RING STRUCTURES OF THE PLINY REGION, NEW HAMPSHIRE

BY

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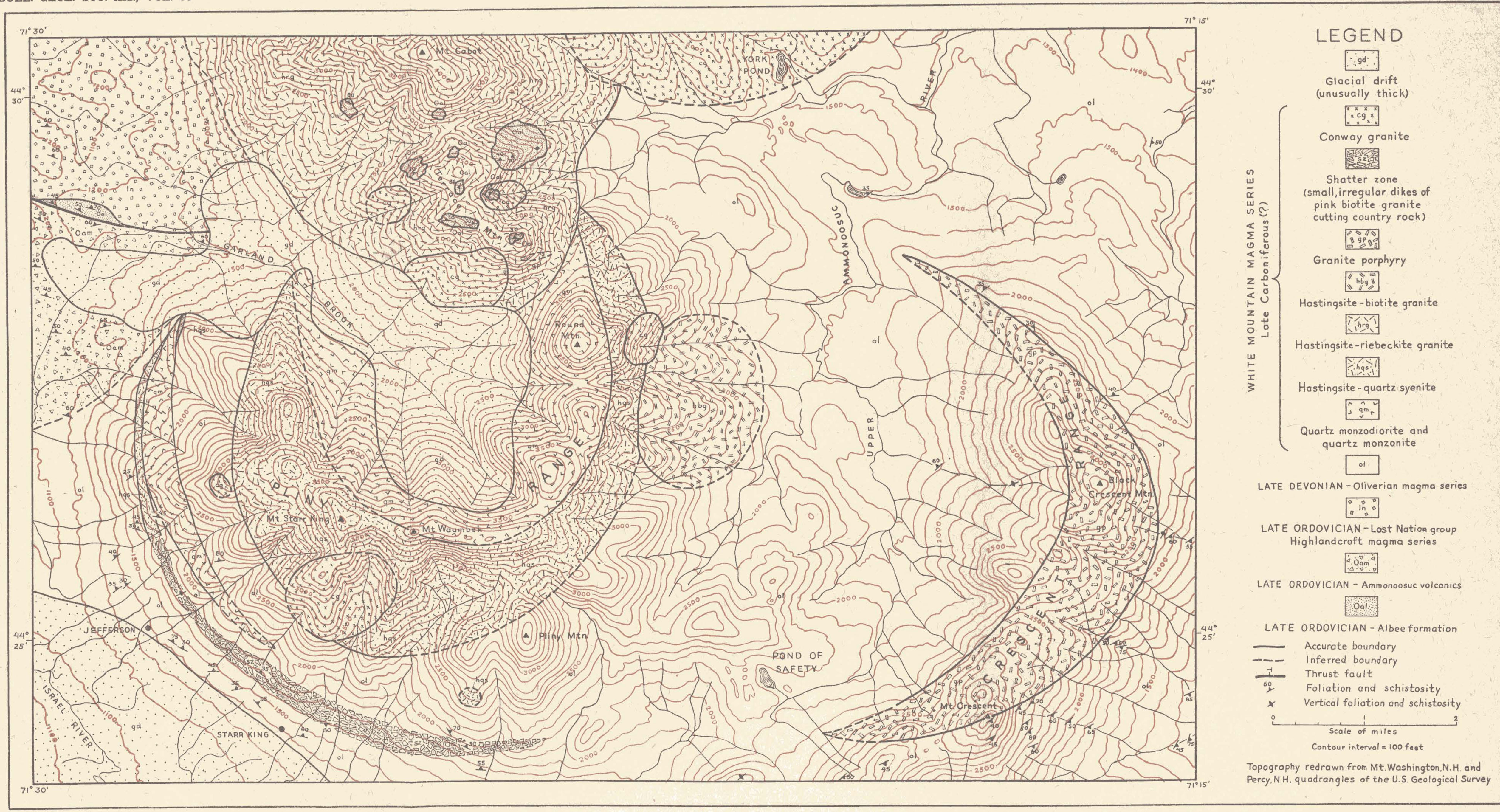

GEOLOGICAL MAP OF PLINY REGION, NEW HAMPSHIRE

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ABSTRACT

The Pliny region, in the northern portion of the Mt. Washington quadrangle, New Hampshire, contains some of the finest examples of ring dikes described in North America. These arcuate bodies intrude older gneiss, quartzite, and quartz diorite, and are, in turn, cut by later granitic stocks. The dikes and stocks, which are grouped about two distinct centers, are composed of differentiates of the White Mountain magma series, which in this area range from quartz monzodiorite to granite. Two of the ring dikes are strikingly expressed in the topography as arcuate mountain ridges.

All the ring dikes and some of the stocks are thought to have originated by cauldron subsidence or ring-fracture stoping. However, this mechanism operated differently for different dikes. In a composite ring dike in the southwestern part of the area, an arcuate zone of intense fracturing developed, resulting in the subsidence of a large cylindrical or domical block of country rock Numerous small dikes of hastingsite-quartz syenite penetrated the northern part of this zone to form a more or less solid dike of hastingsite-quartz syenite. Later, pink biotite granite intruded the southeastern part of the fractured zone, forming a network of irregular dikes.

The Crescent Range ring dike of granite porphyry, however, is a symmetrical crescent with regular, broadly sweeping boundaries. This suggests that it was formed by intrusion en masse along a clean, sharp ring fracture. The dense groundmass of the rock implies rapid cooling.

INTRODUCTION

LOCATION OF AREA

The "Pliny region" covers an area of approximately 100 square miles (Fig. 1), chiefly in the northern portion of the Mt. Washington quadrangle in north-central New Hampshire, between Lats. 44°30′30″ and 44°23′40″ and Long., 71°15′ and 71°30′. The Percy quadrangle (R. W. Chapman, 1935), to which numerous references are made in the present paper, lies directly north. It will be noted, by referring to the latitude lines on the geological map (Pl. 1), that the extreme southern portion of the Percy quadrangle is included in the area which is here known as the "Pliny region."

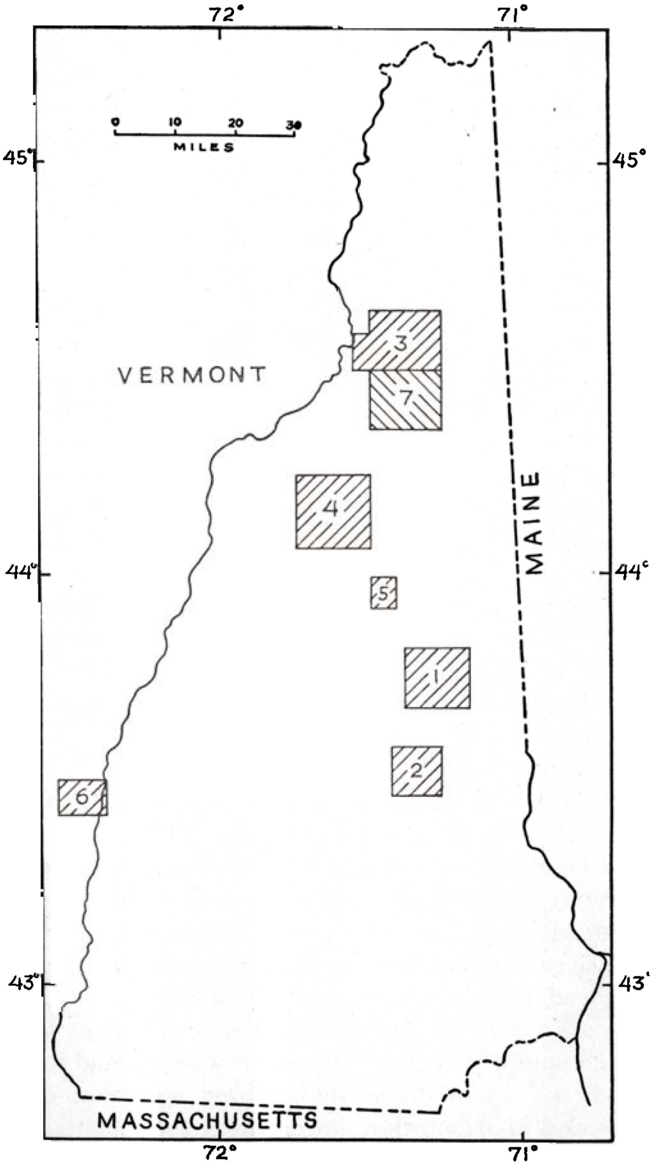

FIGURE 1.—*Index map of Pliny region and other ring dike areas*
1 = Ossipee Mountains, 2 = Belknap Mountains,
3 = Percy region, 4 = Franconia region, 5 = Mt. Tripyramid,
6 = Ascutney Mountain, 7 = Pliny region.

GENERAL GEOLOGICAL RELATIONS

The Pliny region contains some of the finest examples of ring structures described in North America. The "complex" consists of gneissic plutonics intruded by arcuate ring dikes and associated granitic stocks. The ring dikes and stocks are grouped about two distinct centers and are composed of differentiates of the White Mountain magma series. On the whole, these intrusives are more resistant than the surrounding gneisses so that they form high mountains. Two ring dikes are strikingly expressed as arcuate mountain ridges known as the Pliny Range and the Crescent Range.

TOPOGRAPHIC FEATURES

The region considered in this study contains two mountain ranges and a portion of a third. The dominant Pliny Range is distinctly arcuate, has a radius of curvature of 2 miles, and a length of approximately 7 miles. The three highest peaks are Mt. Waumbek (elevation 4005 feet), Mt. Starr King (3913 feet), and Round Mountain (3890 feet). The range takes its name from Pliny Mountain which rises to a height of 3605 feet on the southeast side of the mass (Pl. 2).

Farther to the east is the Crescent Range. Although nearly 1000 feet lower than the Pliny Range, it is no less striking topographically. It is broadly arcuate with a radius of curvature of about 4 miles and a length of over 12 miles. Black Crescent Mountain (3265 feet) and Mt. Crescent (3230 feet) are the two highest peaks (Pl. 1).

North of the Pliny Range a portion of the Pilot Range extends southward into the area. This is represented by the southern slope of Mt. Cabot (4160 feet) and by Terrace Mountain (3640 feet). The topographic break between the Pilot and Pliny ranges is not strong.

