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IGNEOUS ROCKS OF THE MERRYMEETING LAKE AREA OF NEW HAMPSHIRE

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ABSTRACT

The Merrymeeting Lake area, like several other small areas in central New Hampshire, has a considerable variety of igneous rocks grouped together. Rock types include, from oldest to youngest, leucorhyolite, diorite-gabbro, granodiorite, granite, granite porphyry, and several dike rocks.

The leucorhyolite may be extrusive, but the other rocks are intrusive. The intrusions cut sharply across the foliation and contacts of the older rocks. They are mainly round or oval in ground-plan. Field relations indicate the cauldron subsidence method of intrusion, which is the same as that in near-by areas.

Evidence supports the correlation of these rocks with the White Mountain magma series of possible Carboniferous age.

The variety of rock types indicates considerable magmatic differentiation. Similarity to other areas of White Mountain magma series probably indicates similar differentiation.

Introduction[1]

An important development in recent studies in New Hampshire (mainly by Billings and his students) has been the demonstration that the igneous rocks may be grouped, on the basis of age, structural relationships, and petrographic characters, into several magma series. The White Mountain magma series of possible Carboniferous age is perhaps the most interesting because of the extensive differentiation and the unusual rock types and structures. Characteristically in this series, rock types of considerable variety are grouped in rather restricted areas. Most of these areas have been described recently, but the Merrymeeting Lake area has not been described previously.

The reasons for assigning these rocks to the White Mountain magma series will be given more fully after the descriptions of the rocks.

General Setting

The Merrymeeting Lake area is a mass of White Mountain magma series rocks which, like the Ossipee Mountains (Kingsley, 1931), the Belknap Mountains (Modell, 1936), Red Hill (Quinn, 1937), a small area of syenite at the Rattlesnakes just northwest of Squam Lake, and Green Mountain, rises above the lowland of Lake Winnipesaukee. The Merrymeeting Lake area is about as large as the Ossipee Mountains and the Belknap Mountains (Fig. 1). It is less complicated than the Belknap Mountains, however, and is not so definite a topographic unit as either.

Older Rocks

Metamorphic Rocks

The older rocks are lime-silicate rocks and schist, both of sedimentary origin. On the basis of lithology and structure the schist is correlated tentatively with the early Devonian Littleton formation of the Littleton, New Hampshire, area (Billings, 1935; Billings and Cleaves, 1934). The lime-silicate rock may be a member of the Littleton formation or it may be older.

The lime-silicate rock consists largely of diopside, actinolite, quartz, plagioclase, zoisite, and calcite. There are also beds of mica schist. The foliation generally parallels the bedding. Small folds are common.

The lime-silicate rock grades upward into thin-bedded quartz-mica

[1] The senior author while studying the Wolfeboro area discovered an area of White Mountain magma series rocks extending southward into the Alton quadrangle, which quadrangle is being studied by the junior author. Because the rocks in the two quadrangles are so definitely a unit it was decided to prepare a joint paper describing them. The senior author did the field work in the Wolfeboro quadrangle, north of Lat. 43° 30′, the junior author worked the area to the south, and several days were spent in the field together. The laboratory work was done by the senior author at Brown University. The senior author's work was supported by a grant from the Bache Fund of the National Academy of Science.

schist of the Littleton(?) formation. A small mass of slabby quartzitic schist with many small flakes of graphite isolated at the top of Copple Crown Mountain is of unknown relation to the other metamorphic rocks. The foliation of the schist is generally parallel to the bedding, and both are considerably contorted in the southern part of the area, although of

