MOUNT PAWTUCKAWAY RING-DIKE COMPLEX

By

G. Nelson Eby

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G. Nelson Eby
University of Lowell, Lowell

Introduction

The Mount Pawtuckaway ring-dike complex, a member of the White Mountain magma series, is located in Rockingham County, New Hampshire. The north central portion of the recently published Mt. Pawtuckaway Quadrangle provides essentially complete coverage of the Mount Pawtuckaway complex. The complex occupies an area of approximately 3 square miles, is roughly circular in outline, and the maximum relief is on the order of 500 feet. The mafic rocks, which are easily eroded, underlie the lowlands while the more resistant monzonites form ridges. The only notable exception is a gabbro body which underlies Meloon Hill along the southern edge of the complex. The rocks of the Mount Pawtuckaway complex are intruded into foliated quartz monzonites of the Fitchburg Pluton.

The earliest studies on the Mount Pawtuckaway complex (Jackson, 1844; Hitchcock, 1878; and Smith, 1922) identified the rocks as being 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) carried out a largely geochemical study of the major units, but he does report modal data for some of the lithologies. Between 1981 and 1984 Eby and several University of Lowell students (J. Dadoly, M. Lambert, and J. Plunkett) partially remapped the complex and conducted a relatively extensive petrographic study. This has led to a preliminary revision (Fig. 1) of the geologic map found in Roy and Freedman (1944).

General Geology of the Mount Pawtuckaway Complex

The Mount Pawtuckaway complex is a plug-like structure which apparently extends to depth (Joyner, 1963; Bothner, 1976). Field relations indicate that the mafic rocks preceded the felsic rocks. The earliest mafic rocks are apparently pyroxenites which are now preserved as isolated blocks in the foliated diorite (see Fig. 1 for the locations of the various units). The foliated diorite and hornblende diorite are mineralogically similar, the difference being the presence or absence of foliation. Not all samples of the foliated diorite show foliation and, conversely, some hornblende diorite samples are foliated. These rocks do not show cross-cutting or intrusive relationships. A finer-grained phase of the diorite does seem to intrude some of the coarser-grained rocks. The porphyritic diorite and hornblende-biotite diorite are mineralogically similar, the difference being grain size, and are most likely variants of the same lithology. Mineralogically and chemically they can be viewed as late stage differentiates of the dioritic magma. The arcuate gabbro body found along the southern margin of the complex is distinguished by the anorthite content of its plagioclases (An_{60} to An_{46}), the essentially complete absence of apatite (which is a common accessory in the