The topography and drainage of the Pliny region are determined primarily by differences in rock hardness. The ranges, composed of hard resistant intrusives, rise above the surrounding lowlands which are underlain by older and softer intrusive and metamorphic rocks. The three main streams are the Israel River in the southern half of the area, the Upper Ammonoosuc River in the northeastern portion, and westerly flowing Garland Brook which drains that portion northwest of the Pliny Range. A myriad of tributaries, flowing from the mountains, form an intricate drainage pattern in perfect adjustment to the geologic structure (Pl. 1).

The Pliny region is mainly a wilderness. Except in the extreme western portion, the mountains and lowlands alike are clothed with a dense cover of birch, maple, aspen, beech, spruce, and fir. No roads cross the center of the area so that the interior is accessible only by foot trails.

PLINY RANGE, NEW HAMPSHIRE, AS VIEWED FROM THE SOUTHWEST

Peaks in center are Mt. Starr King (left) and Mt. Waumbek. Peak on extreme right is Pliny Mountain. Village of Jefferson at foot of range on left.

Since most of the area lies within the White Mountain National Forest, however, these trails are kept in first-class condition at all times.

GLACIAL DRIFT

The Pliny region is heavily glaciated. Locally the drift completely conceals the underlying rock, and these places have been mapped as glacial drift (Pl. 1). For example, the topographic basin north of Mt. Starr King and Mt. Waumbek is filled with glacial drift which in many places is probably 100 feet or more thick. The flat area south of the village of Jefferson is likewise deeply covered. Somewhat thinner drift occurs northwest and southeast of Mt. Crescent, in the extreme northeast portion of the area, and along the broad valley of the Upper Ammonoosuc River.

METHOD OF STUDY

A number of reconnaissance trips were made by Marland Billings and the writer during the summer of 1936. Detailed mapping, however, occupied approximately 11 weeks during the summers of 1939 and 1940. Enlarged photostatic copies of the Mt. Washington quadrangle of the United States topographic atlas were used as base maps. Elevations were determined by means of an aneroid barometer.

At the time the field work was done, Billings was studying the structure and metamorphism of the Presidential Range. As both areas lie on the same topographic sheet, it was thought advisable to map the entire Mt. Washington quadrangle. Accordingly, Billings undertook the mapping of the southern half of the topographic sheet, and the writer, assisted by Carleton A. Chapman, completed the northern half.

Billings (1941) has published on the structure and metamorphism in the Mt. Washington area, and the present paper deals with the ring structures of the northern part of the Mt. Washington quadrangle. A third paper is in preparation on the petrology and structure of the Oliverian magma series in the Mt. Washington quadrangle. Later, it is hoped that a colored geological map and a quadrangle report may be published.

ACKNOWLEDGMENTS

The present study was made possible by a generous grant from the Penrose Bequest of The Geological Society of America, for which the writer expresses his gratefulness. He is especially indebted to his brother, Carleton A. Chapman, for his companionship and assistance in the field and for his many helpful comments and suggestions in preparing this paper. Thanks are also due Marland Billings for his kind co-operation in the field and for his critical reading of the manuscript.

NATURE OF THE COUNTRY ROCK

Since the exact nature of the country rock is not pertinent to the present problem, it will be mentioned only briefly here.

The oldest formation, the Albee, occurs as a narrow, east-west band, 1 mile long, 4 miles northwest of Mt. Starr King. It is a fine-grained, gray, impure quartzite and has been described in detail by Billings (1937, p. 472-475). Its age is pre-Silurian and probably late Ordovician. Large inclusions of it are abundant in the hastingsite-riebeckite granite on Terrace Mountain (Pl. 1).

Immediately south of the Albee formation, northwest of Mt. Starr King, are the Ammonoosuc volcanics. This volcanic formation is also pre-Silurian (Billings, 1937, p. 457-480) and stratigraphically overlies the Albee formation in the Littleton quadrangle. Its age is also probably late Ordovician. The volcanics are composed largely of fine-grained biotite gneiss with minor amounts of amphibolite and mica schist.

In the extreme northwest corner of the area the country rock belongs to the Lost Nation group (Chapman, 1935, p. 405) which here consists of medium-grained, dark intrusives, including mainly quartz diorite and diorite with some gabbro and syenite. All these rocks show considerable hydrothermal alteration and metamorphism. The Lost Nation quartz diorite is assigned to the Highlandcroft magma series (Billings, 1937, p. 499-500) near Littleton, New Hampshire, which is believed to be late Ordovician.

Most of the country rock consists of the Oliverian magma series (Billings, 1937, p. 501-502), a group of medium- to coarse-grained, light-colored intrusives probably of late Devonian age. In the Pliny region this series consists of: (1) biotite gneiss, (2) porphyritic biotite gneiss, (3) coarse granite, (4) coarse syenite, (5) hornblende-quartz monzonite, and (6) fine, gray quartz monzonite. Some of these types are distinctly foliated whereas others are massive, but all are of igneous origin. The general distribution may be seen in Plate 1. No attempt has been made here to show the distribution of the varieties. In areas southwest of the Pliny region the Oliverian magma series forms a long line of domelike bodies trending north-northeast. Structural studies indicate that the Oliverian rocks in the Pliny region are also part of a large dome into which ring dikes and stocks have been intruded.

The boundary between the Lost Nation group and the narrow band of Albee formation on the north, and the Ammonoosuc volcanics on the south is probably the northward extension of the Ammonoosuc thrust fault (Billings, 1937). Throughout most of western New Hampshire the Ammonoosuc thrust fault trends generally northeast, but in the Pliny region it apparently strikes west-northwest. Further work west and southwest of the Pliny region is necessary to substantiate this view. The Ammonoosuc thrust fault is older than the White Mountain magma series.

PETROGRAPHY OF THE WHITE MOUNTAIN MAGMA SERIES

GENERAL STATEMENT

The rocks forming the ring dikes and stocks belong to the White Mountain magma series which, according to Williams and Billings (1938, p. 1025), is probably Mississippian or early Pennsylvanian. The individual rock types of this series have been previously described in many reports (Daly, 1903; Eggleston, 1918; Billings, 1928; Kingsley, 1931; Jenks, 1934; R. W. Chapman, 1935; 1937; Chapman and Williams, 1935; Modell, 1936; Quinn, 1937; Williams and Billings, 1938; Smith *et al.*, 1939; Chapman and Chapman, 1940). In addition, a comprehensive study of the whole series has been made by Chapman and Williams (1935). Accordingly, only a brief petrographic description of each type is given here. Modes of all rock types compose Table 1.

Special optical study was made of the minerals of the plutonic rocks, and the results are described fully. No new chemical analyses of minerals are available, but on the basis of optical properties the chemical compositions can be compared with chemical analyses of minerals of the White Mountain magma series (Table 5). It is believed that in the future such optical and chemical properties will be of great value in determining the course of differentiation of the White Mountain magma series.

The intrusive rocks of the White Mountain magma series found in the Pliny region, exclusive of the associated complementary dikes, are as follows, oldest at the bottom:

Conway granite
Pink biotite granite[1]
Granite porphyry[1]
Hastingsite-biotite granite[1]
Hastingsite-riebeckite granite
Hastingsite-quartz syenite
Quartz monzodiorite and quartz monzonite

The age sequence is based upon: (1) relations as determined at contacts between these rock types in the Pliny region, and (2) correlation of these rocks with their equivalents in other regions where the relative ages are known. Age relations are discussed in detail in a later section.

QUARTZ MONZODIORITE AND QUARTZ MONZONITE

The quartz monzodiorite and quartz monzonite cannot be differentiated megascopically. Inasmuch as the two rock types apparently grade into one another, both are shown on the geological map (Pl. 1) by the same

---

[1] The exact position in the sequence of these rocks is not certain.

BLE 1.—*Modes, in volume per cent, of intrusive rocks of Pliny region, New Hampshire*

ROCK TYPE	Specimen Number	Orthoclase	Microperthite	Plagioclase	Quartz	Diopside	Hedenbergite	Hornblende	Hastingsite	Riebeckite	Biotite	Magnetite	Apatite	Zircon	Sphene	Allanite	Fluorite	Astrophyllite	Chlorite (from biotite)	Epidote (from plagioclase)	Hematite
QUARTZ MONZODIORITE	15	5		44(An[illegible])	10	4		26			9	2	tr	tr						tr	
	39	12		51(An[illegible])	5	1		14			13	2	2		tr						
	78	6		52(An[illegible])	3	23		2			5	2	tr		tr				7	tr	
	87	5		69(An[illegible])	6	3		10			4	2	1		tr				tr		
	88	23		54(An[illegible])	10	2		8			tr	2	tr	tr					1		
	113	15		42(An[illegible])	8	3		15			8	3	1		1				4	tr	
	120	16		46(An[illegible])	10			15			14	tr	tr	tr	tr				tr		
QUARTZ MONZONITE	10	42		23(An[illegible])	17			13			1	2	tr		tr				2		
	38	25		38(An[illegible])	10			8			16	2	1	tr							
	85	28		36(An[illegible])	9	tr		15			12	tr	tr		tr				tr		
	114	20		41(An[illegible])	16			13			10	tr	tr		tr	tr			tr		
HASTINGSITE-QUARTZ SYENITE	11		66	18(An[illegible])	11				5		tr	tr		tr		tr			tr		
	34		80	7(An[illegible])	10				3		tr	tr	tr	tr	tr				tr		tr
	35		68	22(An[illegible])	8				1		tr	1	tr	tr	tr						
	65		74	3(An[illegible])	19		3					1		tr							
	77		80	1(An[illegible])	8		7		2			2		tr		tr			tr		
	122		62	19(An[illegible])	12				6			tr		tr	tr	1					
	126		72	7(An[illegible])	14				5		2	tr	tr	tr	tr	tr					
HASTINGSITE-RIEBECKITE GRANITE	18		61	18(An[illegible])	14		tr		6	tr	tr	1	tr		tr	tr	tr		tr		tr
	81		55	3(An[illegible])	37				3		2	tr	tr	tr	tr	tr					
	96		50	12(An[illegible])	32					6	tr	tr	tr	tr	tr	tr	tr	tr			tr
HASTINGSITE-BIOTITE GRANITE	62		52	13(An[illegible])	31				1		3	tr	tr	tr					tr		
	63		68	12(An[illegible])	15				1		3	tr		tr	tr				1		tr
	64		51	17(An[illegible])	20				11			1		tr		tr			tr		tr
GRANITE PORPHYRY	17	40	17	3(An[illegible])	39						tr	1	tr		tr	tr			tr		
	31	9	52	3(An[illegible])	29				1		4	1	tr	tr	tr	1	tr				
	43	15	49	1(An[illegible])	28				tr		6	tr	tr	tr	tr				1		tr
	45	33	31	4(An[illegible])	24				5		2	1	tr	tr	tr	tr					
	56	39	26	1(An[illegible])	26						6	1	tr	tr					1		
	60	33	27	1(An[illegible])	28		1		5		3	2	tr	tr		tr					
PINK BIOTITE GRANITE	116		61	14(An[illegible])	17						5	2	tr	tr	1	tr			tr		
	127		50	12(An[illegible])	37							tr	tr	tr	tr	tr			1		
CONWAY GRANITE	36		47	26(An[illegible])	24						2	1		tr	tr	tr					
	98		49	23(An[illegible])	27						1	tr	tr	tr					tr		

