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Abstract

The Lovewell Mountain quadrangle in southwestern New Hampshire is underlain by metasedimentary rocks of the lower Devonian Littleton formation and plutonic rocks of the New Hampshire magma series, which is probably of late Devonian age,

The lower portion of the Littleton formation in the area consists mainly of well-bedded sillimanite schist, pseudo-sillimanite schist, and mica-quartz schist, whereas the upper portion consists of poorly banded gneisses. The thickness of the Littleton formation exposed in the area is probably of the order of 20,000 feet. The plutonic rocks range from quartz monzonite to quartz diorite but granodiorite predominates.

The area is on the eastern flank of a large anticline. The foliation in the metasedimentary rocks is mainly of the axial plane type and is parallel to bedding except at the noses of folds. The plutonic bodies are generally concordant although some parts of the bodies cross-cut several thousand feet of the adjacent metasedimentary rocks. Small scale discordant relationships are common along the contacts of the Kinsman quartz monzonite.

The metasedimentary rocks have been subjected to high-grade metamorphism. Orthoclase formed at the expense of muscovite in a large part of the area in response to the high temperatures which prevailed during the peak of metamorphism, but the orthoclase altered to muscovite and quartz under declining intensity conditions during the final stages of metamorphism in most of the eastern two-thirds of the quadrangle. Changes in chemical composition during metamorphism were apparently not important, although potash was probably added to the pseudo-sillimanite schists and soda and lime were added to a few of the paragneisses.

Most of the bodies of plutonic rocks are intrusive, but the gradational nature of the contacts in a few places suggests that some of the plutonic rocks may have undergone little movement. Definite conclusions regarding the source of the granitic material could not be drawn. Magma rising from great depth may have entered certain favorable horizons to form large sill-like masses. The mineralogical and textural similarity between the plutonic rocks and some of the metamorphic rocks suggests that the granitic material may have originated at a comparatively shallow depth by the solution or partial solution of favorable beds. The mobilized material may have moved along approximately the

same stratigraphic horizon at which it originated to form the intrusive sheets.

Introduction

The Lovewell Mountain quadrangle is located in the southwestern part of New Hampshire (Fig. 1). Early investigations of the bedrock geology in the area were conducted by C. T. Jackson (1844) and C. H. Hitchcock (1875; 1877; 1878). Daly (1897) made brief study of the Kinsman quartz monzonite in the eastern part of the quadrangle. Conant (1935) reported optically positive cordierite and Meyers (1948) described green lazulite from the area. Modern mapping in western New Hampshire has been completed north of the area except in the Sunapee quadrangle where C. A. Chapman is now conducting field work. South of the Lovewell Mountain quadrangle Katharine Fowler-Billings (1949) has completed mapping through the Monadnock quadrangle to the Massachusetts line.

The field work occupied 31 weeks during the summers of 1946 and 1947. The geology was plotted on the 1942 edition of the United States Geological Survey topographic sheet enlarged to a scale of 3 inches to a mile. Most locations were made by inspection or by pace and compass traverses but an altimeter was used on the steeper slopes. Some points were located by means of aerial photographs taken in 1939 by the United States Department of Agriculture. About 12 days were spent making pace and compass maps (scale of 750 feet to the inch) along critical contacts.

Acknowledgments

To Professor Marland P. Billings, who supervised the work, the writer is deeply indebted for many valuable suggestions in the field and in the preparation of the manuscript. Grateful appreciation is expressed to Professor Esper S. Larsen for his willing assistance in the laboratory work and for helpful criticisms of the paper. Thanks are due James B. Carney and John R. Williams for able field assistance. Acknowledgment is made to the R. W. Sayles Fund of Harvard University for financial support for both field seasons and to the Department of Mineralogy and Petrography of Harvard University for funds for thin sections. The cost of the chemical analyses was financed by a grant from the Shaler Memorial Fund and by the Department of Mineralogy and Petrography of Harvard University.

General Lithologic Features

The metasedimentary rocks (Fig. 2) in the Lovewell Mountain quadrangle belong to the Devonian Littleton formation and comprise about half of the area. Largely schists and gneisses, they are in the high-grade metamorphic zone.

The plutonic rocks belong to the late Devonian (?) New Hampshire magma series, which is represented in this area by the Bethlehem gneiss, the Kinsman quartz monzonite, and the Concord granite. Post-metamorphism quartz veins and light-colored granitic dikes are common, especially in the bodies of Kinsman quartz monzonite. Large bodies of pegmatite are numerous in the western part of the quadrangle and small veins of pegmatite are abundant throughout the plutonic bodies.

Littleton Formation

General Statement

In the Lovewell Mountain quadrangle the Littleton formation has been subdivided into three members: the Hubbard Hill member, the May Pond member, and the Dakin Hill member. The Hubbard Hill member is the lowermost portion of the Littleton formation in the area. The base of this member lies about 5000 feet above the base of that portion of the Littleton formation which is exposed to the west in the Bellows Falls quadrangle (Kruger, 1946, p. 186). The Hubbard Hill member is exposed in the southwestern and northwestern portions of the quadrangle. The May Pond member lies stratigraphically above and to the east of the Hubbard Hill member. The uppermost portion of the Littleton formation, the Dakin Hill member, occupies a large area extending from the southern boundary to the northern boundary of the quadrangle in the central portion of the area.

