged topography and is underlain by basalts and rhyolites. The eastern portion is an interior basin underlain by granite. Maximum relief is approximately 750 m. Ossipee has played a central role in models dealing with the origin of ring dikes (Billings, 1943, 1945; Chapman, 1976) and has long been considered a classic example of a ring-dike complex.

The bedrock geology of the Ossipee complex was originally mapped by Kingsley (1931). Portions of the Ossipee complex appear on the geologic maps for the Mt. Chocorua (Smith et al., 1939), Winnipesaukee (Quinn, 1941), Wolfeboro (Quinn, 1953), and Ossipee Lake (Wilson, 1969) quadrangles. With the exception of the Ossipee Lake quadrangle the geology was based on the original work of Kingsley (1931). The intrusion was remapped by Carr (1980), and his thesis is the basis for the geologic map of the Ossipee complex (Fig. 2). Recent detailed mapping by Kennedy and Stix (2004a, 2004b) has emphasized the volcanic nature of the complex. The geologic description below is largely based on the work of Carr and Kennedy.

General Geology

The Ossipee complex occurs within the Merrimack synclinorium and intrudes the Early Devonian calc-alkaline Winnipesaukee tonalite, the Lower Devonian Littleton Formation, and the Pennsylvanian/Mississipian two mica granite of the Sebago batholith and Effingham pluton. The outer margin is an almost complete ring-dike with multiple intrusive phases. Much of the ring-dike consists of medium to coarse-grained quartz syenite, but locally pink medium- to fine-grained granite and/or porphyritic rhyolite are important components. Within the ring dike abundant mixing and mingling textures can be seen - pyroclastic and porphyritic rhyolite occur as diffuse blobs and dike-like bodies and mafic rocks occur as mingled dikes, blobs, and streaks. The ring-dike is almost vertical, but slightly inward and slightly outward dips have been recorded. The complex is unique in the Younger White Mountain igneous province for the large amount of preserved basalt. The basalts generally occur as inward dipping blocks in the rhyolite. In places thick basalt-rhyolite sequences, which were apparently contiguous, have been preserved, thus suggesting that some of the basaltic and rhyolitic volcanism was contemporaneous. A sequence of thinly laminated beds of andesitic and basaltic ash, with shallow to moderate inward dips, occurs along the northeastern margin of the complex. The ash beds are interpreted to be caldera-type lake-bed deposits. The basalts and andesites are frequently brecciated and may be meso- and mega-breccias related to landslides. On the basis of textural and chemical criteria, multiple phases of rhyolite have been identified. Both

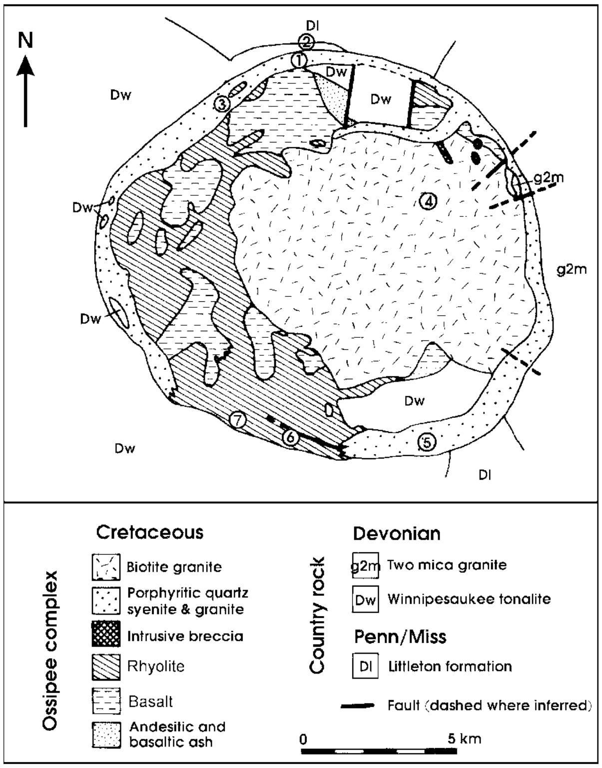

Figure 2. Geologic map of the Ossipee complex modified from Carr (1980). Numbers indicate the locations of the field trip stops.