pattern. They form two separate bodies. The larger body lies on the north side of the Pliny Range, but unfortunately, heavy glacial cover conceals its areal distribution and original shape. The smaller body is a ring dike, 1 square mile in area, which lies due north of Jefferson. Furthermore, the quartz monzodiorite occurs both as inclusions and dikes in the shatter zone portion of the composite ring dike northeast of Jefferson. A large inclusion of quartz monzodiorite, too small to show on Plate 1, was found in the hastingsite-riebeckite granite at an elevation of 3200 feet on the southeast slope of the eastern knoll on Terrace Mountain.

The quartz monzodiorite and quartz monzonite are similar texturally and contain the same minerals but in different proportions. The two types are named according to the rock classification that has generally been used for the White Mountain magma series (Chapman and Williams, 1935). Field relations and laboratory studies show that both of these types are closely related genetically and they appear to grade into one another.

The quartz monzodiorite and quartz monzonite are dark-gray and even-grained with varying proportions of light and dark minerals. The grain size ranges from 0.5 to 3 millimeters in different specimens, although the feldspar phenocrysts in one porphyritic specimen are 1 centimeter in diameter. On the whole the dark constituents are somewhat smaller than the light. In most specimens the normal texture is granular, but in a few a diabasic texture is apparent. Some varieties of the rock are pinkish due to the presence of abundant orthoclase.

Microscopically, all these rocks are hypidiomorphic granular and generally even-grained. Some thin sections show a decided diabasic texture. The essential minerals are orthoclase, plagioclase, quartz, pyroxene, hornblende, and biotite. Accessories include apatite, magnetite, zircon, sphene, and allanite. Secondary minerals such as chlorite, epidote, sericite, and kaolin are abundant. Modal analyses of several specimens are shown in Table 1.

Orthoclase makes up from 5 to 23 per cent of the quartz monzodiorite and from 20 to 42 per cent of the quartz monzonite by volume. It occurs both as individual crystals and as borders on plagioclase laths. All grains are altered either to kaolin or to sericite. Lath-shaped plagioclase crystals compose from 42 to 69 per cent by volume of the quartz monzodiorite and from 23 to 31 per cent of the quartz monzonite. Most of it is sodic andesine (An_{30-40}), but in two specimens of quartz monzodiorite it is labradorite (An_{58}). Polysynthetic twinning is common and most crystals show distinct zoning with cores of andesine and borders of oligoclase. Many cores have altered to epidote and sericite. Quartz, in varying proportions (Table 1), is molded into the interstices between the feldspars and ferromagnesian minerals. Pyroxene, hornblende, and biotite are the chief dark minerals.

The pyroxene occurs as irregular cores, about 0.5 millimeter in diameter, rimmed by pale green hornblende, indicating that the hornblende has been derived from the pyroxene by a late magmatic reaction. The pyroxene is nearly colorless to pale pinkish-yellow in thin section, and contains abundant poikilitic inclusions of quartz and feldspar. Some of the pyroxene from specimen 78 of the quartz monzodiorite was isolated for optical study and gave the properties shown in Table 2.

TABLE 2.—*Optical properties of pyroxenes from rocks of Pliny region*

		1	2	3
Indices	α β γ	1.691 1.698 1.718	1.730 1.737 1.757	1.730 1.736 1.755
Sign		Positive	Positive	Positive
2 V		60°	60°	60°
Dispersion		$r > v$, weak	$r > v$, medium	$r > v$, medium
Orientation		$Z \wedge c = 43°$ $Y = b$	$Z \wedge c = 45°$ $Y = b$	$Z \wedge c = 45°$ $Y = b$
Pleochroism		X = pale yellow—pink Y = pale yellow—pink Z = pale blue—green $X = Y < Z$	X = light green Y = light green Z = green $X = Y < Z$	X = dark olive—green Y = dark yellow—green Z = dark green $X = Y < Z$

1. Pyroxene from quartz monzodiorite (specimen 78).*
2. Pyroxene from hastingsite-quartz syenite (specimen 65).
3. Hedenbergite from syenite in the Percy quadrangle, New Hampshire (Chapman and Williams, 1935, p. 512-513).

* Specimen numbers correspond to specimen numbers in Table 1.

According to Winchell's diagram of the diopside-hedenbergite series (1933, p. 226), it is a diopside, and consists of 63 per cent by weight of diopside and 37 per cent by weight of hedenbergite. It contains 12 per cent by weight of MgO and 11 per cent of FeO.

The hornblende in the quartz monzodiorite and quartz monzonite is green-brown and occurs: (1) as distinct crystals, and (2) as reaction rims around pyroxene. The crystals range in diameter from 0.3 to 1 millimeter and average 0.5 millimeter. A few contain poikilitic inclusions of quartz and feldspar. The reaction rims are irregular and vary greatly in width. It is apparent that both the hornblende crystals and rims have resulted from the magmatic reworking of pyroxene.

In different specimens the indices of refraction of the hornblende vary somewhat, although the other optical properties are essentially constant. These relations are shown in Table 3, where the optical properties of two different specimens of hornblende from the quartz monzodiorite (specimens 87 and 120) are compared with those of a hornblende from a syenite of the White Mountain magma series in the adjacent Percy quadrangle.

The refractive indices suggest that the hornblende from specimen 120 has a somewhat higher MgO:FeO ratio than that from the Percy syenite, a chemical analysis (Chapman and Williams, 1935, p. 512) of which is shown in Table 5. The hornblende from specimen 87 would probably be even richer in magnesia. A rechecking of data suggests that the optic angle of the hornblende from the Percy syenite is about 65° rather than 35° as reported by Chapman and Williams.

The optical properties of the hornblende from specimen 87 are the same as those of an amphibole from a diorite of the White Mountain magma series from Mt. Pequawket in the North Conway quadrangle, New Hampshire (Billings, 1928, p. 103). According to Billings the amphibole from the North Conway quadrangle is a normal hornblende relatively rich in magnesia compared to hastingsite.

Brown biotite, abundant in both the quartz monzodiorite and quartz monzonite, occurs as ragged crystals, 0.3 to 1 millimeter across, some of which are intergrown with pyroxene and hornblende. Poikilitic inclusions are not uncommon, and many grains are altered to green chlorite along cleavage cracks. Refractive indices differ slightly in different specimens of biotite. Complete optical data on two specimens of biotite are shown in Table 4. These biotites were chosen from the same two specimens of quartz monzodiorite (specimens 87 and 120) that yielded the two hornblendes already described.

The optical properties of the biotite from specimen 87 are identical with those of a biotite from the Ames monzodiorite in the Belknap Mountains, New Hampshire (Chapman and Williams, 1935, p. 512-513). Thus the chemical composition is probably essentially the same. A chemical analysis of the biotite from the Belknap Mountains is shown in Table 5.

The biotite from specimen 120 is optically like the biotite from the Conway granite (see Table 4), which suggests identical chemical composition. However, it seems strange that two rocks, such as the quartz monzodiorite and the Conway biotite granite, whose chemical compositions are so different, should contain biotites which are chemically alike. Possibly the indices are not reliable in determining accurately the chemical composition of the biotite.

HASTINGSITE-QUARTZ SYENITE

The areal extent of the hastingsite-quartz syenite in the Pliny region is between 5 and 6 square miles. This resistant rock makes up the largest ring dike in the region, and is chiefly responsible for the great height of the Pliny Range. Hastingsite-quartz syenite also occurs in three other places in the Pliny region: (1) in the northern part of the composite ring dike north of Jefferson, (2) as a small stock 1 mile southwest of Pliny Mountain, and (3) as a small lenslike mass at the northern end of the ring dike of quartz monzodiorite and quartz monzonite 2½ miles northwest of Mt. Starr King.

In hand specimen the typical hastingsite-quartz syenite is even-textured to subporphyritic, medium-grained, and composed essentially of feldspar and hastingsite. A few specimens, however, are medium-fine grained and distinctly porphyritic. The feldspars are commonly lathlike, and are locally arranged in a trachytic fashion. They are 2 to 5 millimeters long and 1 millimeter wide. In other specimens the feldspars are equidimensional with an average diameter of from 1 to 2 millimeters. Carlsbad twins are common. The dark minerals range from a fraction of a millimeter to 3 millimeters. The fresh rock is bluish green but weathers white, pink, or rusty brown.

Microscopically the hastingsite-quartz syenite is hypidiomorphic-granular and consists essentially of microperthite, plagioclase, quartz, and hastingsite. For the most part it is even-grained, but a few specimens are seriate. Accessory minerals are pyroxene, biotite, apatite, magnetite, zircon, sphene, and allanite. Chlorite (from biotite) and hematite are secondary. Modes of several specimens of hastingsite-quartz syenite are shown in Table 1.

The microperthite consists of potash feldspar penetrated by long, slender, parallel stringers or irregular patches of albite. The ratio of orthoclase to albite by volume in the microperthite is from 3:1 to 2:1. Adjacent perthite crystals are commonly intergrown along sutured or interdented boundaries. The plagioclase is sodic oligoclase (An_{10}-An_{15}) and occurs generally as small anhedra showing albite twins.

Quartz occurs chiefly interstitially between the feldspars. Table 1 shows that the quartz content ranges from 8 to 19 per cent by volume. However, most specimens contain between 8 and 15 per cent and are thus classified as hastingsite-quartz syenites.