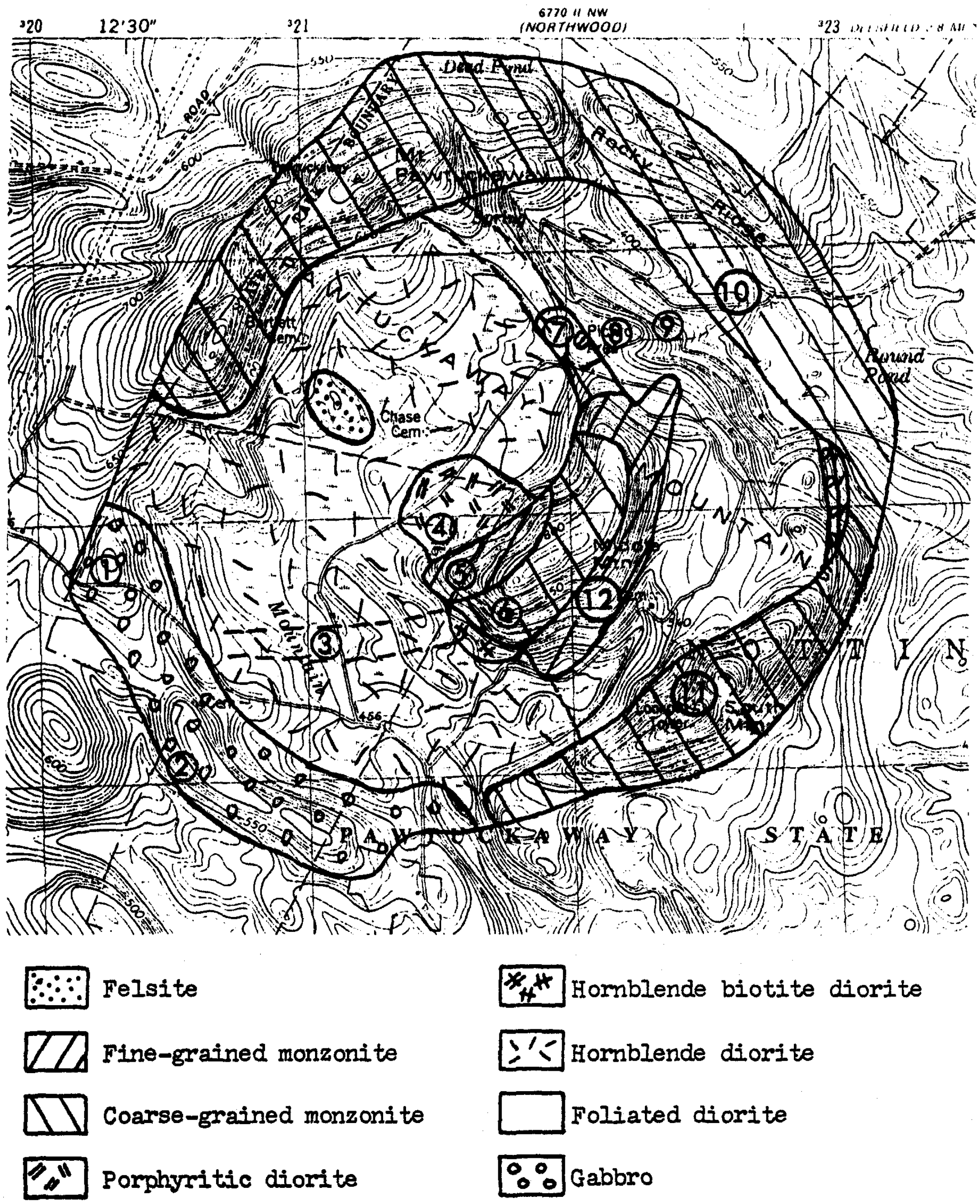

Fig. 1. Generalized geologic map of the Mt. Pawtuckaway complex showing the major lithologic units. Dashed lines indicate possible outline of a second ring dike. Numbers indicate field trip stops. Geology modified from Roy and Freedman (1944).

diorites), and its distinctive trace element geochemistry. 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. The mineral and rock chemistry of the gabbro indicate that the magma from which it crystallized did not serve as a precursor to the dioritic magma.

The fine- and coarse-grained monzonites intrude the mafic units and locally carry mafic inclusions. The only exception to this generalization is the gabbro body in which no monzonite dikes have been found. The central coarse-grained monzonite body locally contains fine-grained monzonite inclusions indicating that it post dates the fine-grained monzonite. In places the central monzonite grades to a syenite. Scattered, isolated outcrops of both fine- and coarse-grained monzonite (and syenite) have been found both northwestward and southwestward of the central body. The northwestward extension is represented by a ridge. This extension of the central body is shown by the dashed lines on the geologic map, and apparently outlines a second ring-dike structure. Scattered outcrops of felsite on a small knoll along the western edge of the hornblende diorite unit indicate the presence of a small felsite intrusive. Similar rocks are found in a quarry in the porphyritic diorite. Lamprophyre and aplite dikes apparently represent the last phase of igneous activity in the Mount Pawtuckaway complex.

Ages determined by a number of methods are currently available for several of the units. The coarse-grained monzonite has been dated as 124 Ma (K-Ar biotite, Foland et al., 1971), 126 Ma (Rb-Sr whole-rock isochron, Eby, unpublished), and 134 Ma (K-Ar biotite, Krueger, personal communication). A Rb-Sr whole-rock isochron gives an age of 129 Ma for the central fine-grained monzonite plug (Eby, unpublished). An apatite fission-track date gives an age of 130 Ma for the foliated diorite (Eby, unpublished), and ages of 129 Ma (K-Ar amphibole) and 123 Ma (K-Ar biotite) have been determined for a sample from the hornblende diorite (Krueger, personal communication). The age data indicate that the igneous activity was confined to a period of 10 m.y., and most likely an even shorter time interval. The one exception is an apatite fission-track age of 107 Ma obtained for a lamprophyre dike located at the top of South Mountain (Eby, unpublished). Similar ages to that of the lamprophyre dike have been found elsewhere in the White Mountain igneous province, including the geographically near Little Rattlesnake Hill (Foland and Faul, 1977), so a minor period of igneous activity of this age in not unlikely for the Mount Pawtuckaway complex.