intrusive and extrusive rhyolite have been identified, but within the complex the majority of the rhyolite formed from large pyroclastic eruptions. The eastern portion of the complex is underlain by pink coarse-grained "Conway" granite. The granite is poorly exposed except at the tops of hills within the interior basin, where rounded and deeply weathered outcrops can be found. Gravity and magnetic data (Sharp and Simmons, 1978) indicate that the complex has a vertical core of mafic rock with a thin granitic carapace. In areas marked by maximum gravity or magnetic anomalies gabbroic and dioritic enclaves are found in the granite. Carr (1980) proposed the following sequence of events for the Ossipee complex. (1) Eruption of basaltic and andesitic magmas from a hypabyssal magma chamber forming ash and flows. (2) Intrusion of basaltic magmas through the volcanic pile forming massive basalts. (3) Rapid intrusion of rhyolitic magmas along dikes disrupting the pile of pre-existing ash and massive basalts and causing the collapse of the pile into the felsic magma. The presence of xenocrystic fragments of quartz and alkali feldspar, and the existence of intrusive breccia pipes with rhyolitic matrix, suggest that this may have been an episode of explosive magmatism. (4) Formation of the outer ring fractures and cauldron subsidence. (5) Emplacement of biotite granite. Since the granite occurs as a sheet above the mafic plug, which may represent the earlier basalt magma chamber, it was suggested that the granitic magma may have been emplaced along a cauldron fracture formed above the earlier magma chamber. (6) Emplacement of "lamprophyric" (basaltic) dikes.

Kennedy and Stix (2004a) emphasized the explosive nature of the volcanic activity and modify the sequence of events as follows: (1) basaltic dikes intrude the pre-collapse volcanic edifice, (2) eruptions of pyroclastic rhyolite and rhyolite lavas lead to the collapse of the magma chamber roof, (3) landslides cascade from the caldera walls into the caldera, and (4) finally the intrusion of quartz syenite and basaltic magmas through the ring-dike fractures.

Lithologic Descriptions

Andesitic and basaltic ash. Ash beds vary in thickness from 1 mm to tens of cms and vary in color from light gray to black. Many of the beds are finely laminated and graded. Identifiable minerals are plagioclase fragments, interstitial brown biotite, magnetite, and tiny euhedral apatites.

Basalt. Two lithologies have been distinguished, one is coarsely porphyritic (Figs. 3a, 3b) and the other is massive and sparsely- to non-porphyritic. Plagioclase is the dominant phenocryst phase and varies from 0.1 to 0.5 cm in size in the sparsely prorphyritic variety and up to 1 cm in size in the coarsely porphyritic variety. Clinopyroxene and biotite also occur as phenocrysts. The groundmass consists of plagioclase, clinopyroxene, amphibole, biotite and magnetite. Some specimens are strongly magnetic. Extensive replacement of plagioclase by epidote has been observed in some specimens. Basalt breccias are also locally abundant and in many localities basalt breccias and basalt lavas are intermixed.

Figure 3a. Porphyritic basalt (OS14). Plagioclase and pyroxene phenocrysts in a flow-banded plagioclase and pyroxene groundmass. Plane light. Width of field of view, 5 mm.

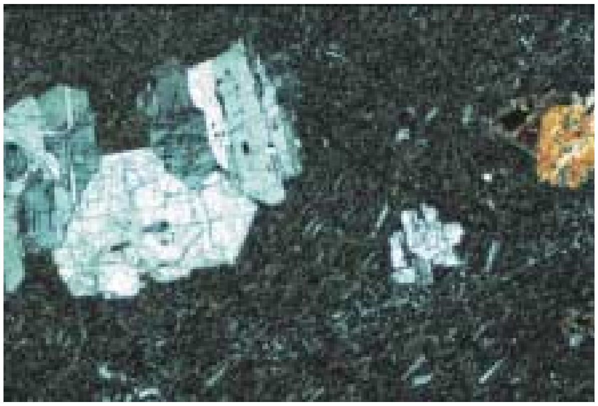

Figure 3b. Same view as Figure 3a, crossed-polars.