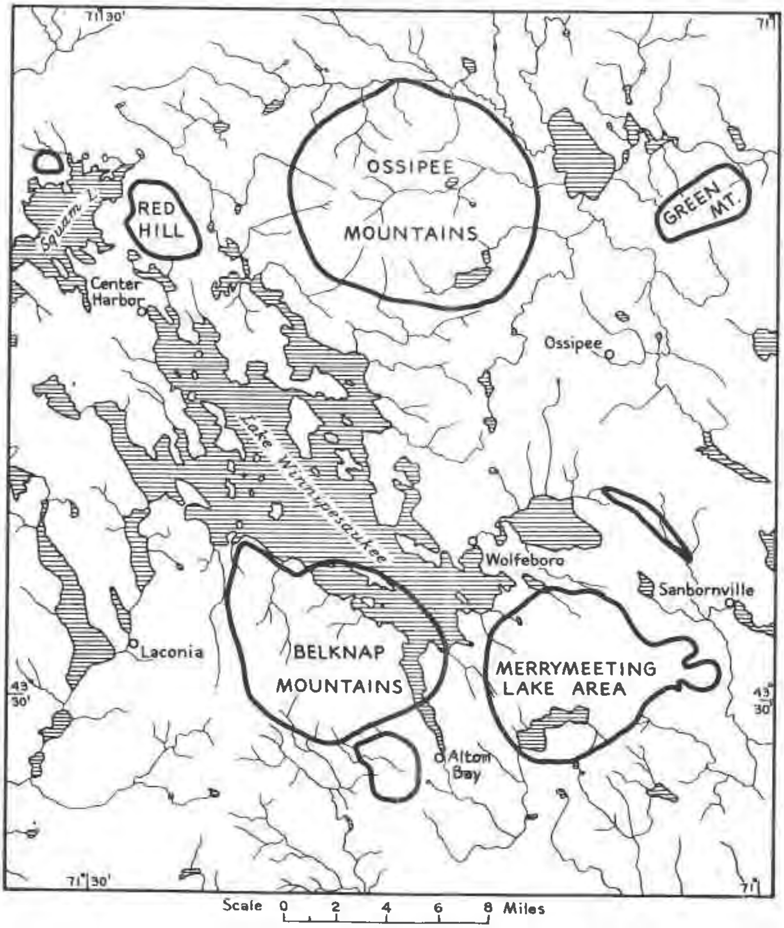

FIG. 1. Areas of the White Mountain magma series in the Winnipesaukee region of New Hampshire.

simpler structure to the north. The detailed structure of the metamorphic rocks has not been determined, but the rocks of the White Mountain magma series are known to cut sharply across the foliation. The cross-cutting relationship is further shown by the way in which the Conway granite cuts across the contact of the schist and the Winnipesaukee quartz diorite (Fig. 2).