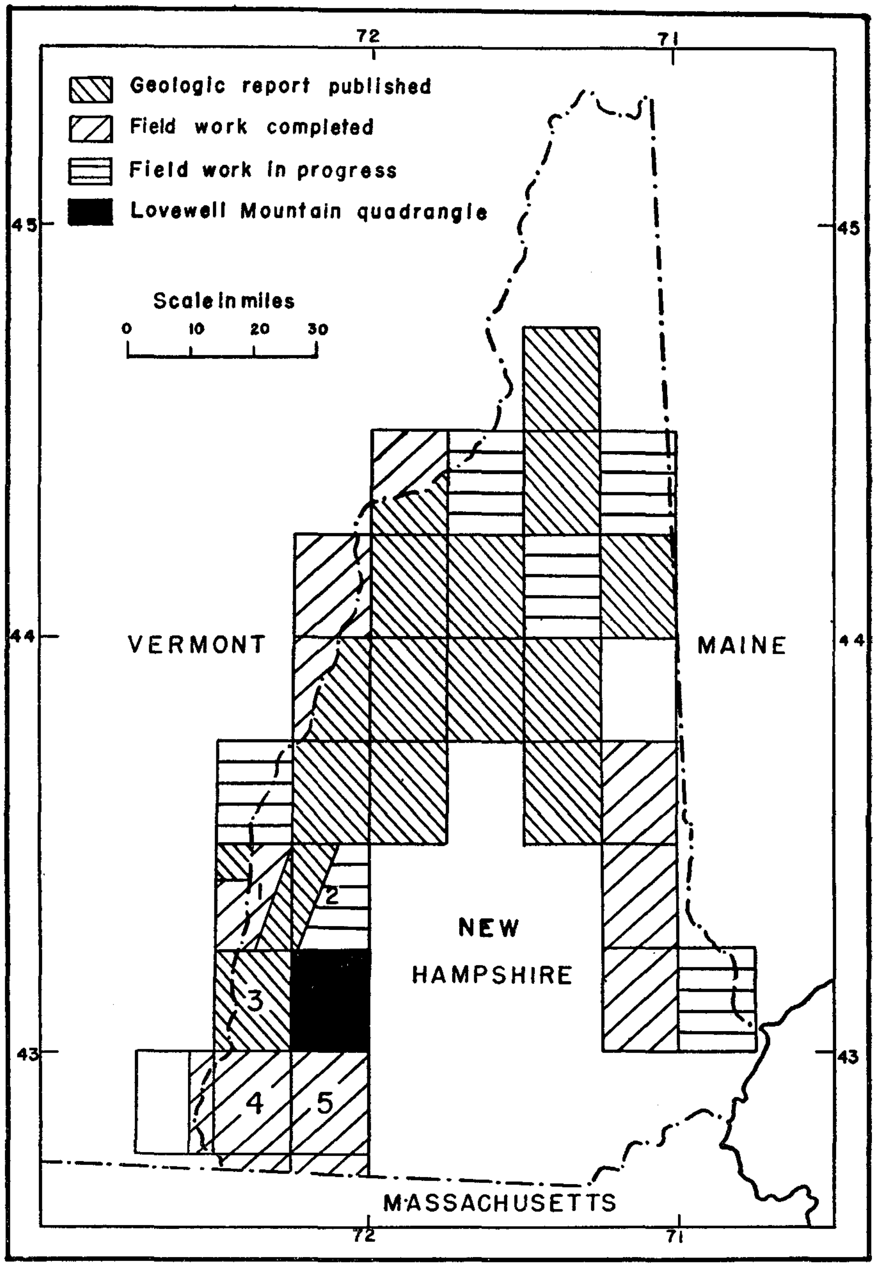


FIGURE 1.—INDEX MAP

Areas adjacent to the Lovewell Mountain quadrangle in which mapping has been recently completed or field work is in progress are: 1 = Claremont quadrangle (R. W. Chapman and C. A. Chapman); 2 = Sunapee quadrangle (C. A. Chapman); 3 = Bellows Falls quadrangle (F. C. Kruger, 1946); 4 = Keene area (G. E. Moore, 1949); 5 = Monadnock region (K. Fowler—Billings, 1949).

Hubbard Hill Member

General Statement.—The Hubbard Hill member in the northwestern part of the area is composed largely of interbedded sillimanite schists and mica-quartz schists.[1] Discontinuous beds of lime-silicate granulite and quartz conglomer-

[1] In accordance with the classification used by Billings (1937, p. 491), rocks composed mainly of mica and quartz with a little feldspar are desig-

ate are exposed in the west-central part of the area, and small masses of amphibolite are found in a few places. In addition to sillimanite schist and mica-quartz schist, banded gneiss occurs columns 1 to 5. The sillimanite in the sillimanite schists generally occurs in porphyroblasts which are 2–5 cm. long and 5 mm. thick. The porphyroblasts generally lie in the plane of

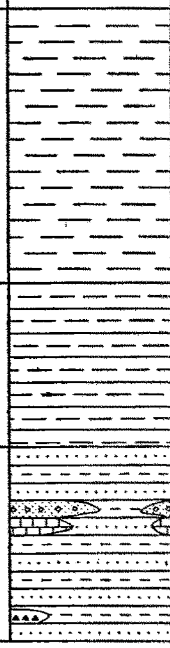
AGE	FORMATION	MEMBER	SYMBOL	COLUMNAR SECTION	LITHOLOGY	THICKNESS IN FEET
LOWER DEVONIAN	LITTLETON FORMATION	DAKIN HILL	Dld		Porphyroblastic orthoclase gneiss, biotite-quartz gneiss, biotite-sillimanite gneiss, and pyritiferous gneiss.	10,000(?)
		MAY POND	Dlm		Orthoclase gneiss and biotite gneiss.	0-5,000(?)
		HUBBARD HILL	Dlh, Dlq, Dll, Dlh, Dlv		Mica-quartz schist, quartz-mica schist, quartz-feldspar-mica schist, sillimanite schist, pseudo-sillimanite schist, and gneiss (Dlh); quartz conglomerate and quartzite (Dlq); diopside granulite, actinolite-diopside granulite, and purplish biotite schist (Dll); amphibolite (Dlv).	6,000

FIGURE 2.—COLUMNAR SECTION OF THE METASEDIMENTARY ROCKS

locally in the Hubbard Hill member in the southwestern part of the area.