Rhyolite. All the rhyolites are mineralogically similar. Phenocrysts are angular to sub-angular alkali feldspar fragments and sub-rounded and embayed euhedral quartz grains. Rare plagioclase and amphibole fragments have been noted. The groundmass consists of quartz, K-feldspar, minor plagioclase, amphibole, and biotite. Basaltic and dioritic enclaves are common in the rhyolites. Hornblende syenite enclaves have also been observed. Many outcrops show a flow foliation. On a textural basis, Carr (1980) distinguished five varieties of rhyolite: (1) small pink alkali feldspar and clear quartz phenocrysts in a dense, black, very fine-grained matrix; (2) cream colored alkali feldspar and gray smoky quartz phenocrysts in a fine- to very-fine-grained dark gray matrix; (3) large pink alkali feldspar and gray smoky quartz phenocrysts in a fine-grained light brown matrix; (4) small cream colored alkali feldspar and gray smoky quartz phenocrysts in a medium- to fine-grained light brownish-gray matrix; and (5) large euhedral to subhedral phenocrysts of pink alkali feldspar and gray quartz in a fine-grained light brown to blue-gray matrix which shows spherulitic textures in thin section. A typical example of fragmental rhyolite is shown in Figures 4a and 4b.

Figure 4a. Fragmental rhyolite (OS17). Broken alkali feldspar and quartz phenocrysts in a fine-grained fragmental groundmass composed of quartz and feldspar. Minor biotite. Plane light. Width of field of view, 5 mm.

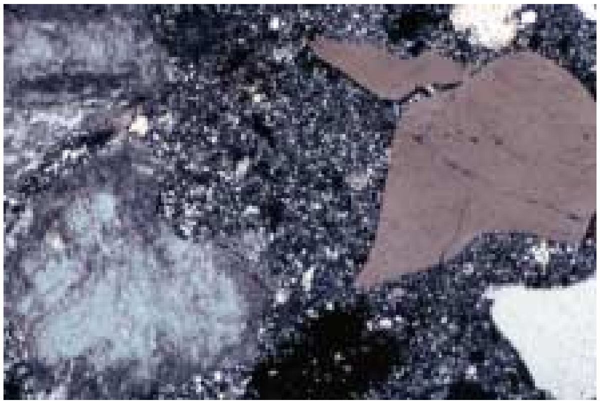

Figure 4b. Same view as Figure 4a, crossed-polars.

Porphyritic quartz syenite. Alkali feldspar and sparse quartz phenocrysts occur in a medium- to fine-grained groundmass of alkali feldspar, quartz, biotite, hornblende and accessory magnetite, ilmenite and apatite and trace zircon (Figs. 5a, 5b). The quartz phenocrysts are partially resorbed. The bulk of the quartz syenite is gray in color, but a somewhat finer grained pink variety has been observed. The groundmass of the pink variety contains abundant quench (graphic) textures. Hornblende syenite, rhyolite, and basalt enclaves are found in the porphyritic syenite.

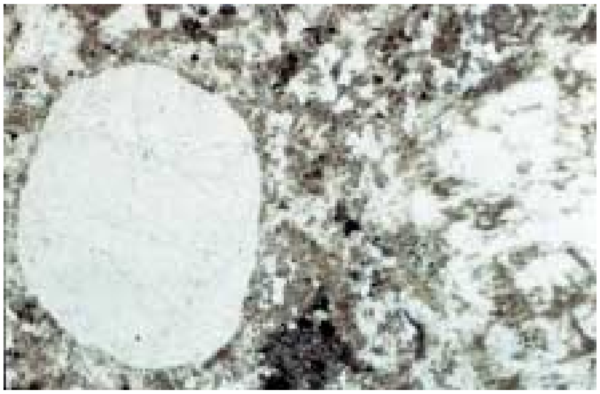

Figure 5a. Porphyritic quartz syenite (OS3). Partially resorbed quartz phenocryst and alkali feldspar in fine-grained matrix. Plane light. Width of field of view, 5 mm.

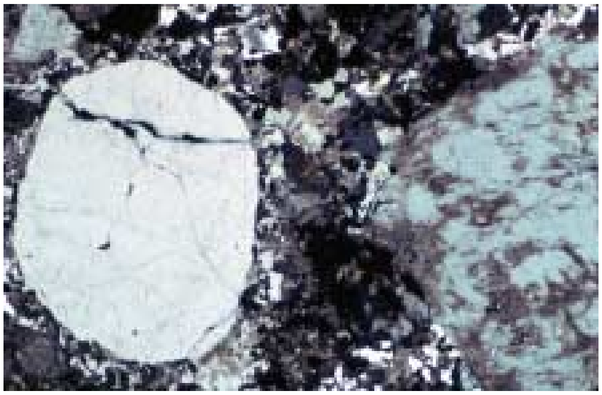

Figure 5b. Same view as Figure 5a, crossed-polars.