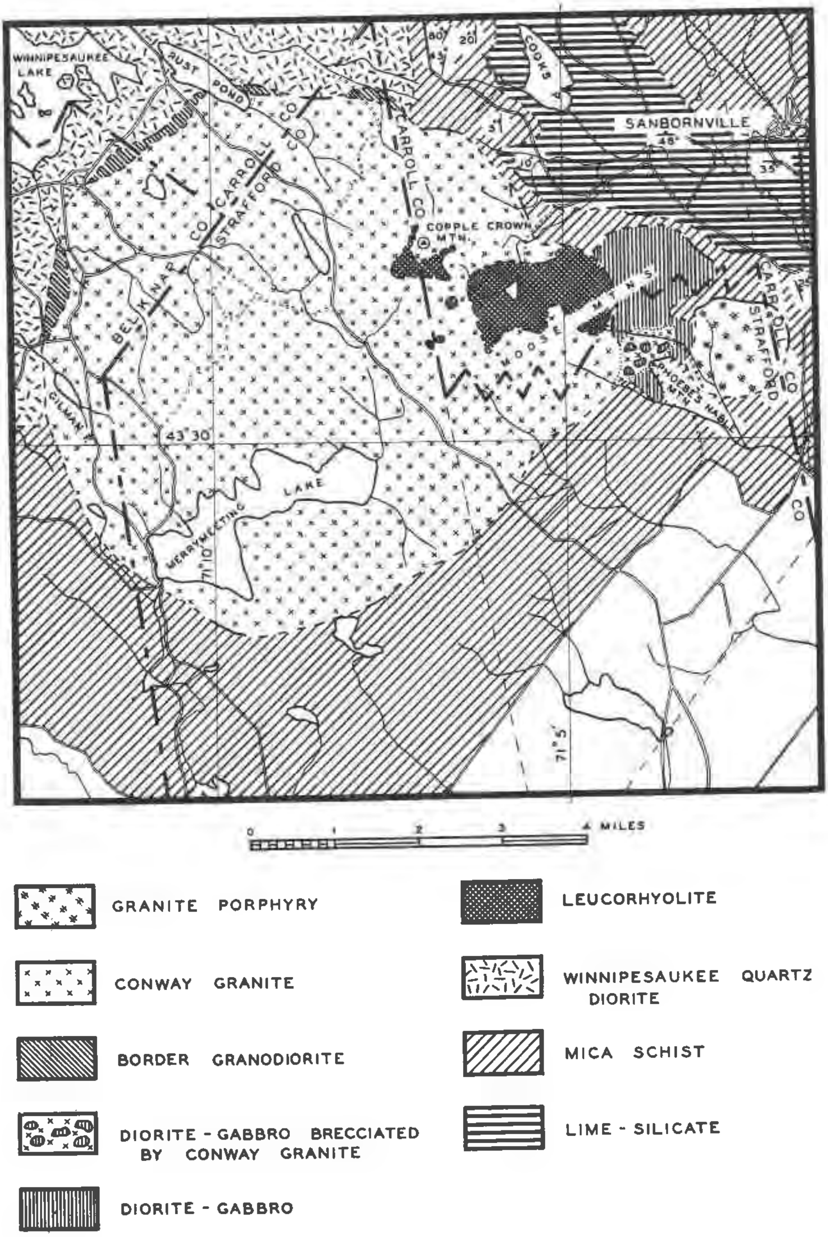

FIG. 2. Geologic map of the Merrymeeting Lake area of New Hampshire.

Winnipesaukee Quartz Diorite

The northwest part of the area is underlain by the Winnipesaukee quartz diorite, which is a member of the New Hampshire magma series of probable late Devonian age (Billings, 1935). It is one of the largest intrusions in this part of New Hampshire, and the Winnipesaukee lowland, which is one of the largest topographic features in New Hampshire, is caused by the more rapid erosion of this rock. It is chiefly quartz diorite, or tonalite, but in places it is granite or granodiorite. Although usually scarce or absent, here and there orthoclase or microcline constitutes up to 40 or 50 per cent of the rock. Considerable quartz is usually present and shows abundant cracks and wavy extinction. Biotite is the main or sole dark constituent. On several islands in Lake Winnipesaukee, especially Bear Island and Mark Island, hornblende is present. Accessories are zircon, apatite, iron ore, sphene, and epidote. At many places a rather faint almost vertical foliation trends almost north-south. The quartz diorite tends to be concordant with the foliation of the schist.

Small pegmatite and aplite dikes are abundant at most outcrops of this rock. The pegmatite usually contains feldspars, quartz, micas, and rarely hornblende, beryl, or tourmaline.

White Mountain Magma Series

General Statement

The rocks of the White Mountain magma series in the Merrymeeting Lake area range from gabbro to granite and from coarse-grained to fine-grained. Most of them are intrusive, but some may be extrusive. Granite of the Conway type is by far the most abundant rock.

Leucorhyolite

On some of the summits and on the northwest slopes of the Moose Mountains, and on the upper part of the Copple Crown Mountain are extensive outcrops of leucorhyolite.

This rock is light gray to flesh or pink and is generally porphyritic with phenocrysts of feldspar, biotite, and quartz. The phenocrysts are usually about 3 to 4 millimeters across and may be up to 8 millimeters across. The structure is massive.