The hastingsite in the hastingsite-quartz syenite is dark green to olive green. Most grains are subhedral or anhedral, 0.3 to 3 millimeters in cross section, and dotted with poikilitic quartz and feldspar. Many of these grains are interstitial between the feldspars suggesting late crystallization. A small percentage of the hastingsite occurs as irregular masses altering from hedenbergite. The optical properties of the hastingsite from specimen 34 are shown in Table 3, where they may be compared with those of a hastingsite from a quartz syenite in the North Conway quadrangle, New Hampshire.

Billings (1928, p. 110) gives a chemical analysis of the North Conway hastingsite and this is shown in Table 5. Inasmuch as the refractive indices of the hastingsite from the hastingsite-quartz syenite of the Pliny region are slightly higher than those of the North Conway hastingsite, it may be that the hastingsite from the Pliny region is poorer in magnesia and richer in ferrous iron.

Pyroxene is not abundant, but it was observed in a few sections as small, pale-green to bright-green, subhedral or euhedral crystals 0.1 to 0.5 millimeter across. Many crystals show fractures along which the pyroxene has altered to yellow antigorite. In Table 2 the optical properties of this pyroxene, taken fom specimen 65, are compared with those of a hedenbergite from a syenite in the Percy quadrangle, New Hampshire.

These two pyroxenes are essentially the same optically except that the hedenbergite from the Percy quadrangle is somewhat more deeply colored. The chemical compositions of the two are probably about the same, i.e. both minerals are hedenbergite. The hedenbergite from the syenite of the Percy quadrangle has been analyzed chemically (Chapman and Williams, 1935, p. 512) and this analysis is shown in Table 5.

HASTINGSITE-RIEBECKITE GRANITE

Hastingsite-riebeckite granite forms an irregular stock-like mass along the northern boundary of the area. Its areal extent in the Pliny region is approximately 6½ square miles. This rock type is an extension of a hastingsite-riebeckite granite body in the Percy region (Chapman, 1935, p. 426-428). There the rock contains three different amphiboles: hastingsite, riebeckite, and hornblende. In the Pliny region, however, hornblende is absent. Inasmuch as some specimens from the Pliny region contain both hastingsite and riebeckite it was found impracticable to try to separate this amphibole granite into two distinct types.

The hastingsite-riebeckite granite is medium-grained and consists principally of feldspar, quartz, hastingsite, and riebeckite. Its texture, both megascopically and microscopically, is similar to that of the hastingsite-quartz syenite, and the color of the hastingsite granite phase is exactly like that of the hastingsite-quartz syenite. Some specimens of the riebeckite phase are white or buff and dotted with jet-black amphibole.

The hastingsite-riebeckite granite is generally richer in quartz than the hastingsite-quartz syenite. Microperthite is somewhat less abundant, and in it the ratio of potash feldspar to soda feldspar is slightly less than in the microperthite of the hastingsite-quartz syenite. Sodic oligoclase (An_{10}) is present in about the same amount as in the hastingsite-quartz syenite. Some specimens contain only hastingsite, some only riebeckite, and others contain both. Accessories include astrophyllite, allanite, fluorite, zircon, sphene, hedenbergite, biotite, apatite, yellow chlorite, magnetite, and hematite. Modes are shown in Table 1.

Most of the hastingsite occurs as clean, irregular crystals, 1 or 2 millimeters across. Its interstitial occurrence between subhedral feldspars suggests late crystallization. Some hastingsite forms alteration rims on bright green hedenbergite.

The optical properties of the hastingsite from specimen 18, shown in Table 3, differ from those of the hastingsite in the other rocks in several respects: (1) The Z direction is bluish green instead of olive green or dark green; (2) the optic angle is smaller; and (3) dispersion is stronger with $r<v$ instead of $r>v$. The blue-green color and the strong dispersion of this mineral, together with its close association with riebeckite, suggests the presence of abundant soda and ferric iron. However, it is believed that the above optical properties justify classifying this mineral as hastingsite.

The riebeckite has two modes of occurrence. Most of it forms large, irregular interstitial crystals, 1 to 3 millimeters in diameter, between subhedral grains of microperthite. These crystals are commonly spongy with poikilitic inclusions of fluorite and magnetite. Riebeckite also occurs in groups of slender, radiating fibers. Its close association with hastingsite in some sections, suggests late hydrothermal alteration of hastingsite by solutions rich in soda and iron.

The optical properties of the riebeckite from the hastingsite-riebeckite granite

TABLE 3.—*Optical properties of amphiboles from rocks of Pliny region*

	1	2	3	4	5	6	7	8
Indices α β γ	1.670 1.683 1.689	1.678 1.693 1.699	1.688 1.699 1.704	1.706 1.725 1.729	1.689 1.710 1.712	1.689 1.704 1.711	1.698 1.719 1.722	1.691 1.694 1.699
Sign	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Positive
2 V	65	65	ca. 35°	48°±2°	25°±5°	ca. 65°	47°±3°	Large
Dispersion	$r>v$, medium	$r>v$, weak	$r>v$, strong	$r>v$, medium	$r<v$, strong	$r>v$, medium	Medium strong	$r>v$, strong
Orientation	$Z \wedge c=18^\circ$ $Y=b$	$Z \wedge c=18^\circ$ $Y=b$	$Z \wedge c=25^\circ$ $Y=b$	$Z \wedge c=19^\circ$ $Y=b$	$Z \wedge c=20^\circ$ $Y=b$	$Z \wedge c=18^\circ$ $Y=b$	$Z \wedge c=20^\circ$ $Y=b$	$X \wedge c=3^\circ-5^\circ$ $Z=b$
Pleochroism	X=light brown Y=olive brown Z=olive green $X<Y<Z$	X=light brown Y=olive brown Z=olive green $X<Y<Z$	X=yellow-brown Y=olive green Z=dark green $X<Y<Z$	X=light brown Y=olive brown Z=olive green $X<Y<Z$	X=light brown Y=olive brown Z=bluish green $X<Y<Z$	X=light brown Y=olive brown Z=olive green $X<Y<Z$	X=light yellow-brown Y=olive green Z=deep green $X<Y>Z$	X=deep blue-gray Y=pale yellow Z=gray $X>Z>Y$

1. Hornblende from quartz monzodiorite (specimen 87).*
2. Hornblende from quartz monzodiorite (specimen 120).
3. Hornblende from syenite in the Percy quadrangle, New Hampshire (Chapman and Williams, 1935, p. 512–513).
4. Hastingsite from hastingsite-quartz syenite (specimen 34).
5. Hastingsite from hastingsite-riebeckite granite (specimen 18).
6. Hastingsite from granite porphyry (specimen 45).
7. Hastingsite from quartz syenite in the North Conway quadrangle (Billings, 1928, p. 109).

.Riebeckite from hastingsite-riebeckite granite (specimen 96).

* Specimen numbers correspond to specimen numbers in Table 1

(specimen 96) on the south slope of Mt. Cabot are given in Table 3. These properties are identical with those of the riebeckite from the riebeckite granite of the Percy quadrangle to the north (Chapman and Williams, 1935, p. 512-513). A chemical analysis of the riebeckite from the Percy quadrangle is shown in Table 5.

HASTINGSITE-BIOTITE GRANITE

The hastingsite-biotite granite crops out east and southeast of Round Mountain, and is approximately 2 square miles in areal extent. The exact shape of the body is not known, but the regional distribution of outcrops suggests an elliptical stock.

The hastingsite-biotite granite is a medium-grained to fine-grained pink rock consisting essentially of feldspar and quartz mottled with hastingsite and biotite. The medium-grained phase is equigranular to subporphyritic with lathlike crystals of microperthite which show Carlsbad twins. The average grain size ranges from 1 to 3 millimeters, but a few biotite flakes are 5 millimeters across. The fine-grained phase shows the same textural features as the medium-grained phase, but the average grain size is slightly less than 1 millimeter.

Under the microscope the hastingsite-biotite granite is allotriomorphic and hypidiomorphic. Microperthite occurs as rectangular or irregular crystals in which the ratio by volume of potash feldspar to soda feldspar is approximately 3:1. Adjacent microperthite crystals are separated by narrow zones of tiny albite grains, many of which show albite twinning. The general appearance of these small grains suggests that they were introduced between the microperthite crystals during the late stages of crystallization. In fact this albite and that which is present as veins and patches in the microperthite may be genetically related. Sodic oligoclase (An_{10}) occurs as well-twinned rectangular crystals many of which show distinct zoning. The quartz forms irregular, strained, interstitial masses between the feldspars.

The hastingsite is like that described previously. Its occurrence and optical properties are identical with those of the hastingsite in the hastingsite-quartz syenite (specimen 34) and further description is not necessary here.

Biotite occurs as irregular grains from 0.2 to 1 millimeter in diameter. Practically all grains are greatly altered at their borders and along cleavages to green chlorite, magnetite, and hematite, preventing accurate determinations of the refractive indices. However, the occurrence and pleochroism of the mineral suggests that it is not greatly different from the biotite in the other rocks of this series.

Accessory minerals include apatite, magnetite, zircon, sphene, and allanite. Secondary minerals, altering from biotite, are green chlorite and hematite. Modes of three specimens of hastingsite-biotite granite are shown in Table 1.

GRANITE PORPHYRY

The granite porphyry, which makes up the Crescent Range, covers about 5 square miles. It is confined entirely to this area except for a small dike which cuts the hastingsite-riebeckite granite at an elevation of 3200 feet on the southeast slope of the eastern knoll on Terrace Mountain.

The granite porphyry is a tough, resistant rock which is easily recognized by its peculiar texture. It is pink to gray and consists of phenocrysts of pink feldspar and smoky quartz in a dense, light-gray groundmass peppered with dark minerals.