Subporphyritic granite. Subporphyritic, medium- to fine-grained granite (Figs. 6a, 6b), pink on fresh surfaces, consisting of quartz, alkali feldspar, minor oligoclase and biotite (often altered to chlorite). A characteristic feature is the intergrowth of quartz and alkali feldspar (graphic texture) in the finer-grained groundmass. Basalt enclaves are occasionally observed.

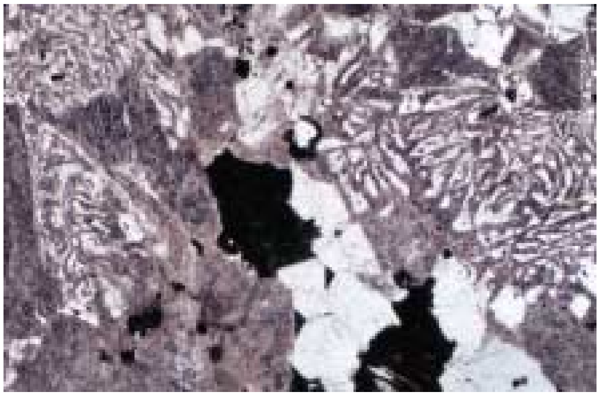

Figure 6a. Subporphyritic medium- to fine-grained granite (OS20). Note graphic texture in groundmass. Plane light. Width of field of view, 5 mm.

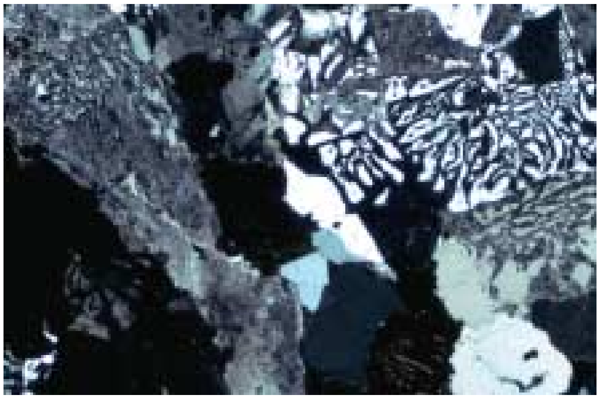

Figure 6b. Same view as Figure 6a, crossed-polars.

Biotite granite. Medium- to coarse-grained, phaneritic to subporphyritic, pink granite (Figs. 5a, 5b). Early maps of the Ossipee complex identified this granite as "Conway" (because of its pink color), but it is clearly not correlative with the Conway granite of the White Mountain batholith. Mineralogically the rock consists of rounded gray quartz, buff-colored alkali feldspar, minor plagioclase and biotite, and rare amphibole. The accessory minerals are fluorite, allanite, zircon, apatite, and opaque oxides. In the subporphyritic varieties quartz and alkali feldspar form the phenocrysts. Miarolitic cavities are locally common and often contain orthoclase and smoky quartz crystals up to 3 cm long. In many localities the granite is cut by pink to buff colored, fine-grained aplite dikes that are mineralogically similar to the granite. The dikes are usually less then 5 cm wide and show no preferred orientation.

Figure 7a. Medium- to coarse-grained, phaneritic, pink granite (OS44). Quartz, alkali feldspar, and brown biotite. Plane light. Width of field of view, 5 mm.

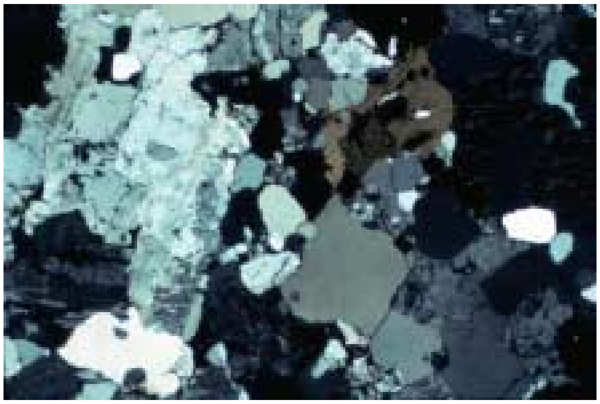

Figure 7b. Same view as Figure 7a, crossed-polars.