The main constituent is microperthite, which is present both as phenocrysts and in the groundmass. The groundmass is mainly microperthite and quartz, in certain places in rude intergrowth. Oligoclase (An_{12-19}) occurs as phenocrysts and in the matrix. Biotite, the main mafic mineral, has the following optical properties: biaxial negative; β and $\gamma = 1.652 \pm .001$ to $1.646 \pm .001$; Y and Z=brown, X=light yellowish-brown; 2V very small. Green amphibole similar to that in the Conway granite is sparse. Accessories are iron ore, zircon, apatite, sphene, and allanite. The mode of the rock is given in Table 1.

TABLE 1. MODES OF MAIN ROCK TYPES IN THE MERRYMEETING LAKE AREA OF NEW HAMPSHIRE

	Diorite-gabbro			Range of diorite-gabbro	Border grano-diorite Wo 24	Conway granite Wo 32	Conway granite border phase Wo 23	Leuco-rhyolite Wo 99	Granite por-phyry Wo 90
	Wo 58	Wo 63	Wo 73						
Microperthite			11	0–15	8	55	42	59	51
Plagioclase	52	63	64	50–81	57	20	36	24	13
Quartz		1	8	0–13	11	22	15	15	32
Biotite	4		7	0– 7	6	3	6	2	3
Amphibole		24	4	0–34	16		1		
Pyroxene	30		4	0–30					
Magnetite	9	2	2	1– 9					
Sphene		2		0– 2					
Accessories				0– 2	2				1
Alterations; chlorite, etc.	5	8		0– 8					
	100	100	100		100	100	100	100	100

Wo 23—Small abandoned quarry 1.9 miles southwest of Rust Pond.
Wo 24—1.3 miles southwest of Rust Pond, just south of county line.
Wo 32—Just north of the road corner which is 2.0 miles southwest of Rust Pond.
Wo 58—East end Moose Mountains, 0.8 mile north of Phoebes Nable Mountain.
Wo 63—South slope of Phoebes Nable Mountain, 0.2 mile south of summit.
Wo 73—North slope of Moose Mountains, in northwest part of diorite-gabbro area.
Wo 90—Brook bed, near southwest edge of granite porphyry area.
Wo 99—Just west of summit of Copple Crown Mountain.

Similar rocks in other areas of the White Mountain magma series have been described as volcanics. These rocks may also be extrusive, but there is no flow structure or other good evidence of volcanic origin.

The leucorhyolite is older than the Conway granite, as indicated by inclusions of it in the Conway granite on Copple Crown Mountain and near the main summit of the Moose Mountains. Its relationships to the other rocks are not shown, except that a few inclusions of a similar rock have been seen in the gabbro. Probably the leucorhyolite is the oldest in the White Mountain magma series. In other areas of the White Mountain magma series, rhyolitic and other types of extrusions are commonly the oldest of the series (Chapman, 1940, p. 209).

Diorite-gabbro

On the east end of the Moose Mountains and on the slopes of Phoebes Nable Mountain are outcrops of diorite and gabbro. The rock is quite variable in composition and texture, but all types seem to belong to the same intrusion. This rock is intrusive into the schist, is perhaps intrusive into the leucorhyolite, is intruded by the Conway granite, and is probably intruded by the granite porphyry. It appears to be the oldest of the White Mountain magma series rocks with the exception of the leucorhyolite.

The rock ranges from gray to dark gray in color. Near the top of the Moose Mountains it carries considerable pinkish potash feldspar. On the southeast slope of the Moose Mountains, near the border of the diorite-gabbro mass, it contains considerable pale green pyroxene. A dark heavy type occurs on the south slope of Phoebes Nable Mountain and on the northeast slope of the Moose Mountains. The grain size varies from about 1 to 3 or 4 millimeters. The rock is usually massive, but the finer diorite tends to have slabby jointing. In general, the fine-grained dioritic types are intrusive into the coarser gabbroic types. All types seem to have been intruded as a liquid.