TABLE 4.—*Optical properties of biotites from rocks of Pliny region*

		1	2	3	4	5
Indices	α β γ	1.599 1.665 1.665	1.606 1.671 1.672	1.583 1.653 1.653	1.596 1.656 1.656	1.606 1.671 1.672
Sign		Negative	Negative	Negative	Negative	Negative
2 V		ca. 3°	ca. 3°	ca. 4°	5°	3°
Dispersion		r< v, medium	r< v, medium	r< v, medium	r< v, weak	r< v, medium
Orientation		$X \wedge c = 3°$	$X \wedge c = 3°$	$X \wedge c = 3°$	$X \wedge c = 4°$	$X \wedge c = 3°$
Pleochroism		X = light yellow Y = red-brown Z = red-brown X< Y = Z	X = light yellow Y = brown Z = brown X< Y = Z	X = light yellow Y = brown Z = brown X< Y = Z	X = light brown Y = brown Z = brown X< Y = Z	X = light yellow Y = brown Z = brown X< Y = Z

1. Biotite from quartz monzodiorite (specimen 87).*
2. Biotite from quartz monzodiorite (specimen 120).
3. Biotite from pink biotite granite (specimen 116).
4. Biotite from gabbro at Tripyramid Mountain, New Hampshire (Chapman and Williams, 1935, p. 512-513).
5. Biotite from Conway granite (specimen 36).

*** Specimen numbers correspond to specimen numbers in Table 1.**

The smoky quartz phenocrysts, 1 to 2 millimeters in diameter, are always well rounded, a feature found only in the granite porphyry. The pink feldspar phenocrysts are square or rectangular and 1 to 3 millimeters in cross section. In most cases the groundmass is so fine-grained that individual crystals are not discernible megascopically.

Irregular or rounded fragments, 1 inch or less in diameter, were found in the granite porphyry. These are composed of very dense, dark-gray, crystalline material spotted with pink feldspar phenocrysts 2 to 3 millimeters across. They are believed to represent inclusions which were incorporated and reworked by the granite porphyry during its intrusion.

Microscopically the granite porphyry has much the appearance of an extrusive rock. The groundmass, composing 25 to 75 per cent, is a remarkably uniform fabric of crystals of orthoclase and quartz approximately 0.05 millimeter in diameter. Slightly more than half the groundmass is orthoclase, and the remainder is quartz with a few grains of sodic oligoclase (An_{10}).

In cross section many of the quartz phenocrysts suggest the bipyramid so common in lavas. Other quartz grains are well rounded, and some are corroded; many show evidence of straining. The feldspar phenocrysts are all microperthite, and, like the quartz crystals, generally evince rounding and corrosion.

Hastingsite occurs as small rounded or subhedral phenocrysts which range from 0.1 to 0.5 millimeter in diameter. It is notably spongy or poikilitic with numerous rounded inclusions of quartz and orthoclase. A sample was isolated from specimen 45, and its optical properties are shown in Table 3.

Biotite occurs in all specimens of granite porphyry as irregular phenocrysts 0.2 to 0.5 millimeter across. It is so badly altered to chlorite and hematite, however, that its optical properties could not be measured.

Accessory minerals are hedenbergite, apatite, magnetite, zircon, sphene, allanite, and fluorite. Biotite alters to green chlorite and hematite. Six modal analyses of the granite porphyry are shown in Table 1.

According to Billings (personal communication) the granite porphyry is similar to the Mt. Lafayette granite porphyry of the Franconia quadrangle, New Hampshire (Williams and Billings, 1938).

PINK BIOTITE GRANITE

The pink biotite granite forms dikes and small irregular intrusive masses in the composite ring dike immediately northeast of Jefferson. Small masses, not shown on Plate 1, were also found 1 mile north of the village of Starr King.

This granite is pinkish-gray and shows a uniform character in all outcrops. Subporphyritic varieties occur, but on the whole the rock is remarkably even grained with individual crystals averaging 1 millimeter in diameter. Some specimens show a crude alignment of feldspar laths. The essential minerals are potash feldspar, quartz, and biotite.

Thin sections show this rock to be closely similar to the Conway granite, of which it may indeed be a phase. The texture is hypidiomorphic and even grained, and adjacent grains commonly interlock. Microperthite is the chief mineral, and its ratio by volume of potash feldspar to soda feldspar is 3:1. Sodic oligoclase (An_{15}) and interstitial quartz are the other essential felsic constituents.

TABLE 5.—*Chemical composition of minerals of White Mountain magma series*

	1	2	3	4	5	6	7
SiO_2	37.74	35.88	33.48	47.58	46.56	37.40	46.98
TiO_2	5.22	4.17	2.94	.37	1.83	3.20	1.49
Al_2O_3	16.31	14.96	13.64	1.16	2.48	12.34	1.29
Fe_2O_3	none	2.33	8.00	2.60	6.24	4.16	11.93
FeO	15.52	20.88	23.54	24.21	27.27	25.84	23.38
MnO	.06	.18	1.02	.59	1.08	1.24	.24
MgO	14.23	10.04	4.97	3.34	1.35	2.20	.13
CaO	.04	.12	.56	18.80	6.15	9.72	1.91
Na_2O	.44	.36	.53	.47	4.17	1.80	8.90
K_2O	8.88	9.20	7.80	.21	1.37	1.36	2.74
H_2O+	1.17	.80	2.63	.34	1.27	tr	1.10
H_2O-					nd	.60	none
F	.45	1.58	.95	......	......	......	......
	100.06	100.50	100.06				
Less O for F.	.19	.66	.40				
Total	99.87			99.67	99.77	99.86	100.09

1. Biotite from gabbro (7052)*, Black Cascade, Tripyramid Mountain.
2. Biotite from monzodiorite (609), one-third mile northwest of Ames Station, Belknap Mountains.
3. Biotite from granite (19287), granite quarry 1 mile south of Beech Hill, Percy quadrangle.

* Numbers in parentheses refer to Harvard University rock collections. F. A. Gonyer, analyst of all except specimen 6. All analyses except number 6 quoted from Chapman and Williams (1935, p. 512).

4. Hedenbergite from syenite (19258), east slope of knoll south of Burnside Brook at elevation 2160 feet, Percy quadrangle.
5. Hornblende from syenite (19247), in Moore Brook at elevation 2000 feet, Percy quadrangle.
6. Hastingsite from quartz syenite (18299), Jackson Falls, Jackson, North Conway quadrangle, (Billings, 1928, p. 110).
7. Riebeckite from granite (19274), one-quarter mile northeast of small swamp on Mill Mountain, Percy quadrangle.

Biotite is the only primary ferromagnesian mineral. In some specimens clean, irregular grains measure 0.2 to 1 millimeter across. Pleochroic halos surrounding zircon inclusions are common. In other specimens, all the biotite has altered to chlorite. The optical properties of the biotite from specimen 116 resemble those of a biotite from a gabbro of the White Mountain magma series from Tripyramid Mountain, New Hampshire (Chapman and Williams, 1935, p. 512-513). These are compared in Table 4.

The birefringence of the biotite from the pink biotite granite is higher than that of the biotite from the Tripyramid Mountain gabbro. In fact it is higher than that of any biotite of the White Mountain magma series determined to date. This may be due to abundant ferric iron and/or titanium (Winchell, 1933, p. 273). The chemical analysis of the biotite from the gabbro of Tripyramid Mountain (Chapman and Williams, 1935, p. 512) is shown in Table 5. In spite of somewhat similar indices, the biotite from the pink biotite granite may be much richer in iron than the biotite from the Tripyramid Mountain gabbro.

Accessory minerals of the pink biotite granite are apatite, magnetite, zircon, sphene, and allanite. Secondary chlorite from biotite is common. Two modes of the pink biotite granite are shown in Table 1.

CONWAY GRANITE

The Conway granite forms numerous, small, probably more or less circular stocks (Pl. 1). It also occurs at the very northern edge of the area on the southern margin of a large stock which extends south from the Percy quadrangle. The total area of the Conway granite exposed in the Pliny region is about 4 square miles.

This granite, an important member of the White Mountain magma series, is a granular rock, composed principally of pink potash feldspar, smoky quartz, and biotite. Each of these minerals collects into aggregates. The rock is typically pink and weathers white or brownish. Its texture varies widely so that in some other areas it has been divided into several textural phases (Billings, 1928, p. 118-124; Chapman, 1935, p. 428-430). In the Pliny region no attempt was made to map variations because the bodies are small and isolated and the outcrops are poor.

In the Pliny region the Conway granite is generally medium-grained with individual crystals ranging from 1 to 5 millimeters in diameter, but some specimens are fine-grained. A porphyritic phase, extending into the Pliny region from the north, is exposed in a small quarry along the unimproved road 1 mile west-southwest of York Pond. The groundmass is similar in texture and grain size to that of the medium-grained granite, but the lathlike phenocrysts of microperthite attain a diameter of nearly 15 millimeters. Most of these phenocrysts show Carlsbad twinning.

Microscopically the Conway granite is hypidiomorphic-granular and consists essentially of microperthite, slightly strained quartz, twinned and zoned oligoclase (An_{15}), and brown biotite. Accessory minerals are apatite, magnetite, zircon, sphene, and allanite. Other accessories have been reported from other areas. Chlorite occurs as an alteration from biotite.

The nature and occurrence of the biotite in this rock are the same as for the biotite of the pink biotite granite, but the indices of refraction are much higher.

The optical properties of the biotite in a specimen (36) of Conway granite from the small body 1½ miles west-northwest of Mt. Starr King are shown in Table 4. They match those measured on biotite from the Conway granite in the Percy quadrangle, New Hampshire (Chapman and Williams, 1935, p. 512-513). The chemical analysis of the biotite from the Percy quadrangle is shown in Table 5.

AGE RELATIONS OF ROCKS OF THE WHITE MOUNTAIN MAGMA SERIES

The relative ages of the rock members of the White Mountain magma series in the Pliny region are based upon: (1) relations as determined at contacts between these rock types in the Pliny region, and (2) correlation of these rocks with their equivalents in other regions where the relative ages are known.

The quartz monzodiorite and quartz monzonite are similar petrographically and intergradational, and they are, therefore, probably essentially contemporaneous. Fortunately, there is considerable evidence in the Pliny region as to the relative ages of these two rock types.

In Garland Brook, where the quartz monzodiorite and quartz monzonite disappear beneath the drift, they are cut by dikes and stringers of white, medium-grained biotite granite. The former are, therefore, older than the granite which has been identified as Conway granite, the youngest plutonic rock in the region. Northeast of Jefferson, and in the "shatter zone" of the composite ring dike, irregular inclusions of quartz monzodiorite are abundant in the pink biotite granite. Thus the quartz monzodiorite is older than the pink biotite granite. Similarly, the quartz monzodiorite is older than the hastingsite-riebeckite granite because on the southeast slope of the eastern knoll on Terrace Mountain, at an elevation of 3200 feet, a large inclusion of quartz monzodiorite was found in the hastingsite-riebeckite granite.