Mineral Chemistry

Electron microprobe analyses have been done for feldspars, amphiboles, and iron and titanium oxide minerals from the various lithologic units. These data were obtained by Eby, and the data are available in the form on an Excel spreadsheet on the first author’s web site. A more extensive data set, particularly for the feldspars, obtained by Kennedy will be reported elsewhere.

Amphiboles. According to the classification of Leake et al. (1997) the Ossipee amphiboles are ferroactinolites, ferrohornblendes, and magnesiohornblendes (Fig. 8). Although the data are limited, amphibole compositions tend to fall in three clusters as represented by the lithologic groups rhyolite, basalt - diorite, and quartz syenite. Of note is that amphiboles from the quartz syenites fall into two of the clusters - quartz syenite and basalt-diorite. This observation supports the inference that there was interaction between the basalt and quartz syenite magmas. Amphiboles rare rarely found in the rhyolites, and when found their compositions are distinctly different from the amphiboles in the other lithologic units.

Feldspars. The compositions of feldspars from the various units are projected into the Ab-An-Or feldspar ternary diagram (Fig. 9). The plagioclases from the basalt vary in composition from An_{70} to An_{85}. Plagioclases in the diorite range between An_{15} and An_{25}. Alkali feldspar compositions vary from Or_{90} to essentially pure albite. Of note is that the alkali feldspars fall in low temperature portion of the feldspar diagram, indicating that there has been some subsolidus re-equilibration. The feldspars from the rhyolite fall on the 800°C isotherm, indicating rapid quenching. Also, recall that there is abundant textural evidence for rapid quenching in both the quartz syenites and fine- to medium-grained granites.

Oxide minerals. The common oxide minerals are magnetite and ilmenite. For several of the quartz syenite samples it was possible to calculate equilibration temperatures using the Fe-Ti oxide geothermometer-geobarometer program of Andersen and Lindsley (1988). Calculated temperatures ranged from 684°C to 722°C. For two of the pairs $\log f_{O_2} = -17.116$ and -18.664. For the third pair, $\log f_{O_2} = -13.879$, but this result fell outside the calibration range for the geothermometer-geobarometer. While the calculated temperatures are probably not magmatic, they do indicate rapid cooling. Oxygen fugacities are low and consistent with rapid cooling and water loss.

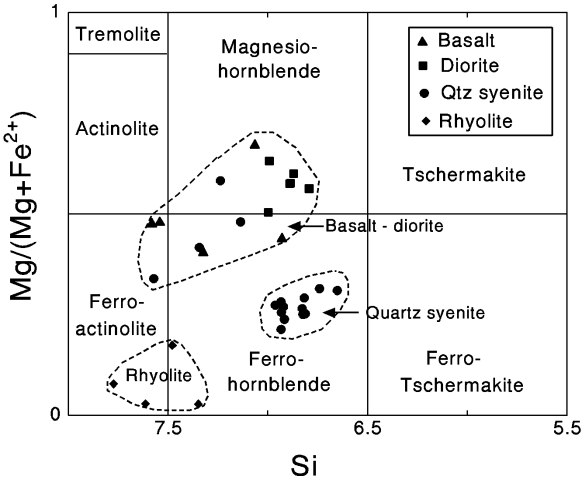

Figure 8. Amphibole classification diagram (Leake et al., 1997).