The main constituent is plagioclase. It ranges from An_{35} to An_{55}, and much of it is near An_{50}. Here and there microperthite is present in large irregular grains.

Amphibole, the most abundant mafic mineral, varies in optical properties as is indicated by the following types: (*a*) $\alpha=1.664\pm.002$, $\beta=1.679\pm.001$, $\gamma=1.689\pm.001$; 2V large, X=light brown, Y=brown, Z=dark brown, Z>Y>X; Y=*b*, maximum extinction angle in vertical zone=27°; dispersion moderate; (*b*) $\alpha=1.634\pm.002$, $\beta=1.647\pm.001$, $\gamma=1.656\pm.001$; 2V large, X=almost colorless, Y=light green, Z=light green; Y=Z>X; Y=*b*; maximum extinction angle in vertical zone=29°; dispersion moderate.

Pyroxene is present sparingly in several places and comprises about 30 per cent of the rock at the east summit of the Moose Mountains. There it is intergrown in ophitic texture with plagioclase. It has the following optical properties: $\alpha=1.686\pm.001$, $\beta=1.702\pm.001$; $\gamma=1.724\pm.002$; 2V large; maximum extinction angle in vertical zone=38°; almost colorless.

Biotite, present in most specimens, has optical properties near: β and $\gamma=1.647\pm.001$, 2V very small, X=pale yellow, Y and Z=dark reddish-brown.

Quartz is present as scarce interstitial grains, many of which are rather large considering that the quartz makes up a very small portion of the whole rock. A few small patches of micropegmatite were seen.

Accessory minerals and alterations include: iron ore, abundant needles of apatite, sphene, zircon, epidote, pyrite, muscovite, chlorite, limonite, calcite, and serpentine.

Several representative modes of this rock are given in Table 1.

Intrusion Breccia

To the north and west of Phoebes Nable Mountain is an area of intrusion breccia, a fine-grained rock of granitic composition, probably a phase of the Conway granite, with inclusions of dioritic composition which range from small pieces a few inches across to blocks several feet across. Some of these dioritic blocks are similar to the diorite-gabbro types; others are porphyritic and not found in the diorite-gabbro.

The porphyritic diorite has a fine-grained groundmass and plagioclase phenocrysts up to 2 or 3 millimeters across. Plagioclase (An_{40-45}) comprises about three-quarters of the rock and is somewhat zoned. Amphibole, which comprises about a quarter of the rock, has the following optical properties: $\alpha=1.649\pm.002$, $\beta=1.668\pm.001$, $\gamma=1.675\pm.001$; 2V about

60°; X=light yellowish-brown, Y=brownish-green, Z=green; Y=Z>X; Y=b, maximum extinction angle in vertical zone=28°. Accessories include iron ore, sphene, and apatite. Small inclusions of this type of rock are found at many places in the large area of Conway granite and at many occurrences of Conway granite in other parts of New Hampshire; it is believed to be a differentiate formed below the present surface and carried up by the invading Conway granite.

The breccia contains inclusions of schist also. On Phoebes Nable Mountain it appears that first the diorite invaded the schist and enclosed blocks of it, and that later the granite came in and enclosed blocks of both.

This breccia resembles somewhat the intrusion breccias of the Belknap Mountains (Modell, 1936, pp. 1899–1900) and is probably genetically related to them. The ring-dike structure, so well developed in the Belknap Mountains, is generally considered to involve tensional collapse and that would probably favor brecciation.

Border Granodiorite

Along the northwest margin of the large Conway granite mass is a discontinuous outcrop of granodiorite. It intrudes the Winnipesaukee quartz diorite and is itself cut by the Conway granite. Brecciation by the Conway granite is exposed on the hill just east of Rust Pond and along the brook about 1½ miles east of Rust Pond. The arcuate shape of the granodiorite outcrop suggests the ring-dike structure, but the shape of the inner contact of the granodiorite has been determined by the later Conway granite intrusion rather than by the granodiorite intrusion itself. The original shape and extent of the granodiorite are unknown. The many small inclusions of granodiorite in the Conway granite to the south and east of this arcuate mass suggest that the granodiorite may have been much more extensive than now.