At the north end of the ring dike of quartz monzodiorite and quartz monzonite, northwest of Mt. Starr King, a small lens of hastingsite-quartz syenite intrudes the eastern boundary between the dike and the country rock. Tongues of medium-grained hastingsite-quartz syenite cut the dike rock which is here a quartz monzonite, and blocks of quartz monzonite are included in the hastingsite-quartz syenite, indicating clearly the age relations. Similar contact relations were observed farther south and on the west side of the ring dike of quartz monzodiorite and quartz monzonite where it comes in contact with the hastingsite-quartz syenite in the northern part of the composite ring dike.

Nothing more can be said about the age relations of the quartz monzodiorite and quartz monzonite to the other rocks, from data gathered here. However, studies in other areas, indicate that the quartz monzodiorite and quartz monzonite are the oldest rocks of the White Mountain magma series in the Pliny region.

The relative age of the granite porphyry composing the Crescent Range ring dike is somewhat uncertain since it is entirely isolated from other intrusions of the White Mountain magma series. However, a small dike of granite porphyry, very similar to that of the Crescent Range, cuts the hastingsite-riebeckite granite at an elevation of about 3200 feet on the southeast slope of the eastern knoll of Terrace Mountain. The similarity and rather unusual nature of the two granite porphyries suggest that they are contemporaneous. Since the granite porphyry cuts the hastingsite-riebeckite granite it must be younger.

Since the hastingsite-riebeckite granite stock apparently cuts off the ring dike of hastingsite-quartz syenite it must be younger. On the other hand, the hastingsite-riebeckite granite is older than the Conway biotite granite because it is cut by three small intrusions of Conway granite in the Pliny region, and by one large stock in the Percy quadrangle (Pl. 1).

The hastingsite-quartz syenite is older than the Conway biotite granite, because it has been intruded by an elliptical stock of Conway granite south of Mt. Starr King, and by a similar but smaller stock due east of Round Mountain. This view is substantiated by the fact that in the Percy region (Chapman, 1935, p. 415-416) the Conway granite has been shown to be younger than the hornblende syenite (similar to the hastingsite-quartz syenite of the Pliny region).

Regional mapping suggests that the large stock of hastingsite-biotite granite southeast of Round Mountain has cut out the hastingsite-quartz syenite ring dike, and that the hastingsite-biotite granite is thus younger than the hastingsite-quartz syenite.

The hastingsite-biotite granite resembles the Conway biotite granite petrographically and the two are probably nearly contemporaneous. The pink biotite granite is doubtless a phase of the Conway biotite granite. As in other regions, the Conway biotite granite in the Pliny region seems to be the youngest plutonic rock of the White Mountain magma series.

In summary, the intrusive rocks of the White Mountain magma series occurring in the Pliny region, excluding complementary dikes, are arranged chronologically as follows, oldest at the bottom:

Conway granite
Pink biotite granite [2]
Granite porphyry [2]
Hastingsite-biotite granite [2]
Hastingsite-riebeckite granite
Hastingsite-quartz syenite
Quartz monzodiorite and quartz monzonite

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[2] The exact position in the sequence of these rocks is not certain.

TABLE 6.—*Structural units of Pliny region, New Hampshire* *

Structural unit	Shape	Dimensions	Area	Rock type
Conway granite stocks	Circular to elliptical	Diameter 1/4 to 1 mile. For large stock near York Pond *see* Plate 1	1/15 to 1 sq. mile. For large stock near York Pond *see* Plate 1	Pink, generally medium-grained biotite granite
Composite ring dike (southern portion)	Arcuate	Radius of curvature 3 1/2 miles	1 sq. mile	Pink to gray, even-grained to subporphyritic biotite granite
Crescent Range ring dike	Arcuate	Radius of curvature 2 1/2 miles	5 sq. miles	Pink to gray granite porphyry
Hastingsite-biotite granite stock	Probably roughly elliptical	Long diameter 2 3/4 miles. Short diameter 1 1/2 miles	2 sq. miles	Pink, medium-grained to fine-grained hastingsite-biotite granite
Hastingsite-riebeckite granite stock	Roughly elliptical	Long diameter 5 miles. Short diameter 3 miles	Complete stock 10 sq. miles. Portion in Pliny region 6 1/2 sq. miles	Medium-grained hastingsite-riebeckite granite. Fresh specimens blue green
Composite ring dike (northern portion)	Arcuate	Radius of curvature 3 1/2 miles	1/5 sq. miles	Medium-grained hastingsite-quartz syenite. Fresh specimens blue green
Hastingsite-quartz syenite stock	Unknown	Unknown	Unknown	Medium-grained hastingsite-quartz syenite. Fresh specimens blue green
Hastingsite-quartz syenite ring dike	Asymmetrically arcuate	Radius of curvature 2 1/2 miles	5 to 6 sq. miles	Medium-grained hastingsite-quartz syenite. Fresh specimens blue green
Ring dike of quartz monzodiorite and quartz monzonite	Arcuate	Radius of curvature 3 miles	1 sq. mile	Dark-gray, medium-grained quartz monzodiorite and quartz monzonite
Body of quartz monzodiorite and quartz monzonite	Circular or arcuate	Average diameter 3 1/2 miles	At least 4 1/2 sq. miles	Dark-gray, medium-grained quartz monzodiorite and quartz monzonite

* Arranged chronologically, as nearly as possible; oldest at bottom.

STRUCTURE OF THE RING DIKE COMPLEX

DESCRIPTION OF STRUCTURAL UNITS

General statement.—The structural units of the Pliny region are ring dikes and stocks, intrusive into older crystalline rocks. Most of the ring dikes and stocks are concentric about a center in the interior of the Pliny Range, although the center of the Crescent Range ring dike is 3 miles to the east-southeast. The ring dikes form only arcs or crescents, with radii of from 2½ to 3½ miles. The largest stock has an average diameter of 3½ miles, whereas the smallest is about ¼ mile across. It is possible to arrange these structures in a definite chronological order, as in Table 6, since the relative ages of the rocks, which belong to the White Mountain Magma series, have been determined.

In the following pages each structural unit will be considered in detail. For the sake of simplicity and convenience these will be discussed according to type rather than according to age, i.e. the ring dikes will be considered first and then the stocks.

Body of quartz monzodiorite and quartz monzonite.—This body underlies the circular basin north of the Pliny Range (Pl. 1), at least in part, and is either an arcuate ring dike or a circular stock averaging approximately 3½ miles in diameter. It is apparently cut off on the north by the hastingsite-riebeckite granite stock. The best exposures of quartz monzodiorite and quartz monzonite occur on Round Mountain and on and around the two peaks to the south.

The outer contact of this body, although not exposed, has been located rather accurately by regional mapping. Whether it is vertical or inclined is not known. Unfortunately, there are no structural features such as foliation or lineation to indicate the attitude of the contact.

Ring dike of quartz monzodiorite and quartz monzonite.—This long, slender, arcuate dike 1½ miles west of Mt. Starr King and north of Jefferson trends somewhat west of north and has a radius of about 3 miles. It is 4 miles long, has a maximum thickness of a third of a mile, and tapers on both ends. Its areal extent is about 1 square mile. The quartz monzodiorite and quartz monzonite resemble that of the last body described. Outcrops are fairly abundant, particularly along the southwesterly trending ridges due west of Mt. Starr King.

The boundary, although not exposed, has been fairly accurately located except at the southeastern end where outcrops are scarce. It is probably steep since it trends undeflected across rather rugged topography. The structure of the country rock (syenite of the Oliverian magma series) was not greatly affected by this intrusion, for the foliation near the dike conforms in general to the regional trend.

Hastingsite-quartz syenite ring dike.—This ring structure, covering 5 or 6 square miles, is the largest in the Pliny region. It underlies most of the Pliny Range and is responsible for the great height and crescentic shape of the latter. Inside the arc the dike is bounded by the body of quartz monzodiorite and quartz monzonite and outside the arc by syenite of the Oliverian magma series. In ground plan the dike is an asymmetrical crescent or a portion of a ring whose major axis is 5 miles long and trends north-northeast. The minor axis of the ring is 4¼ miles long and trends east-southeast. Originally the dike may have been a complete ring, now cut off on the north by the hastingsite-riebeckite granite stock.

Despite the rugged topography, outcrops are not plentiful. The best exposures occur at the northwest end of the dike (north of hill, elevation 3343 feet) and along the east slope of the Pliny Range southeast of Round Mountain. The tough, massive hastingsite-quartz syenite forms rugged cliffs, up to 50 feet or more in height.

The contact between the hastingsite-quartz syenite and the surrounding country rock is not exposed, and where outcrops are lacking, it is mapped with a dashed line. Where the contact has been fairly definitely located—*i.e.*, in the region northwest of Mt. Starr King and in the vicinity of Round Mountain—it crosses rugged topography without deflection, suggesting that it is steep.

Composite ring dike.—The composite ring dike is a long, very slender, somewhat irregular series of intrusions west, southwest, and south of the Pliny Range. Its arcuate trend closely parallels that of the hastingsite-quartz syenite ring dike. It is 7 miles long and its thickness varies greatly. From the vicinity of Jefferson northward it is 500 to 700 feet thick; southeast of Jefferson, however, it becomes a zone of intrusion, and attains a maximum thickness of nearly 1500 feet.

The best exposures occur along the westerly flowing streams and on the intervening ridges north of Jefferson. Southeast of Jefferson, outcrops are generally poor.

The trend of this body seems to be more or less independent of the structure of the surrounding rock (Pl. 1). Northwest of Jefferson, the foliation of the country rock trends northeast and dips northwest. Southeast of Jefferson, however, the foliation strikes northwesterly and dips northeast. Whether these structural complexities were caused by the emplacement of the composite dike or by an earlier deformation cannot be determined.

This ring dike is called a composite dike because it consists of two distinct portions. The portion north of a line extending due west from the summit of Mt. Starr King is more or less uniform in thickness and is composed of medium-grained hastingsite-quartz syenite. It apparently emplaced itself along the western boundary of the ring dike of quartz monzodiorite and quartz monzonite. Half a mile south of the north end of the composite dike, and on its east side, tongues and stringers of hastingsite-quartz syenite cut and include fragments of the quartz monzodiorite and quartz monzonite. Many of these inclusions show signs of partial assimilation. Inclusions of black, fine-grained rock, which possibly belongs to the Lost Nation group, also occur here. On the west side of the composite dike, stringers of hastingsite-quartz syenite intrude coarse, pink syenite of the Oliverian magma series. No data are available on the attitude of the dike walls.