The chemical composition of the minerals of these rocks is considered in a later section of the paper.

Schist.—Interbedded sillimanite schist and mica-quartz schist comprise most of the Hubbard Hill member in the northwestern part of the area. Quartz-mica schist and quartz-feldspar-mica schist occur locally. Individual beds are only a few inches thick, but are continuous over considerable distances (Pl. 2, fig. 1). A representative measured section of the schists is given in Table 1. In the southwestern part of the area bedding is not as conspicuous as in the northwestern portion.

The schists are gray and medium-grained to coarse-grained. Modes are given in Table 2, schistosity and in a few places show a slight linear parallelism. Most of the porphyroblasts have been drawn out into augen and are partially altered to muscovite. Pseudo-sillimanite schist occurs locally where the sillimanite has largely altered to muscovite. Although the sillimanite has been completely replaced in some of the schists, small remnants of sillimanite are generally found in the core of the muscovite pseudomorphs. Accessory tourmaline is slightly more abundant in the pseudo-sillimanite schists than in the other types. The pseudo-sillimanite schists near the northern boundary of the quadrangle are moderately contorted and contain small lenses of quartz and feldspar. In this area, large cross-muscovite flakes are conspicuous in the matrix as well as in the pseudomorphs. The fact that the muscovite is only slightly deformed indicates that it formed after most of the deformation.

nated as follows: mica schist, less than 60 per cent quartz and feldspar; mica-quartz schist, 60 to 80 per cent quartz and feldspar; quartz-mica schist and quartzite, over 80 per cent quartz and feldspar.

TABLE 1.—SECTION OF INTERBEDDED SILLIMANITE SCHISTS AND MICA-QUARTZ SCHISTS OF THE HUBBARD HILL MEMBER

Summit of Silver Mountain, Lempster

	Thickness (inches)
Mica-quartz schist	1.0
Sillimanite schist	0.5
Mica-quartz schist	1.1
Sillimanite schist	0.8
Mica-quartz schist	1.0
Sillimanite schist	0.1
Mica-quartz schist	1.0
Sillimanite schist	7.0
Mica-quartz schist	0.1
Sillimanite schist	5.5
Mica-quartz schist	0.5
Sillimanite schist	0.5
Mica-quartz schist	0.3
Sillimanite schist	2.0
Mica-quartz schist	0.3
Sillimanite schist	3.0
Mica-quartz schist	1.5
Sillimanite schist	1.5
Mica-quartz schist	1.0
Sillimanite schist	0.3
Mica-quartz schist	0.8
Sillimanite schist	11.0
Mica-quartz schist	0.5
Sillimanite schist	0.3
Mica-quartz schist	0.3
Sillimanite schist	2.3
Mica-quartz schist	2.0
Sillimanite schist	6.0
Mica-quartz schist	0.3
Sillimanite schist with a few 0.3 inch mica-quartz schist beds	17.0
Mica-quartz schist	1.0
Sillimanite schist	1.3
Mica-quartz schist	0.3
Sillimanite schist	2.0
Mica-quartz schist	0.3
Sillimanite schist	2.0
Mica-quartz schist	0.3
Sillimanite schist with a few 0.3 inch mica-quartz schist beds	12.0
Sillimanite schist	0.5
Mica-quartz schist	0.5
Sillimanite schist	1.5
Mica-quartz schist	1.0
Sillimanite schist	0.5
Mica-quartz schist	0.8
Total	93.5

Sillimanite schist.................83 per cent
Mica-quartz schists...............17 per cent

Lime-silicate granulite[2] *and associated schist.*—Beds of lime-silicate granulite occur discontinuously at one horizon in the Hubbard Hill member between Gee Mill and the western knoll of Marlow Hill in Marlow (Pl. 1). A measured section of the lime-silicate beds and associated schists is given in Table 3. The granulites are medium-grained and light gray or pale green. A few of the beds are pyritiferous and have a rusty-brown weathered surface. The lime-silicate rocks were probably derived from impure dolomitic limestones.

Microscopic study shows that the texture is essentially granoblastic and that the grain size ranges from 0.1 to 1.0 mm. Essential minerals are actinolite, diopside, plagioclase, microcline, and quartz. The plagioclase ranges from bytownite (An_{87}) to anorthite (An_{93}) in different specimens. Common accessories are garnet, biotite, pyrite, and sphene. Modes are given in Table 2, columns 8, 9, and 10.

Purplish biotite schists and pyritiferous mica schists are interbedded with the lime-silicate granulites. The schists are fine-grained to medium-grained and are composed mainly of quartz, anorthite, biotite, and garnet. A mode of the purplish biotite schist is given in Table 2, column 11. Originally these schists were probably calcareous shales.

Quartz conglomerate and quartzite.—Quartz conglomerates and quartzites overlie the lime-silicate beds. The quartz conglomerates crop out almost continuously from Gee Mill to the southwestern slope of Marlow Hill (Pl. 1). Discontinuous lenses of quartz conglomerate and quartzite, which are too small to be shown on the geologic map, are common between Marlow Hill and the western boundary of the quadrangle. Most of the pebbles in the conglomerate are composed of quartz and are 1 inch to 2 feet long. They are highly drawn out and have axial lengths ranging from 1:2:4 to 1:3:16. The matrix generally contains mor than 80 per cent quartz, but locally it is ricl in muscovite. Biotite, oligoclase, and microcline occur in minor amounts with accessory pyrite, sphene, zircon, and garnet. A mode is given in Table 2, column 6. Only one outcrop of relatively pure quartzite has been observed in

[2] Granulite, as used in this paper, refers to quartzo-feldspathic metamorphic rock without conspicuous schistosity.