The granodiorite is gray to dark gray and generally has a "pepper and salt" appearance. The texture is fine with grain size generally about 1 or 2 millimeters. Some phases have amphibole needles 3 or 4 millimeters long.

The main constituent is zoned plagioclase (An_{35-52}, generally andesine). Large irregular grains of microperthite, interstitial quartz, and a little micropegmatite are usually present. Amphibole and biotite are the chief mafics. The amphibole is generally in irregular grains and has optical properties near the following: $\beta=1.680\pm.001$, $\gamma=1.687\pm.001$; 2V moderate to large; X=light yellowish-brown, Y=greenish-brown, Z=dark brownish-green, Z>Y>X; Y=b, maximum extinction angle in vertical zone=24°. In places the amphibole is pale green. Biotite is common and has the following optical properties: β and $\gamma=1.677\pm.001$; Y and Z=dark brown, X=light yellowish-brown. A very little pyroxene was seen in thin sections. Among the accessory minerals are irregular grains and long crystals of iron ore, abundant needles of apatite, sphene, and zircon. A mode of this rock is given in Table 1.

Conway Granite

By far the most abundant rock of the White Mountain magma series is the Conway granite. It is finer-grained and less pink than the typical building stone quarried at Redstone, New Hampshire, the type locality, but is similar to what is called Conway granite in the Belknap Mountains and to the rock at Green Mountain in Effingham. It appears to be the youngest of the rocks of the White Mountain magma series, with the exception of the dikes and possibly the granite porphyry. The Conway granite underlies a great circular area and is fairly uniform, except for a finer-grained gray phase which has been quarried just north of Gilman Pond and at a few other places. A similar phase is exposed along the road just west of Merrymeeting Lake. This finer rock is considered to be a phase of the Conway granite; it differs only in the finer grain, the gray color, and a greater proportion of plagioclase. The typical Conway granite of this area is characterized by a pinkish cast, which is most apparent at a distance, by small inclusions of dark diorite and granodiorite, and by miarolitic cavities and druse minerals along joint faces. The minerals of the druses are usually the same as those in the granite—crystals of microperthite, plagioclase, quartz, and biotite—but just north of Gilman Pond there are black needles of tourmaline ($\epsilon = 1.642 \pm .001$, $\omega = 1.666 \pm .001$; ϵ=faint brown, ω=dark gray, slightly bluish) and a little stilbite (Gillson, 1927). Great blocks of this granite are common in the glacial drift, and massive bluffs are common on the southeast sides of the hills.

Occasional small dikes having the appearance of aplite are found in the Conway granite, and microscopic examination reveals that they are almost entirely micropegmatite.

The grains are commonly 1 to 3 millimeters across, but some biotite flakes and amphibole needles attain 10 millimeters. The structure is massive.

Microperthite, the chief constituent, occurs usually in rather large Carlsbad twins. Oligoclase usually shows some zoning and ranges in composition from An_{12} to An_{20}, with much of it being about An_{16}. Small oligoclase crystals are commonly enclosed or partially replaced by microperthite. Quartz is present in fairly large grains and along the contacts of other minerals. It partially replaces the feldspars. Biotite, the most abundant mafic, appears to be replaced along the edges by quartz and the feldspars. Optical properties of biotite have been determined as follows: $\alpha = 1.625 \pm .002$, β and $\gamma = 1.666 \pm .001$; 2V very small; X=light brown, Y and Z=dark brown and in places with a greenish cast. These properties vary from place to place; β and γ have been found as high as $1.678 \pm .001$ and as low as $1.653 \pm .001$. Amphibole is generally present in small amount. The following optical properties are typical of the amphibole: $\alpha = 1.686 \pm .002$, $\beta = 1.703 \pm .001$, $\gamma = 1.708 \pm .001$; 2V moderate; X=light yellowish-brown, Y=greenish-brown, Z=brownish-green, $Z > Y > X$; $Y = b$, maximum extinction angle in vertical zone 28°; dispersion moderate $v < r$. Accessories and alterations include iron ore, zircon, apatite, allanite, sphene, epidote (?), chlorite, muscovite, and hematite. Modes of this rock are given in Table 1.