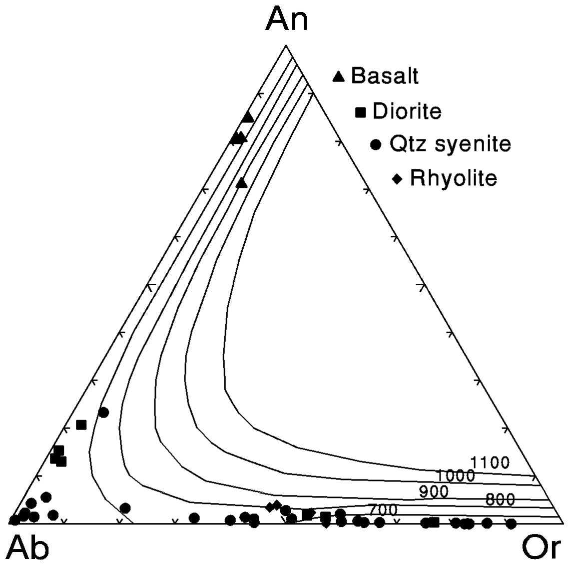

Figure 9. Feldspar compositions projected into the Ab-An-Or ternary diagram. One bar feldspar solvi (°C)are from Nekvasil (1992).

Road Log

0.0 miles, Start, entrance to Chocorua Valley Lumber Company

The first stop is on the south side of Rt. 25 at the entrance (opposite Rt. 113) to the Chocorua Valley Lumber Company. Depending on your route to the Ossipee area this stop is either 19.8 miles northeast of the juncture, in Meredith, of Rts. 3 and 25 or 3.8 miles west of the juncture of Rts. 16 and 25. Please arrive at least 5 minutes before our 9:00 AM start. Note that this location is a 2+ hour drive from Salem, Massachusetts. Hence, we recommend that you plan to spend the night before the field trip in the Ossipee area. Note that this is the Columbus Day weekend.

STOP 1. Granitic facies of the ring-dike. (20 MINUTES) Good outcrops of pink fine- to medium-grained subporphyritic granite are exposed along the access road leading to the lumber yard. The Rt. 25 road cut slightly east of this site exposes the same lithology. In thin section this rock has a finer-grained matrix with graphic intergrowths (Figs. 6a, 6b)indicative of rapid cooling. Sparse, partly digested, basaltic enclaves are found in this unit (Fig. 10). This granitic facies is just outward of the porphyritic quartz syenite which forms the bulk of the ring dike, and it is apparently part of the ring dike. Somewhat similar, but not as quartz-rich, rocks comprise the ring dike in the southwest corner of the Ossipee complex. Contacts have not been observed between this granitic phase and the quartz syenite porphyry.

Figure 10. Basalt enclaves in medium-grained pink granite.

From the lumber yard stop go north on Rt. 113 (directly opposite lumber yard).

0.3 miles. The outcrops are located in the river to the north (left side) of the road opposite the Pioneer Restaurant parking lot.

STOP 2. River outcrop of Winnipesaukee Tonalite (?) (30 MINUTES) According to the New Hamsphire bedrock geologic map (Lyons et al., 1997) we are in the Winnipesaukee tonalite. This is a delightfully complicated outcrop (Fig. 11) which should provoke a great deal of discussion. Hopefully the discussion won't be too heated. On a warm summer day this is a cool spot, so there will be ample opportunity for a cooling-off time. A coarse-grained quartz-feldspar rock that appears to be a pegmatite pod is located along the river bank. This pod occurs within a medium- to fine-grained, gray tonalite (Winnipesaukee?) that contains metamorphic enclaves (Littleton?). The tonalite is cut by pegmatitic and aplitic dikes. A mafic dike, perhaps related to the Ossipee complex, cuts all of the other units. The dike strikes N80E and dips 23N, inwards towards the Ossipee complex. Just upstream from these outcrops are numerous cobbles and boulders of typical quartz syenite from the Ossipee complex.

Figure 11. Mafic dike cutting gray tonalite. Pegmatite pods.

Return to Rt. 25 and turn right (west).

2.2 miles. Flashing yellow light (South Tamworth). Turn left (south) onto Mountain Road. Continue to bridge crossing the Coldbrook.

2.9 miles. Park as far off the road as possible. Other cars will need to get past. The bridge spans the outcrops of interest.