FIGURE 1. HUBBARD HILL MEMBER
Interbedded mica-quartz schist and sillimanite schist.

FIGURE 2. MAY POND MEMBER
Crudely banded biotite gneiss. Light-colored lenses are composed of quartz, muscovite, and plagioclase.

FIGURE 3. DAKIN HILL MEMBER
Orthoclase gneiss. The light-colored clots are largely orthoclase with a few per cent of quartz.

METASEDIMENTARY ROCKS

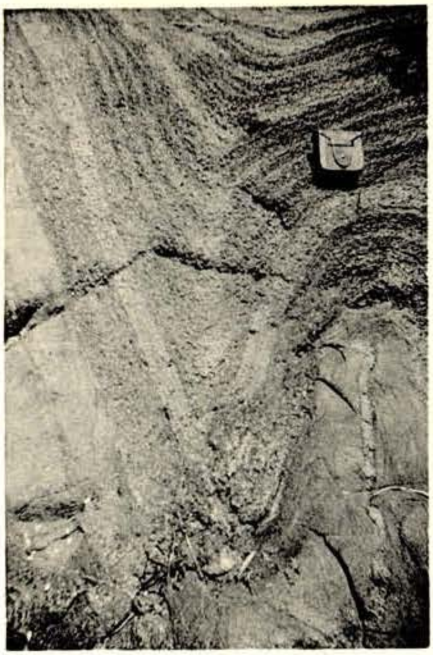


FIGURE 1. FOLDS IN SCHIST

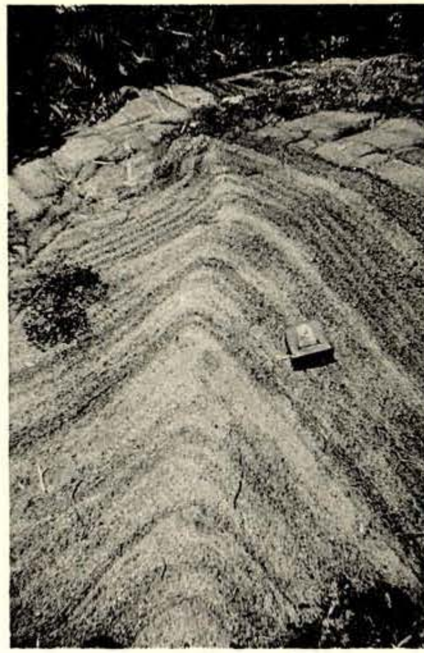


FIGURE 2. FOLDS IN SCHIST

FIGURE 3. FOLDS IN QUARTZ VEINS AND QUARTZITE

The bed of quartzite is shown to the left of the hammer. The quartz veins, which occur in micaceous beds, are more highly contorted than the quartzite.

FIGURE 4. STRETCHED PEBBLES IN QUARTZ CONGLOMERATE

FOLDS AND STRETCHED PEBBLES IN THE

Photographs by J. R. Williams

TABLE 2.—ESTIMATED MODES OF THE HUBBARD HILL MEMBER

	Schists					Quartzites		Lime- silicate granulites and associated schists				Amphi-bolites
	1	2	3	4	5	6	7	8	9	10	11	12
Number of thin sections	1	3	1	5	2	1	1	1	2	1	2	1
Quartz	79	53	55	51	59	88	94		3	10	40	5
Microcline							3	38	32			
Oligoclase	5	13	28	14	4	6						
Andesine												51
Bytownite									5			
Anorthite								20		48	33	
Biotite	12	22	12	21	18	6	tr	2		tr	22	3
Muscovite		9		5	13	tr	2				tr	
Chlorite		tr					tr					
Hornblende												40
Actinolite								tr	37	39		
Diopside								40	23	tr		
Sillimanite	tr	tr		8	1							tr
Garnet	4	2	5	1	4	tr	tr			1	4	
Magnetite	tr	1	tr	tr	tr	tr	tr	tr			tr	tr
Tourmaline	tr	tr		tr	1				tr	tr		
Pyrite								tr	tr	2	1	
Apatite	tr	tr	tr	tr	tr	tr					tr	tr
Zircon	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	
Sphene							tr	tr	tr	tr		
Graphite				tr					tr	tr		
Zoisite							1					
Rutile							tr					
Epidote												1
Per cent of anorthite in plagioclase	25	27	28	27	28	28		93	87	90	92	35
Grain size in mm	0.1–1.0	0.1–3.0	0.2–1.0	0.1–40	0.2–8	0.1–1.5	0.5–1.0	0.1–1.0	0.1–1.0	0.2–1.0	.05–1.0	0.2–1.0
Texture*	G	S	G	S	S	G	G	G	G	G	S	G

* G—Granulose; S—Schistose.

Schists

1. Quartz-mica schist.
2. Mica-quartz schist.
3. Quartz-feldspar-mica schist.
4. Sillimanite schist.
5. Pseudo-sillimanite schist.

Quartzites

6. Matrix of quartz conglomerate.
7. Quartzite.

Lime-silicate granulites and associated schists.

8. Diopside granulite.
9. Actinolite-diopside granulite.
10. Pyritiferous actinolite granulite.
11. Purplish biotite schist.