South of a line extending due west from the summit of Mt. Starr King the composite ring dike becomes a zone of intrusion. Accordingly, its thickness varies and its boundaries are not sharp. A screen of country rock intervenes between this zone of intrusion and the ring dike of quartz monzodiorite and quartz monzonite. The country rock in the zone is coarse, pink, porphyritic syenite of the Oliverian magma series with some inclusions of black, fine-grained schist and amphibolite. It is cut by numerous, scattered, irregular or dikelike intrusions of medium-grained to fine-grained, pink biotite granite from a few inches up to 10 feet thick. Numerous, irregular, blocklike inclusions of syenite of the Oliverian magma series, cut by small stringers of pink biotite granite, are common in the granite intrusions.

In the shatter zone, northeast of Jefferson, irregular inclusions of quartz monzodiorite occur in pink biotite granite dikes. Many of these inclusions are penetrated by slender biotite granite stringers. One particular granite dike, filled with inclusions, has sharp, regular walls indicating that the inclusions were brought up at least some distance as the granite moved into place. A few dikelike intrusions of quartz monzodiorite cut the Oliverian syenite. One dike, 30 feet long and 1 foot thick, is cut and displaced along shear fractures observable in both the dike and the country rock. The intrusion of pink biotite granite may account for this displacement.

Fine-grained, dark trap dikes cut the syenite of the Oliverian magma series in this zone. Most of these are probably older than the White Mountain magma series since they are slightly metamorphosed. In two localities these trap dikes are intruded by the pink biotite granite.

The southeastern part of the composite ring dike appears to be a shatter zone into which pink biotite granite has been intruded as dikes and irregular masses. Modell (1936, p. 1906) found a similar phenomenon, but on a much smaller scale, in the ring dike of Albany quartz syenite in the Belknap Mountains.

The quantity of quartz monzodiorite in the shatter zone is so small and the distribution so local that it is impossible to prove whether the rock was intruded before or after shattering. However, the abundant, irregular fragments of quartz monzodiorite believed to have been brought up from depth by the pink biotite granite, suggest that the quartz monzodiorite antedated the shattering. In other words, the quartz monzodiorite apparently was not intruded into the shatter zone, and is not, therefore, a part of the composite ring dike.

As the pink biotite granite is probably younger than the hastingsite-quartz syenite the ring dike is truly composite. The northern hastingsite-quartz syenite portion of the dike was probably contemporaneous with the large hastingsite-quartz syenite ring dike of the Pliny Range. The southeastern part is younger and consists of a shatter zone containing numerous pink biotite granite dikes.

Crescent Range ring dike.—This body of pink granite porphyry forms the backbone of the Crescent Range. Its arcuate shape, regular boundaries, and remarkable symmetry are strong indications that it was emplaced along either a circular, elliptical, or arcuate fracture, although the fracture has not been observed beyond the limits of the intrusion. In its northern portion the dike and mountain range are coextensive, but toward the south, in the vicinity of Mt. Crescent, the dike swings westward, and the mountain ridge continues to the southwest for nearly 5 miles (Pl. 1). Along the arc, the dike measures nearly 8 miles, and the maximum width, just south of Black Crescent Mountain, is 1 mile. The dike becomes progressively thinner until it finally pinches out at both ends. It is not known whether the dike was emplaced along a circular or elliptical fracture, but if we assume the former, the radius of curvature, 2½ miles, is about equal to that of the hastingsite-quartz syenite ring dike. However, the areal extent (about 5 square miles) is slightly less than that of the hastingsite-quartz syenite dike.

The Crescent Range ring dike is probably the best-exposed structural unit in the region. Outcrops are particularly abundant in the vicinity of Mt. Crescent and along the easterly flowing streams north and south of Black Crescent Mountain. Near the horns of the crescent, outcrops are scattered. On the whole, exposures are better on the east side of the range than on the west side where glacial drift is thick.

A sharp contact between the ring dike and the pink gneiss of the Oliverian magma series is exposed at an elevation of 2540 feet in the southeasterly flowing stream which heads half a mile northeast of Mt. Crescent. The contact is sharp and distinct, and although the dip could not be measured accurately, it is apparently very steep. The contact has not been observed elsewhere, but it has been located within a few hundred feet at several places, both in deep valleys and on some high ridges. When these points are connected, smooth, curved boundaries are produced, without deflection by topography, implying that the walls of the dike are very steep if not vertical. Specifically, the contact has been located within about 100 feet horizontally on the summit of Mt. Crescent. Its altitude is 3230 feet. In the stream valley half a mile northeast of Mt. Crescent the contact is exposed at an altitude of 2540 feet. Thus there is a vertical difference of 690 feet within a horizontal distance of half a mile, and yet both points lie on the smooth curve determined by several other such points.

Locally, near the northeastern boundary of the ring dike, the foliation of the country rock seems to have been diverted from its general northeasterly trend. When considered regionally, however, the Crescent Range ring dike cuts directly across the structure of the country rock (Pl. 1).

At an elevation of 3200 feet in the hastingsite-riebeckite granite on the southeast slope of the eastern knoll on Terrace Mountain is a small dike of granite porphyry identical with that of the Crescent Range. This dike, although small, lies on what might be considered the projection of the north end of the Crescent Range ring dike. It may represent an intrusion along the same ring fracture. In any event, since the small dike on Terrace Mountain is similar petrographically to the Crescent Range ring dike, and since the rock of which both are composed is a rather unusual type, it appears that both were intruded contemporaneously.

Hastingsite-quartz syenite stock.—One mile southwest of Pliny Mountain is a large outcrop of medium-grained to fine-grained hastingsite-quartz syenite. There is no information as to the size or shape of the mass; consequently, it is outlined on the geological map (Pl. 1) with dashes. As this body petrographically resembles the hastingsite-quartz syenite ring dike of the Pliny Range, the two were probably more or less contemporaneous.

Hastingsite-riebeckite granite stock.—The hastingsite-riebeckite granite stock lies mainly in the Mt. Washington quadrangle, but the mass extends north for about 1 mile into the Percy quadrangle. The outline of the body is roughly elliptical with the long axis, nearly 5 miles, trending northwest-southeast. The short axis is approximately 3 miles long. The area of the stock (excepting inclusions and younger intrusions) is about 10 square miles, but the portion in the Pliny region covers about 6½ square miles.

In the Percy quadrangle, the stock is not well exposed, but outcrops may be seen near the summit of Mt. Cabot and on the ridge directly west between elevations 2500 feet and 3000 feet. In the Pliny region, exposures are excellent along the crest and upper slopes of Terrace Mountain.

Since the contacts of the hastingsite-riebeckite granite stock are not exposed, their dips are not known. The eastern boundary has been rather accurately located, but because of poor exposures the western boundary can be established only in a general way. On the south the contact is covered by glacial drift.

In 1935 when R. W. Chapman published on the ring dike complex of the Percy quadrangle, little was known about the geology of the Pliny region, and this body of hastingsite-riebeckite granite, was believed to be a thick ring dike. However, present studies show the body to be a stock, and it was, therefore, necessary to alter somewhat those boundaries which had been drawn in the Percy region.

The hastingsite-riebeckite granite stock contains abundant quartzite inclusions, many of which may be seen in the well-exposed granite along the crest of Terrace Mountain. Others occur on the flanks of Terrace Mountain and on the south slope of Mt. Cabot. The outlines of these inclusions are probably irregular, but only limited portions of their boundaries are visible. They range in cross section from a few hundred feet to nearly 3000 feet, the largest one lying less than 1 mile northeast of the northernmost peak of Terrace Mountain. The inclusions consist of dense, dark quartzite of the Albee formation, like the country rock to the west. Most of the blocks are well stratified, and show random strike and dip.

Hastingsite-biotite granite stock.—This body of pink, medium- to fine-grained hastingsite-biotite granite lies east and southeast of Round Mountain, adjacent to the ring dike of hastingsite-quartz syenite. Due to the paucity of outcrops, the exact shape of the body is unknown, and its boundaries, therefore, are mapped with a dashed line. The body covers an area of about 2 square miles. Its north-south axis is 2¾ miles, and its east-west axis is 1½ miles. The distribution of outcrops at least suggests that the hastingsite-biotite granite stock has cut into the hastingsite-quartz syenite ring dike and that the former is, therefore, younger.

Conway granite stocks.—In the Pliny region the Conway granite is represented by numerous small stocks, six of which are mapped (Pl. 1). They are all roughly circular in plan, although in many cases boundaries could not be located accurately. The largest of these stocks lies due south of Mt. Starr King where it intrudes the ring dike of hastingsite-quartz syenite. A smaller one cuts the hastingsite-quartz syenite ring dike due east of Round Mountain, and a third occurs in the country rock (pink syenite of the Oliverian magma series) 1⅓ miles west-northwest of Mt. Starr King. Three more small stocks intrude the hastingsite-riebeckite granite on the flanks of Terrace Mountain. Many others, too small to map, were found cutting the older rocks in several places. The abundance and distribution of these bodies suggest that they represent cupolas rising from a much larger intrusive mass below.

The southern portion of a large stock of Conway biotite granite lies along the northern edge of the Mt. Washington quadrangle just east of the hastingsite-riebeckite granite stock. It is well exposed in a small quarry along the unimproved road 1 mile west-southwest of York Pond. Although its southern boundary is mapped with a dashed line, its location is believed to be fairly accurate since it is extrapolated from detailed mapping farther north. This large stock apparently cuts out part of the hastingsite-riebeckite granite stock east of Mt. Cabot.

RELATION OF THE PLINY REGION TO OTHER RING DIKE AREAS

General statement.—Before attempting to determine the origin of the structural units of the Pliny region, it will be helpful to consider the relation of this area to other New England districts in which ring dikes have been described: the Ossipee Mountains, New Hampshire (Kingsley, 1931), the Percy region, New Hampshire (R. W. Chapman, 1935), the Belknap Mountains, New Hampshire (Modell, 1936), the Franconia quadrangle, New Hampshire (Williams and Billings, 1938), the Mt. Chocorua quadrangle, New Hampshire (Smith, *et al.*, 1939), and Ascutney Mountain, Vermont (Chapman and Chapman, 1940).