Granite Porphyry

East of the main mass of White Mountain magma series rocks, granite porphyry crops out rather extensively on several hills, but fresh specimens are most readily obtained in the brook near the west margin of the mass. This rock intrudes the schist and probably the diorite-gabbro.

The granite porphyry is light gray where fresh and yellowish or brown where weathered. The grains of the groundmass are mainly less than 1 millimeter across. Phenocrysts of feldspars and quartz constitute a large portion of the rock. Most of them are about 5 millimeters across, but some of the feldspars are as much as 15 millimeters across. Both plagioclase and potash feldspar are present and show twinning.

Microperthite, the main constituent, forms phenocrysts and much of the groundmass. Many of the phenocrysts are twinned according to the Carlsbad law. Oligoclase (An_{10-15}) occurs in irregular grains in the groundmass and as phenocrysts. Quartz forms irregular grains in the groundmass and irregular phenocrysts. Biotite is the main mafic mineral and has the following optical properties: β and $\gamma = 1.660 \pm .001$, $\alpha = 1.620$ (calculated from the birefringence); 2V very small; pleochroism dark brown to light brown. A very few small fragments of bluish amphibole were seen. Accessories include iron ore, apatite, zircon, allanite, and sphene. The mode of this rock is given in Table 1.

Dikes

In almost all the areas of White Mountain magma series there are many dikes of various types, owing, no doubt, to the great amount of differentiation of the magma. Dikes are common in the Merrymeeting Lake area, also, but not so common as at Red Hill (Quinn, 1937, pp. 390–394) or the Belknap Mountains. No study of them was made, but their appearance in the field indicates that they are similar to those at Red Hill and the Belknap Mountains.

Structure

The leucorhyolite may be extrusive. The present mass of it is only a remnant left after the intrusion of the Conway granite. Both the leucorhyolite and the schist mass at the top of Copple Crown Mountain are probably pendants from, or inclusions near, the roof of the large Conway granite intrusion.

The intrusions cut sharply across the older rocks, and affect neither the foliation of the metamorphic rocks nor the contact of the schist and the Winnipesaukee quartz diorite.

The diorite-gabbro, the Conway granite, and the granite porphyry form circular areas, although the diorite-gabbro is somewhat irregular. The border granodiorite has the shape of an incomplete ring-dike, but it may have been intruded in some other form, and its present shape may be due to the later intrusion of the Conway granite, as explained in the description of the border granodiorite.

There seems to be sufficient evidence here to reveal the method of emplacement of the intrusions. The cross-cutting relationship shows that the intrusions did not thrust aside the older rocks, though they may have pushed them up or the older rocks might have sunk. The schist block at the top of Copple Crown Mountain and the masses of older leucorhyolite on the upper slopes of Copple Crown Mountain would be difficult to explain if the older rocks had been pushed up, but seem to fit in well with the subsidence explanation as roof pendants or inclusions a short distance below the roof. Down-sinking is a demonstrated process in New Hampshire and elsewhere, and there is good reason to believe that solid rocks are generally more dense than magmas of about the same composition. Furthermore, the almost circular areas of these intrusions, especially the Conway granite, support the subsidence idea. Similar shapes characterize intrusions in areas where cauldron subsidence has been demonstrated, as, for example, the near-by Ossipee Mountains (Kingsley, 1931), the Belknap Mountains (Modell, 1936), the Percy region of New Hampshire (Chapman, 1935), and Ascutney Mountain, Vermont (Chapman and Chapman, 1940). Cauldron subsidence may produce circular intrusions, ring-dikes, or both, depending upon the amount of subsidence of the central mass and upon the position of the surface of exposure (Chapman, 1935, p. 421; Chapman and Chapman, 1940, pp. 204–205). Piece-meal stoping would probably produce bodies of less regular shapes and would be indicated by more abundant large inclusions.