STOP 3. Porphyritic quartz syenite, basalt, and rhyolite. (1.5 HOURS) The Coldbrook has been walked by everyone who has worked on the Ossipees, and every investigator has had a different version of the geology. Kennedy and Stix (2004b) recently described this section in great detail. We will make one stop, the most accessible location, where the road crosses the Coldbrook. Exposed in this area (Figs. 12, 13) are quartz syenite, various examples of mingling fragmental and porphyritic rhyolite, fragmental basalt, intrusive basalt, and a basalt dike. The basalts appear to be mostly fragmental, although there are areas of intrusive basalt that have irregular fluidal shapes and appear to be mingling with the fragmental basalt. The basalt also appears to be mingling with strongly banded fragmental rhyolite. Some of the best pyroclastic textures are seen under the bridge. Continuing upstream, similar mingled fragmental rhyolite and basalt exposures can be seen. Locally the basalts are coarsely porphyritic with abundant plagioclase phenocrysts. Much of the plagioclase has been replaced by epidote giving the rock a greenish cast.

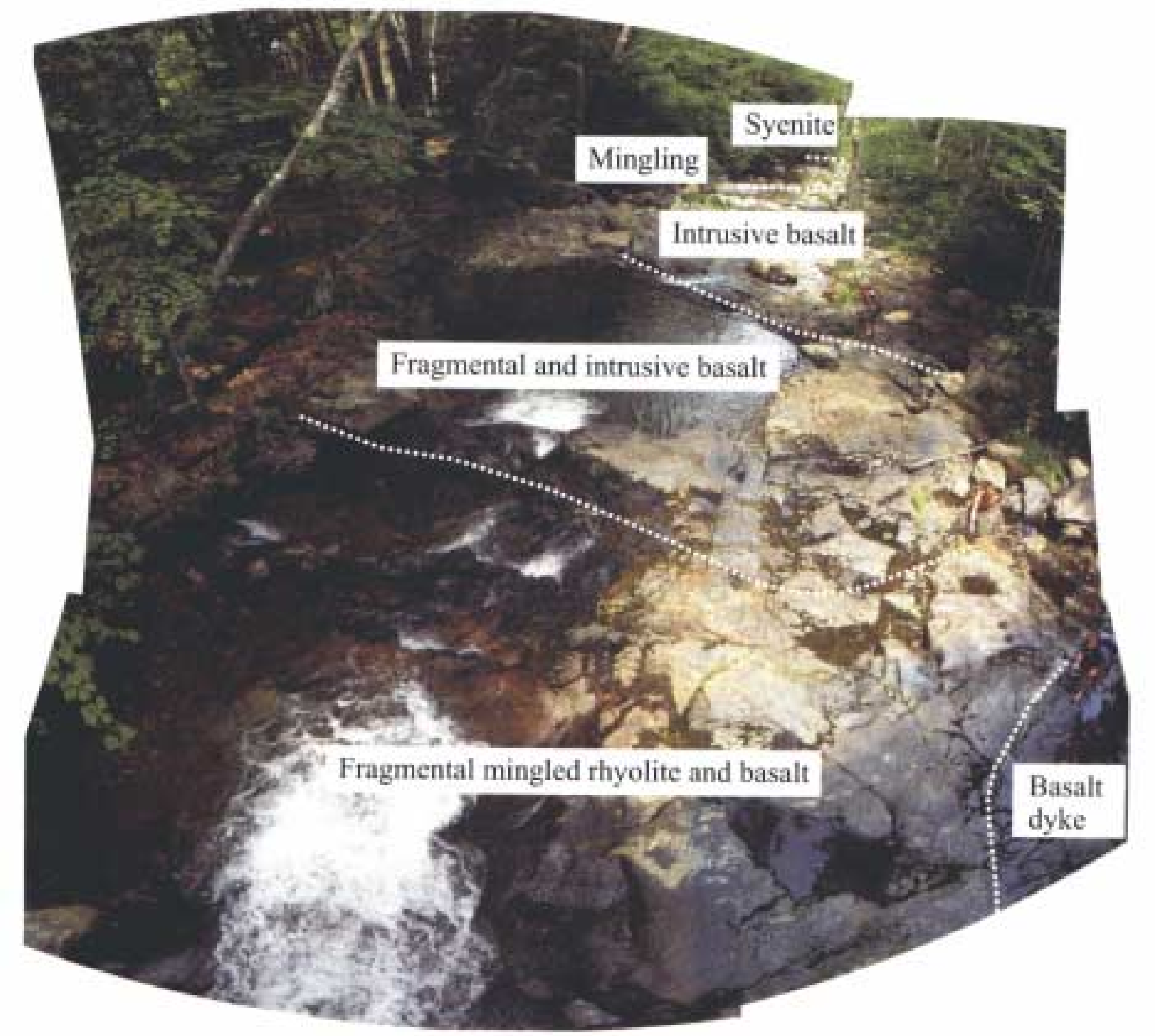

Figure 12. Looking downstream (north) from the bridge crossing the Coldbrook.