Amphibolites

12. Amphibolite.

TABLE 3.—MEASURED SECTION OF LIME-SILICATE BEDS AND ASSOCIATED ROCKS

Road cut at Gee Mill in Marlow

	Thickness (feet)
Top not exposed	
Actinolite-diopside granulite	0.4
Purplish mica-quartz schist	6.6
Actinolite-diopside granulite	1.0
Mica-quartz schist	1.8
Actinolite-diopside granulite	0.8
Interbedded pyritiferous mica-quartz schist and purplish biotite schist	6.8
Garnetiferous granulite	0.2
Interbedded pyritiferous mica-quartz schist and purplish biotite schist	4.2
Actinolite-diopside granulite	0.4
Concordant quartz vein	0.6
Actinolite-diopside granulite	2.5
Gap	1.7
Pyritiferous actinolite-diopside granulite	12.5
Interbedded pyritiferous actinolite-diopside granulite and mica schist	18.9
Pyritiferous mica-quartz schist	14.0
Pyritiferous actinolite-diopside granulite	12.3
Light-brown actinolite-diopside granulite	48.5
Pyritiferous actinolite-diopside granulite	2.8
Interbedded pyritiferous sillimanite schist and pyritiferous mica-quartz schist	12.8
Pegmatite	3.0
Pyritiferous sillimanite schist	1.2
Pegmatite	0.3
Sillimanite schist	1.8
Pegmatite	0.3
Sillimanite schist	0.8
Pegmatite	0.5
Mica-quartz schist and sillimanite schist	0.7
Pegmatite	2.4
Sillimanite schist with a few half-inch beds of mica-quartz schist	4.2
Interbedded pyritiferous mica-quartz schist and pyritiferous sillimanite schist	0.8
Sillimanite schist	1.2
Interbedded pyritiferous mica schist and sillimanite schist with a few beds of garnet granulite 3 mm. thick	3.0
Typical nonpyritiferous schists of the Hubbard Hill member	
Total (excluding pegmatites and quartz veins)	160.2

the area. This quartzite has a glassy appearance and contains 94 per cent quartz (Table 2, column 7).

Gneisses.—Gneisses are not common in the Hubbard Hill member, but they occur at a few localities in the southwestern part of the area. Well-formed lenses of light-colored minerals comprise 5–20 per cent of the rock. The lenses are several centimeters long and 5 to 10 mm. thick. They are composed of andesine and quartz with minor amounts of potash-feldspar, muscovite, and biotite. Most of the lenses are very coarse-grained, with andesine crystals as much as 2 cm. long. Because of the coarse-grained texture of the lenses, accurate modal determinations could not be made. It is estimated that the lenses contain 60–75 per cent andesine (An_{32}) and 25–40 per cent quartz. The dark layers in the gneiss are schistose and have the same mineralogical composition as ordinary mica schist. Some of the gneisses in the eastern portion of the Hubbard Hill member in Sullivan contain about 5 per cent potash-feldspar and are poorly foliated. These rocks are similar to the gneisses of the May Pond member which are described in a later section.

Amphibolite.—Small masses of amphibolite occur north of Gustin Pond in Marlow. The amphibolites are composed mainly of andesine and amphibole with minor amounts of biotite and quartz. A mode is given in Table 2, column 12. These rocks are similar to the amphibolites in the Littleton-Mooselauke area which are believed to be of igneous origin (Billings, 1937, p. 493).

May Pond Member

General statement.—The May Pond member lies stratigraphically above and to the east of the Hubbard Hill member. In the northern part of the quadrangle, the two members are separated by a sill of Kinsman quartz monzonite. The May Pond member is composed predominantly of banded gneiss although beds of well-stratified schist occur in a few places.

Lithologic characteristics.—The light-colored minerals in the gneiss are generally concentrated in short lenses rather than continuous layers (Pl. 2, fig. 2). In some of the gneiss, banding is vague and the light-colored constituents occur in irregular contorted stringers. In the well-foliated rocks, the lenses are thinner and more continuous than in the massive types.

The average lens is about 7 cm. long and 1.5 cm. thick, but some of the lenses reach a maximum of 20 cm. in length and 4 cm. in thickness. The degree of segregation of the light and dark minerals is highly variable. In some of the gneiss the light-colored aggregates are composed almost entirely of quartz, feldspar, and muscovite; the dark layers consist largely of biotite and garnet. More commonly the light-colored portions contain a moderate amount of biotite and the dark layers contain considerable quartz and feldspar. The ratio of light to dark layers ranges between wide limits. On the average, the light-colored bands constitute 10–20 per cent of the rock, but they may comprise as much as 30 per cent of the rock.

The dark layers are generally fairly schistose and are composed of biotite, quartz, oligoclase, garnet, and sillimanite. Muscovite does not occur in any of the unaltered rocks which contain orthoclase. Although the percentage of oligoclase in the dark layers is variable, it is unrelated to the amount of feldspar in the light-colored bands. The composition of the oligoclase is approximately the same in the light and dark layers. Sillimanite occurs in fibrous clots and as fine needles in biotite and quartz. Sillimanite porphyroblasts, 2–4 cm. long, are present in some of the gneisses near the contact with the Kinsman quartz monzonite.

In the west-central portion of the quadrangle, the light-colored bands in the gneiss are rich in orthoclase and poor in plagioclase. Some of the orthoclase forms large euhedral porphyroblasts 2–5 cm. long, but most of the orthoclase occurs in coarse-grained lenses with small amounts of quartz. Modes of the gneisses containing orthoclase are given in Table 4, columns 1 and 2. The mode of the orthoclase gneiss given in column 2 was determined from a crushed sample of a large block of gneiss.

In the northern part of the quadrangle, the light-colored portions of gneiss are composed mainly of quartz, muscovite, and oligoclase with only small amounts of orthoclase (Table 4, column 5). Some of the light-colored aggregates have the form of orthoclase crystals. It is believed that originally the light-colored portions of the gneiss consisted mostly of orthoclase which was replaced by muscovite, quartz, and oligoclase during a later period of retrograde metamorphism. The composition of the oligoclase in the pseudomorphs after orthoclase is approximately the same as that of the oligoclase in the enclosing rock. Modes of the gneiss occurring in the northern portion of the May Pond member are given in Table 4, columns 3 and 6.