The evidence seems to justify the conclusion that these intrusions were emplaced by cauldron subsidence.

Correlation with the White Mountain Magma Series Elsewhere

On previous pages it has been indicated that these rocks are to be correlated with the White Mountain magma series elsewhere, but a statement of the reasons for the correlation was postponed until the descriptions of the rocks had been given. Considerable variety of evidence supports this correlation. (1) The proximity of these rocks to other areas of White Mountain magma series supports this correlation. Proximity is a necessary, but not a sufficient, condition for correlation of this type. (2) Similar rock types and minerals occur. The Conway granite, which is one of the most widespread types of this series, is present. It has the same characteristics, including miarolitic cavities and small dark inclusions. Such inclusions are common in many rocks of the White Mountain magma series. The intrusive breccia of diorite in Conway granite is similar to the intrusive breccia in the Belknap Mountains. Such minerals as the amphiboles and the microperthite are very similar to those of many other areas of White Mountain magma series. Pegmatites are uncommon here, which is in contrast to the intrusions of the older magma series in this part of New Hampshire. (3) The age of these rocks may be the same as that of other White Mountain magma series rocks, although at no place is the age of these rocks known within close limits. In common, they cut the rocks of the New Hampshire magma series, are later than the metamorphism of the schist and lime-silicate rock, and are older than the Pleistocene glaciation. Physiographic evidence indicates an age considerably greater than Pleistocene. That, admittedly, may be a rather long time, but, at any rate, there is no known evidence against their common age. (4) Differentiation is marked in these rocks and dikes of several types are common, as is usual for White Mountain magma series, and the course of differentiation is the usual one. (5) The igneous structure is of the cauldron subsidence type, which is common for rocks of this series.

Differentiation

No new evidence concerning the method of magmatic differentiation has been found, but there are several indications that the differentiation was similar to that at other areas of the White Mountain magma series, particularly the Belknap Mountains.

The presence of several different types of rock in this small area seems to indicate considerable magmatic differentiation. There is no indication here of any important differentiation in place, however, and the differentiation must have occurred below the present surface. This is true of most of the near-by areas of White Mountain magma series, with the possible exception of Red Hill where the nepheline-sodalite syenite seems to show differentiation in place (Quinn, 1937, p. 396).

So far as the age relations can be determined, the gabbroic rocks preceded the more granitic rocks. The leucorhyolite is older than the Conway granite and may be older than the diorite-gabbro, and at near-by areas rhyolitic and other lavas commonly preceded the more basic intrusions. That relationship has not been satisfactorily explained.

These similarities indicate that the rocks of the Merrymeeting Lake area probably went through the same type of differentiation as did the rocks of near-by areas of the same series. The final solution of the problem of differentiation will probably come from a complete study of the White Mountain magma series.

Summary and Conclusions

Descriptions are given for the older rocks which include mica schist, lime-silicate rock, and the Winnipesaukee quartz diorite.

Rocks of the White Mountain magma series from gabbro to granite are described. Most of them are intrusive, but leucorhyolite may be extrusive.

The intrusions are considered to have been emplaced by cauldron subsidence, because of the cross-cutting relationship, the circular shape, and the near-by examples of cauldron subsidence.

These rocks are correlated with the White Mountain magma series on the basis of proximity, similarity of rocks and minerals, age, differentiation, and structure.

The similarity of rock types, methods of intrusion, and order of intrusion indicate magmatic differentiation similar to that for other areas of the White Mountain magma series.

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