The available data suggest that the Mount Pawtuckaway complex represents a cross-section through a vertical conduit up which moved a series of magmas closely spaced in time. At least three separate mafic magmas are required to account for the pyroxenites, the diorites, and the gabbros. On the basis of preservation it might be suggested that the magma forming the diorites represents the last of these pulses. In each of the pulses crystallization apparently proceeded from the walls inward, and a number of the mafic rocks are largely composed of cumulus minerals. The conduit eventually became plugged and differentiation of a mafic magma in a chamber at depth led to a monzonitic liquid. The partial evacuation of this chamber and upward passage of the liquid, most likely to the surface, is represented by the fine-grained monzonites. The overlying column of mafic rock then collapsed into the chamber and the extrusion of additional liquid led to the coarse-grained monzonite units. Chemically the fine-grained and coarse-grained monzonites are quite similar suggesting that they were derived from the same magma. A later minor period of activity is represented by the felsites, lamprophyres, and aplites

Petrography of the Various Lithologies

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. A green mineral (hercynite?) is associated with the opaque minerals. 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 and seggregation of mafic from felsic minerals. Plagioclase (An_{60} to An_{46}) and a light pink augite are the major minerals, but olivine is locally abundant. The augites contain oriented minute opaque inclusions. The augites are rimmed and spotted by red-brown amphibole. Apatite occurs in trace amounts.

Hornblende diorite

The grain size is variable from medium-fine-grained to coarse-grained and locally foliation can be found. The plagioclases are 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?) amphibole. 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 and the separation of mafic from felsic minerals. The plagioclase is generally andesine, but it may be zoned to oligoclase and occasionally labradorite cores are found. The pyroxenes are light pink and light green, and where the two varieties occur together the light pink pyroxene constitutes the core. The pyroxenes are spotted and replaced by red-brown and green amphibole, and locally this replacement is almost 100%. The pyroxenes contain oriented minute opaque inclusions, and the preservation of these inclusions in the amphiboles indicates the prior existence of pyroxene. Olivine occurs 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%

Porphyritic diorite and hornblende-biotite diorite

These two rocks are mineralogically similar, the difference being the much coarser grain size of the porphyritic diorite. The plagioclase is generally oligoclase and K-feldspar occurs in minor amounts. Particularly in the porphyritic diorite, the oligoclase is often rimmed by K-feldspar. A green pyroxene is occasionally found, usually largely replaced by red-brown amphibole. Large flakes of reddish-brown to straw-brown biotite usually exceed amphibole in modal abundance. Apatite and opaque minerals are the accessories.

Table 1
Representative Modes for the Mafic Rocks

	Pyrox-enite	Gabbro		Hornblende diorite		Foliated diorite		Porph. diorite	Hb-Bio diorite
	MP73	MP81	MP83	MP1	MP50	MP9	MP75	*	*
Plagioclase	8.3	61.0	66.7	45.6	63.5	45.3	62.9	47	55
K-feldspar	—	—	—	—	—	—	—	10	5
Olivine	18.2	4.8	20.5	—	—	7.0	0.9	—	—
Pyroxene	50.6	10.0	0.4	16.4	1.0	11.0	6.1	—	5
Amphibole	18.2	19.1	5.9	20.4	25.9	23.6	20.0	18	12
Biotite	—	—	—	8.8	1.4	2.4	3.9	17	18
Opaque	4.5	5.1	6.3	6.1	4.7	8.1	4.4	3	5
Apatite	0.2	—	0.2	2.7	3.5	2.6	1.8		

*Modes from Roy and Freedman (1944)

Coarse-grained monzonites and syenites

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 syenites tend to occur towards the center of the large monzonite bodies suggesting that differentiation proceeded from monzonites to syenites. 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 monzonites

The grain size varies from very-fine-grained to fine-grained and some sections have phenocrysts of biotite and hornblende. The major minerals are oligoclase and microperthite. Quartz is interstitial. The amphiboles are green to dark green and the biotites are reddish brown to straw brown. Opaque minerals and apatite occur as accessories.

Felsite

Small phenocrysts of alkali feldspar, plagioclase, pyroxene, and amphibole are found in a fine-grained groundmass of alkali feldspar, plagioclase, pyroxene, amphibole, and opaque minerals. The phenocrystic plagioclase is high oligoclase while the groundmass plagioclase is low oligoclase. The pyroxenes are green and slightly pleochroic. The phenocrystic amphibole is red-brown while the groundmass amphibole is green to dark green. The plagioclase phenocrysts are surrounded by reaction rims and the pyroxene phenocrysts are rimmed by dark green amphibole.