TABLE 4.—ESTIMATED MODES OF THE MAY POND MEMBER

	1	2	3	4	5	6
Number of thin sections	2	*	3	3	*	2
Quartz	55	35	38	35	40	52
Potash feldspar	3	11				
Oligoclase	5	16	9	4	53	29
Biotite	24	27	35	40	2	12
Muscovite			4	3	5	1
Sillimanite	8	7	10	13		3
Garnet	5	4	4	5		3
Magnetite	tr	tr	tr	tr		tr
Pyrite			tr	tr		
Apatite	tr	tr	tr	tr		tr
Zircon	tr	tr	tr	tr		tr
Sphene			tr	tr		tr
Per cent of anorthite in oligoclase	27	28	30	30	30	28
Grain size in mm	0.2–30	0.2–10	0.05–4.0	0.05–2.0	0.05–4.0	0.03–2.0

* Mode based on thin sections and powdered samples.

1. Porphyroblastic orthoclase gneiss.
2. Banded orthoclase gneiss.
3. Biotite gneiss.
4. Dark portion of biotite gneiss.
5. Light-colored portion of biotite gneiss.
6. Quartz-oligoclase-biotite gneiss.

Metamorphosed concretions, similar to those described by Billings and others (1946, p. 264) in the Mt. Washington area are fairly common in the May Pond and Dakin Hill members. The concretions are ellipsoidal and range in size from a few inches to several feet. Megascopic study indicates that they are rich in quartz and garnet with green amphibole occurring in some specimens.

TABLE 5.—ESTIMATED MODES OF THE DAKIN HILL MEMBER

	Porphyroblastic orthoclase gneiss		Biotite gneiss							Pyritiferous gneiss				
	1	1a	2	3	4	4a	5	6	7	8	9	10	10a	11
Number of thin sections	2		5	3	1		1	1	1	3	2	2		1
Porphyroblasts														
Orthoclase	8	8.2												3
Garnet														2
Groundmass														
Quartz	36	40.5	58	46	37	35.2	39	44	40	58	48	40	39.0	46
Oligoclase	3	5.2	11		6	14.1	10	34	15	14	3	2	0.0	19
Oligoclase-andesine				4										
Biotite	28	25.1	22	35	37	29.3	24	17		15	32	6	6.1*	20
Muscovite	tr		3	2	3	3.0*	15	4	20	6	6	35	35.2	
Chlorite			tr	tr	1	1.0*			12	2		9	10.2	
Cordierite	2	2.0*									tr			
Sillimanite	15	11.5	3	7	7	7.3	tr		2	3	6	tr	1.2	7
Garnet	7	7.0*	3	6	7	9.3	11		10	tr	2			
Magnetite						0.1							0	
Magnetite, Ilmenite	1		tr	tr	2		1	1	1	tr	tr	1		tr
Ilmenite		0.5				0.5							0.7	
Pyrite		tr			tr	0.3				1	3	4	2.4	1
Tourmaline			tr											
Apatite	tr	0.3	tr	tr			tr	tr	tr	tr	tr	tr	0.3	tr
Zircon	tr		tr	tr	tr		tr	tr	tr	tr	tr	tr		tr
Sphene			tr	tr						tr		tr	0.2*	
Graphite			tr							1	tr	2	1.6	1
Zoisite	tr													
Myrmekite										tr				1
Melanterite (?)										tr		1	3.2	
Per cent of anorthite in plagioclase	28	28	26	29	30	30	28	29	30	28		28	16	27
Size of porphyroblasts in mm	20–50													10–30
Size of groundmass in mm	0.2–2.0		0 1–2.5	0.05–2.0	0.1–2.0		0.1–2.0	0.1–1.0	0.05–1.0	0.1–3.5	0.1–2.0	0.2–1.5		0.05–1.0

* Assumed to be equal to amount observed in thin section.

Porphyroblastic orthoclase gneiss.

1. Porphyroblastic orthoclase gneiss.

1a. Porphyroblastic orthoclase gneiss, calculated from chemical analysis, specimen LM 6.

Biotite gneiss.

2. Biotite-quartz gneiss.
3. Biotite-sillimanite gneiss.
4. Biotite-sillimanite gneiss, specimen LM 125.

4a. Biotite-sillimanite gneiss, calculated from chemical analysis, specimen LM 125.

5. Biotite-muscovite gneiss.
6. Quartz-feldspar-biotite gneiss.
7. Chloritized biotite gneiss.

Pyritiferous gneiss.

8. Pyritiferous mica-quartz gneiss.
9. Pyritiferous biotite gneiss.
10. Pyritiferous muscovite gneiss.

10a. Pyritiferous muscovite gneiss, calculated from chemical analysis, specimen LM 358.

11. Pyritiferous orthoclase gneiss.

Dakin Hill Member

General Statement.—The Dakin Hill member is the uppermost portion of the Littleton formation exposed in the area. Originally the member consisted of a thick massive series of shales, some of which were black pyritiferous shales. During metamorphism the sediments were transformed into porphyroblastic orthoclase gneiss, biotite gneiss, and pyritiferous gneiss. Evidence of bedding is rare and foliation is poorly developed.