Proximity to the Percy region.—The Percy region bounds the Pliny region on the north. The topography, rock types, and structural features of these two areas are very similar; the two regions are part of one large intrusive complex which covers an area of nearly 200 square miles.

Similarity of structural units.—Some of the structural units of the Pliny region resemble those in other New England areas. For example, although the ring dike of the Crescent Range is much longer, covers a greater area, and is composed of granite porphyry rather than syenite porphyry, it has the same crescentic shape and the same radius of curvature as the Cape Horn ring dike of the Percy complex. Field relations indicate that the walls of both dikes are very steep: the Cape Horn dike is believed to dip about 75°, and the Crescent Range dike may dip even more steeply.

A second comparison may be made between the hastingsite-quartz syenite ring dike of the Pliny Range and the Albany quartz syenite ring dike of the Belknap Mountains (Fig. 1). Both are asymmetrical crescents of quartz syenite, and the radius of curvature of both is the same. The dike of the Belknap Mountains, however, is somewhat more slender and less regular.

In the third place, the composite ring dike of the Pliny region is similar to the Rattlesnake composite ring dike of the Belknap Mountains. Both are discontinuous and both are composed of several kinds of rock. The composite dike of the Belknap Mountains is considerably thicker however.

Finally, the role of the Conway granite as stocklike bodies is also common in the other ring dike areas of New England, but small ring dikes of it are found in the Belknap Mountains and in the Percy complex. The stocks in the Pliny region are smaller and more numerous than those in other areas.

Centers of intrusion.—The ringlike intrusions of the Pliny region are grouped about two separate centers. One lies in the midst of the Pliny Range about 2 miles northeast of Mt. Starr King, and it is about this center that the older ring dikes are arranged. The granite porphyry ring dike, which is probably the youngest in the region, has a center of intrusion 3 miles northeast of Pliny Mountain. The granitic stocks are distributed irregularly about the earlier center of intrusion. A similar arrangement of ring structures and associated stocks about more than one center of intrusion has been demonstrated in the Belknap Mountains, the Percy region, and at Ascutney Mountain, Vermont (Fig. 1).

Rock types.—In the Pliny region, as in the other New England ring dike areas, the intrusions belong to the White Mountain magma series. The older structural units are composed of the more basic rocks, whereas the later bodies are made of siliceous varieties. Inasmuch as the stocks are generally the latest, they are composed principally of granite. Apparently the rocks of the White Mountain magma series have followed the normal order of differentiation, and consequently the rock type composing a particular body depends upon the relative age of that body. In the case of composite ring dikes, there has been more than one period of intrusion along the same fracture.

INTRUSION OF THE RING DIKES

General theory.—Due to a lack of good rock exposures, information on the origin of the ring structures of the Pliny region is incomplete. Although there is no positive evidence of the sinking of large, cylindrical blocks, the similarity of the ring structures here to those in other New England areas where the origin has been fairly definitely established, suggests that cauldron subsidence or ring-fracture stoping has been the method of origin of the ring dikes and perhaps some of the stocks. This theory has been discussed so much recently in the literature that only a résumé of the essential features will be given here.

The concept of cauldron subsidence or ring-fracture stoping was developed by E. M. Anderson (Clough, *et al.*, 1909, p. 11-12). He assumes a paraboloidal magma chamber in the crust at a depth of several miles. As long as the roof and magma chamber remain under the same hydrostatic pressure no fractures will form, but if the magmatic pressure is reduced, a tension is set up. This results in a number of steeply dipping fractures that slope outward. The sinking of the central block into the magma chamber and the intrusion of magma along these fractures result in ring dikes. During the sinking of the central block a portion of the ring fracture may become closed up in one manner or another so that the intrusion of magma along it is impossible. Thus a partial or incomplete ring dike, having an arcuate or crescentic shape, might form. Various other modes of formation of such structures have been discussed in some detail by Modell (1936, p. 1925-1927).

The theory outlined above is general and does not explain in detail the mechanism by which the ring dikes emplace themselves. Fortunately, the Pliny region offers some evidence on this problem.

Evidence offered by the composite ring dike.—The northern portion of the composite ring dike is the older and is composed of hastingsite-quartz syenite, whereas the southern part is a more or less irregular zone with intrusions of pink biotite granite. The dike is not a solid intrusion which has emplaced itself between the two walls of a sharp fracture, but instead, it is a zone of intense fracturing into which many small dikelike intrusions have worked their way. The writer believes that the body originated somewhat as follows.

Tensional stresses in the region formed a curved fracture which now marks the general position of the dike. An isolated, cylindrical block produced by the curved fracture, settled downward into the magma chamber. As the two walls moved past one another, they shattered and crushed the rock on both sides of the break. Possibly this displacement caused considerable deformation of the earlier structures in the surrounding rock. Spreading of the fracture walls in the late stages of the movement produced a zone of porous rubble which favored magmatic intrusion. In the northern portion of this porous zone hastingsite-quartz syenite magma rose, engulfing the fractured blocks, until a more or less solid dike was formed. Quite likely piecemeal stoping was important in making room for the rising magma. A somewhat similar mechanism has been suggested by Williams and Billings (1938) in the Franconia quadrangle.

Later, and perhaps accompanied by further displacement of the walls, intrusion was initiated in the southern portion of the composite dike. Pink biotite granite rose as a network of small, irregular dikes, filling fractures and spaces between irregular blocks.

Evidence offered by the Crescent Range ring dike.—The Crescent Range ring dike differs from the composite ring dike in several ways: (1) It is a symmetrical crescent; (2) its boundaries are regular and smoothly curving; (3) it is a solid dike which lacks inclusions of any great size (a few small inclusions are discussed in the petrographic description); and (4) it is composed of granite porphyry which has corroded phenocrysts in a very dense groundmass.

It is evident from these comparisons that the granite porphyry ring dike had a quite different origin. Its symmetrical, crescent shape and its regular, smoothly curving boundaries indicate clearly that it rose en masse along a sharp, curving fracture. The sharp, regular boundaries and the lack of abundant inclusions suggest that stoping of small blocks was unimportant. In contrast with the other dikes of the area, the Crescent Range ring dike must have cooled quickly since the groundmass of the granite porphyry is dense. However, the large, corroded phenocrysts of orthoclase and quartz suggest that the magma must have been cooling slowly at some deep level prior to its final injection.

The genesis of the Crescent Range ring dike seems to have been somewhat as follows: somewhere beneath the present surface lay a body of granitic magma which was cooling slowly. Early formed crystals of orthoclase and quartz were being resorbed and corroded by the cooling melt. Apparently resorption and corrosion took place at depth rather than in the dike, since cooling of the magma was very rapid after the dike was emplaced. Then a steeply dipping, circular or slightly elliptical fracture developed across the structure of the country rock, as a result of tensional stresses. The cylindrical or domical block thus formed sank and crowded westward so that a crescentic opening instead of an annular opening was produced. Into this opening the granitic magma was injected and suddenly cooled to produce a symmetrical, crescentic ring dike of granite porphyry. The original fracture may have extended as far west as Terrace Mountain because a small dike of granite porphyry was found at an elevation of 3200 feet on the southeastern slope of the eastern knoll.

The crescent-shaped Cape Horn ring dike in the Percy region is composed of dense syenite porphyry. Its history is probably essentially the same as that of the Crescent Range ring dike. According to Billings (personal communication) the ring dike of granite porphyry forming the Franconia Range is also analogous.

Evidence offered by the other ring dikes.—The ring dike of quartz monzodiorite and quartz monzonite and the hastingsite-quartz syenite ring dike have fairly regular, broadly sweeping boundaries, and neither contains inclusions. This suggests that they were intruded en masse along sharp fractures, and that piecemeal stoping of small blocks was unimportant. Both dikes, however, are composed of medium-grained rock which implies that cooling was relatively slow. These two bodies are typical of most of the ring dikes of northern New England.

INTRUSION OF THE STOCKS

The large Conway granite stock extending south from the Percy region, the large hastingsite-riebeckite granite stock of Terrace Mountain, and perhaps even the hastingsite-biotite granite stock southeast of Round Mountain can all be explained by ring-fracture stoping if it be assumed that in each case the central block has dropped below the present erosion surface. However, the smaller stocks composed of Conway granite may represent small cupolas which have risen from a large granite mass below, by piecemeal stoping of the country rock.

ORIGIN OF THE ROCK TYPES

The rocks of the Pliny region are believed to have originated in a large reservoir of basaltic magma at some depth. Inasmuch as they exhibit a definite sequence from basic to acid types, fractional crystallization is thought to have been the dominant process of formation. At various stages during differentiation the reservoir was tapped by fractures extending toward the surface, and the magma rose along these breaks to form the ring dikes and stocks. Late granitic types are particularly abundant in the Pliny region, however, and it is difficult to account for large quantities of silica by fractional crystallization alone. Possibly in the late stages of differentiation, large masses of assimilated siliceous country rock helped to form abundant granitic magma.

The concept outlined above is the same as that proposed some years ago to explain the White Mountain magma series as a whole (Chapman and Williams, 1935).

SUMMARY AND CONCLUSIONS

The conclusions drawn from the present study are summarized as follows: (1) The Pliny region is similar to several other New England areas in that it has ring dike and stock intrusions; (2) the intrusive bodies are grouped about two distinct centers; (3) the ring dikes are probably all arcs or partial rings; (4) for the most part the stocks are younger than the ring dikes and they cut across the latter; (5) cauldron subsidence or ring-fracture stoping (the settling of large, cylindrical or domical blocks along curved fractures) is believed to be the best explanation of the intrusion of all of the ring dikes and some of the stocks; (6) the composite ring dike near Jefferson resulted from the injection of magma into a highly fractured, arcuate zone; (7) the ring dike of the Crescent Range, however, was formed by the injection en masse of granite porphyry along a smooth, sharp, curved fracture; (8) all intrusive bodies are composed of differentiates of the White Mountain magma series and are believed to have originated chiefly through fractional crystallization of a basaltic magma somewhere at depth; and (9) the presence of many granitic types among these intrusions, however, implies that assimilation of siliceous country rock was also important in producing the late granitic differentiates.

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