Table 2
Representative Modes for the Felsic Rocks

	Coarse-grained monzonites & syenites				Fine-grained monzonite
	MP8	MP12	MP15	MP49	*
Plagioclase	19.4	31.3	23.8	8.4	40
K-feldspar	46.2	33.6	53.6	83.9	35
Quartz	—	0.5	2.2	2.5	2
Olivine	0.7	0.9	—	—	—
Pyroxene	12.0	13.9	4.0	0.2	4
Amphibole	0.4	6.2	11.3	3.2	7
Biotite	14.6	7.5	3.9	—	9
Opaque	5.4	5.3	1.2	1.8	3
Apatite	1.3	0.8	—	—	

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Road Log

Mileage	
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 101.
1.5	Stop 1. Small pull-off on north side of road. Walk 200 feet north into small clearing for scenic vista of the Pawtuckaway Mountains. Return to the road and walk west past the park service sheds. Foliated outcrops of quartz monzonite of the Fitchburg Pluton are found along the road. Proceeding back toward pull-off, outcrops of fine-grained gabbro on hill just east of park service sheds, which apparently represent a chill zone. The rock coarsens rapidly over a distance of 100 feet. Scattered outcrops in woods on south side of road occasionally show foliation and several lamprophyre dikes are exposed.
2.0	Stop 2. Park by small farm cemetary on south side of road. Follow logging road departing from west side of cemetary 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. The gabbro is differentiated from the other mafic units on the basis of the anorthite content of the plagioclases (An_{60} to An_{46}), the essentially complete absence of apatite, and its distinctive trace element geochemistry.
2.5	Stop 3. Outcrops of medium- to coarse-grained hornblende diorite to the west of the road. Some of the outcrops show a poorly-developed foliation. Also found in the immediate area are outcrops of fine-grained monzonite and diorite. One of the hornblende diorite outcrops is cut by an intermediate dike showing a trachytic texture. Syenite and monzonite dikes are also found cutting the hornblende diorite.
2.8	Stop 4. Walk east 200 feet along logging road. Small quarry located just to the north of the road. This is the best exposure of the porphyritic diorite. At the western end of the quarry coarse-grained monzonite has been engulfed by fine-grained bluish-gray material which may be classified as monzodiorite. Isolated outcrops of this monzodiorite are found in the immediate area. This rock apparently represents one of the last igneous events in the Mount Pawtuckaway complex. Proceeding eastward in the quarry, outcrops of porphyritic diorite are observed. These outcrops are cut by both felsite and fine-grained monzonite dikes. The felsite appears to be identical to the rock which underlies a small knoll along the western edge of the hornblende diorite body (shown as a small felsite plug on the geologic map).

Stop 5. 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 woumd 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. On fresh surfaces the rock is greenish-black.

Stop 6. 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.

3.4 Stop 7. 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 4 and Stop 7. Walk back (west) along the road several 100 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 found several outcrops of fine-grained monzonite. These outcrops are texturally interesting because blebs of coarse-grained monzonite are found in the fine-grained monzonite. In thin section no sharp boundaries are observed, but simply a distinct change in grain size. If time permits, continue westerly along the ridge. Scattered outcrops of coarse- and fine-grained monzonite are found along with outcrops of foliated diorite. This ridge may represent a continuation of the monzonite bodies which would suggest the presence of a second ring dike.

Stop 8. Return to 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. Outcrops of pyroxenite are found throughout this area and in places they have been intruded and engulfed by fine- to medium-grained diorite. The pyroxenites, therefore, must represent an early stage of the magmatic history.

Stop 9. 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 found in contact, the fine-grained diorite appears to intrude the medium-grained diorite. The foliation parallels the contact with the coarse-grained monzonite and dips steeply inward.

Stop 10. Continue eastward to Round Pond. Outcrops of coarse-grained monzonite north of road and just west of brook carry inclusions of fine-grained diorite. A mafic dike cutting the monzonite is exposed in the stream bed.

4.2 Stop 11. Continue southward on loop road to parking area for fire tower trail. Proceed up trail to top of South Mountain. Excellent exposures of the coarse-grained monzonite are found along the upper portion of the trail. Fresh samples have a definite greenish cast. A number of lamprophyre dikes are exposed in the immediate area of the fire tower. An apatite fission-track date for one of these dikes gives an age of 107 Ma. At the southern end of the fire tower outcrop, a lamprophyre dike has been disrupted and engulfed by aplite.

Stop 12. Optional. Climb Middle Mountain directly across from the fire tower. The fine-grained monzonite tends to be slightly coarser on this side of Middle Mountain and mafic inclusions are relatively common. Continue on into the coarse-grained monzonite unit which locally grades into syenite.

Continue around the loop road to the starting point. At the time this field guide was written, the telephone company was putting in a line and blasting for the poles provided fresh samples of hornblende diorite and foliated diorite. These samples can be collected along the east-west segment of the loop road.