Porphyroblastic orthoclase gneiss.—Gneisses with large porphyroblasts of orthoclase are common in the west-central portion of the Dakin Hill member (Pl. 2, fig. 3). An outcrop of typical porphyroblastic orthoclase gneiss is well-exposed in the road cut 500 feet south of the junction of Highways 10 and 123 in Marlow. The porphyroblasts of orthoclase are commonly 5 cm. long and contain many inclusions. Some of the crystals are euhedral, others have been drawn out into augen. The porphyroblasts grew largely by replacement without displacing the foliation. In the center of many of the porphyroblasts, there are unreplaced portions of the gneiss. The foliation of the gneiss in the core of the porphyroblasts is parallel to the foliation in the surrounding gneiss. The percentage of porphyroblasts is highly variable, ranging from 1 to 10 per cent. In the hand specimen, the orthoclase is fairly clear and has a sub-vitreous luster. Under the microscope, a fine microperthitic structure is visible. A chemical analysis of the orthoclase from the gneiss is given in Table 9.

The matrix of the porphyroblastic orthoclase gneiss is composed of quartz, oligoclase, biotite, sillimanite, garnet, and magnetite. Muscovite does not occur in the unaltered gneisses which contain orthoclase. The variation in the amount of oligoclase is independent of the percentage of orthoclase porphyroblasts. In most specimens the oligoclase is partially replaced by quartz. Myrmekite occurs in small amounts along the borders of the orthoclase porphyroblasts. Partially altered cordierite was found in one specimen. The cordierite is laced with brown isotropic alteration material and is strongly embayed by quartz. Pale-green mica, which is probably magnesium-rich biotite, is associated with the cordierite. Modes of the gneiss are given in Table 5, columns 1 and 1a[3]; a chemical analysis is given in Table 15, column 1.

Biotite gneiss.—Biotite gneiss is common throughout most of the Dakin Hill member. Irregular lenses and clots of light-colored minerals constitute 2–20 per cent of the rock. The lenses are generally 2–5 cm. long and 1 cm. thick. Most of the light-colored aggregates are composed of muscovite and quartz with only a small amount of oligoclase-andesine. The rectangular outline of some of these aggregates suggests that they are pseudomorphs after orthoclase.

The dark portion of the gneiss is gray, medium-grained, and generally massive. The texture is granoblastic and the grain size ranges from 0.5 to 2.0 mm. In some places the gneiss has a mottled appearance due to a mixture of fine-grained and medium-grained patches about 1–2 inches in diameter; the fine-grained portions are rich in quartz and poor in garnet and biotite, whereas the medium-grained portions are rich in these dark minerals.

The biotite gneiss is composed mainly of quartz, biotite, oligoclase-andesine, sillimanite, garnet, and muscovite. Magnetite and aptite are common accessories. Modes of the gneiss are given in Table 5, columns 2 to 7. In the analyzed specimen of biotite gneiss (LM125) given in Table 15, the light and dark minerals are fairly evenly distributed throughout the rock.

Quartz generally occurs in 2–3 mm. aggregates composed of 0.5 mm. grains. Although the quartz has conspicuous strain shadows and moderately sutured borders, it is not highly granulated. Quartz forms embayments in other minerals and fills the fractures in shattered biotite grains. The quartz which penetrates plagioclase commonly has a polygonal outline. Coarse sillimanite needles generally occur in the micaceous layers and fine needles of sillimanite are conspicuous in quartz. In some of

[3] The calculation of the mode from the rock analyses is not entirely automatic in these rocks because some of the oxides occur in a large number of minerals. For this reason the quantities of a few of the minerals were determined by Rosiwal analyses (shown by an asterisk in Table 5). The mineral analyses of biotite, garnet, cordierite, and orthoclase (Table 9) were used in the calculations except for the ratio $MgO:FeO$ in biotite. The ratio $K_2O:Na_2O$ in muscovite was determined from the rock analysis of specimen LM358.

the quartz grains, the needles of sillimanite have a preferred orientation parallel to the long dimension of adjacent biotite flakes. Muscovite occurs in large clear flakes as well as in small grains in feldspar. In most cases the muscovite is less deformed than the biotite. Although garnets are common, they form only small crystals 1–2 mm. in diameter.

Some of the biotite gneisses in the northern portion of the Dakin Hill member contain 20–35 per cent oligoclase-andesine and have a coarse igneous-looking texture somewhat similar to that of the nonporphyritic phases of the Kinsman quartz monzonite. Although some of these gneisses occur near bodies of the Kinsman, they are also found half a mile from the Kinsman.

Pyritiferous gneiss.—Pyritiferous gneiss is common in all parts of the Dakin Hill member. The rusty-brown to jet-black weathered surface of the gneiss is distinctive in the field. In even the freshest road cuts, the gneiss is highly stained. The pyritiferous gneiss grades into biotite gneiss with which it is closely associated.

Most of the pyritiferous gneisses are massive, but in limited areas a vague foliation is developed. Lenses of light-colored minerals are not as common in the nonpyritiferous gneisses. Although the main constituents are the same as in the other gneisses in the Dakin Hill member, the pyritiferous gneiss is richer in graphite and pyrite and poorer in garnet and magnetite. Some of the gneiss contains as much as 2 per cent graphite and 5 per cent pyrite. The yellow alteration material that is present in most specimens is probably melanterite, from the decomposition of pyrite. Porphyroblasts of orthoclase are not common in the pyritiferous gneisses except in a few places in the western portion of the Dakin Hill member. Garnets normally occur only in the pyritiferous gneisses which contain orthoclase. In these rocks the garnets form large porphyroblasts up to 1 cm. in diameter, whereas garnets in the other metamorphic rocks are generally only 1–2 mm. in diameter. Modes of the pyritiferous gneiss are given in Table 5, columns 8 to 11, and a chemical analysis is given in Table 15.