Return to Rt. 25

3.6 miles. Turn right (east) onto Rt. 25. Drive east on Rt. 25 to juncture of Rts. 25 and 16

9.0 miles. Turn right (south) onto Rt. 16.

11.6 miles. Turn right (west) onto Pine Hill Road.

15.1 miles. Turn left onto Connor Pond Road.

Figure 13. Looking upstream (south) from the bridge crossing the Coldbrook.

15.2 miles. A large block of reasonably fresh Conway granite is found on the right side of the road. We will stop here to sample the Conway granite.

STOP 4. "Conway" Granite. (15 MINUTES) The "Conway" Granite is poorly exposed and most outcrops, which are found at or near the tops of hills (Fig. 14), are rounded and deeply weathered. At this location recent road work has exposed a large block of reasonably fresh granite. Aplitic layers are also a relatively common feature of the "Conway" Granite, but none are present at this location.

17.8 miles. Turn right (south) onto Ossipee Mtn. Road miles).

Figure 14. Outcrops of "Conway" granite along Pine Hill road.

19.2 miles. In Moultonville turn left (east) to Center Ossipee.

20.1 miles. Just before railroad tracks turn right (south) onto Dare Road (subsequently becomes Chickville Road).

26.8 miles. Tuftonboro. Turn right (west) onto Rt. 171.

27.5 miles. Turn right onto road marked Sentinel Lodge.

28.5 miles. At top of ridge turn right (east) onto Sentinel Baptist camp road.

28.7 miles. Trail on the right side of the road labeled "Ledge". Park well to the side of the road.

STOP 5. Rhyolite. (1 HOUR) Follow the trail to the end (approximately 0.3 miles) where you will find a large cliff face of rhyolite (Fig. 15). Numerous basalt blocks and enclaves are found in the rhyolite along the trail before the ledge. A variety of basaltic enclaves are found in the rhyolite (Fig. 16) exposed on the cliff face. The rhyolite strikes N30E and dips 25NW, towards the center of the Ossipee complex.

Figure 15. Rhyolite on exposed cliff face at end of "Ledge" trail.

Figure 16. Basalt enclaves in rhyolite.

Return to the intersection of Sentinel Lodge road and Rt. 171.

29.9 miles. Turn right (west) onto Rt. 171.

33.1 miles. Jeep trail (also Mount Shaw hiking trail) departs on the right side of the road. Park in the trail head parking spot.

STOP 6. Porphyritic quartz syenite, rhyolite, and basalt. (1.5 HOURS) Follow the jeep trail until it comes to Hunter Brook (approximately 500 m). Porphyritic quartz syenite outcrops is the stream bed. Proceed up Hunters Brook. The outcrop at the beginning of this section is very weathered but in the upstream direction the outcrop becomes fresher. The next unit encountered is intrusive rhyolite and the change from porphyritic quartz syenite to intrusive rhyolite seems to be gradational over a relatively short distance. Continue upstream to outcrops of massive basalt. The abundance of phenocrysts is quite variable, and most phenocrysts are less than 0.2 cm in size. At the upper end of this section a contact with fine-grained rhyolite is exposed. The contact dips steeply inward and there is evidence of shearing. The phenocrysts in the basalt increase in both size and number as the contact is approached.

Continue west on Rt. 171.

36.6 miles. Turn right (north) onto Ossipee Park Road (also marked to Bottling plant).

37.5 miles. Outcrops on the left (west) side of the road.

STOP 7. Quartz syenite and ring-dike. (30 MINUTES) This outcrop shows multiple phases of intrusion. Fine-grained quartz syenite, which contains blocks of massive basalt, crops out at the lower end of the outcrop. In the uphill direction there is an abrupt change to a very porphyritic facies of the quartz syenite. Blocks of fine-grained rhyolite are also found in the quartz syenite.

Return to vehicle.

38.4 miles. The service road intersects Rt. 171. End of Ossipee field trip.

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