Thickness

The Hubbard Hill member is about 6,000 feet thick. The beds of lime-silicate granulite and associated schists have a total maximum thickness of about 160 feet. An exact determination of the thickness of the May Pond member is not possible because data indicating the proportion of overturned beds are meager. The probable total thickness of the May Pond member is 5000 feet, but this member is absent near the northern and southern boundaries of the quadrangle. Even less information is available on the thickness of the Dakin Hill member. The great breadth of outcrop may mean that the thickness is of the order of 10,000 feet. The total maximum thickness of the Littleton formation including the 5,000 feet exposed below the Hubbard Hill member in the Bellows Falls quadrangle may be approximately 25,000 feet.

Age

No fossils have been found in the Lovewell Mountain quadrangle. However, it is possible to trace the Littleton formation through the Bellows Falls quadrangle to the Littleton-Moosilauke area. Billings and Cleaves (1934) have shown by paleontological evidence that the Littleton formation is lower Devonian in the Littleton-Moosilauke area.

Plutonic Rocks

General Statement

The plutonic rocks in the Lovewell Mountain quadrangle belong to the late Devonian (?) New Hampshire magma series and are represented by the Bethlehem gneiss, the Kinsman quartz monzonite, and the Concord granite. The Bethlehem gneiss and Kinsman quartz monzonite were metamorphosed during the closing stages of the orogeny in late Devonian time. Dikes of light-colored granitic rocks are common, but no mafic dikes have been observed. Large bodies of pegmatite are abundant in the western part of the quadrangle. Small pegmatite veins are found throughout the area but are more numerous in the plutonic rocks. The problem of the age of the New Hampshire magma series is considered after the description of the individual members.

Bethlehem Gneiss

Three bodies of Bethlehem gneiss are exposed in the Lovewell Mountain quadrangle. The

the quartz grains, the needles of sillimanite have a preferred orientation parallel to the long dimension of adjacent biotite flakes. Muscovite occurs in large clear flakes as well as in small grains in feldspar. In most cases the muscovite is less deformed than the biotite. Although garnets are common, they form only small crystals 1–2 mm. in diameter.

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No fossils have been found in the Lovewell Mountain quadrangle. However, it is possible to trace the Littleton formation through the Bellows Falls quadrangle to the Littleton-Moosilauke area. Billings and Cleaves (1934) have shown by paleontological evidence that the Littleton formation is lower Devonian in the Littleton-Moosilauke area.

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Bethlehem Gneiss

Three bodies of Bethlehem gneiss are exposed in the Lovewell Mountain quadrangle. The

TABLE 6.—ESTIMATED MODES OF THE BETHLEHEM GNEISS AND ASSOCIATED SCHISTS

	Type									
	1	2	3	4	5	6	7	8	9	10
Number of thin sections	1	7	2	1	1	1	1	1	1	1
Quartz	28	30	31	59	40	2	25	26	29	30
Microcline	23	6	10	5	3			31		
Albite						83				
Oligoclase							57	30		
Oligoclase-andesine		49	45							
Andesine	36			6	44				55	46
Biotite	11	12	12	13	10		15	11	15	15
Muscovite	1	2	2	17	2	5	2	tr	1	8
Chlorite		1		tr		10	tr	tr		
Garnet		tr			1					tr
Sillimanite		tr						tr		
Myrmekite	1	tr	tr					2		1
Pyrite		tr	tr	tr		tr		tr		
Magnetite	tr	tr	tr	tr		tr	tr	tr	tr	tr
Apatite	tr	tr	tr	tr		tr	tr	tr	tr	
Zircon	tr	tr	tr	tr		tr	tr	tr	tr	tr
Sphene	tr	tr	tr				1			
Per cent of anorthite in plagioclase	32	30	32	32	30	8	28	27	30	30
Size of phenocrysts in mm	2.0–5.0	2.0–6.0	3.0–15							
Size of groundmass in mm	0.2–2.0	0.1–3.0	0.2–6.0	0.5–3.0	0.2–1.0	0.2–1.0	0.1–2.0	0.05–6.0	0.2–3.0	0.2–3.0

Mt. Clough Pluton.

1. Quartz monzonite.
2. Granodiorite.
3. Coarse granodiorite.
4. Schist inclusion, 0.25 mi. SW of Dodge Hollow, Lempster.
5. Schist inclusion, 0.5 mi. NE of Beaver Pond, Lempster.
6. Albitized gneiss.
7. Fine-grained gneiss from layer 2 inches thick, 1500 feet west of the upper (eastern) contact.
8. Transitional rock near the upper (eastern) contact.
9. Quartz diorite, 7′ above the base (western contact) of the pluton.

Small body at Gilsum-Sullivan town line.

10. Quartz diorite.

there are relatively fine-grained layers which range from a few inches to several feet thick. They extend across outcrops which are exposed for several tens of feet. Microscopic study of one of the fine-grained layers which occurs 1500 feet from the contact indicates that it is mineralogically similar to the normal gneiss except for a lack of potash feldspar (Table 6, column 7). Although the origin of many of these layers is not known, some of the layers near the contact represent feldspathized schist. The schists overlying the pluton have undergone considerable alteration. Some beds have been feldspathized and resemble the Bethlehem gneiss in texture and mineralogical composition; other beds have not been greatly altered. It is not possible to decide whether some of the transitional rocks near the contact represent a contaminated phase of the Bethlehem gneiss or a granitized portion of the schist. A mode of one of the transitional rock types is given in Table 6, column 8.

The lower (western) contact of the Mt. Clough pluton is sharp and the Bethlehem gneiss near the contact appears to be homogeneous. However, microscopic study reveals significant differences in the amount of microcline in the Bethlehem. A specimen obtained 1 foot from the lower contact on Gates Mountain contained 7 per cent microcline, whereas a specimen 7 feet from the contact contained no microcline (Table 6, column 9).

The specific gravity of most specimens from the Mt. Clough pluton ranges from 2.69 to 2.72. No systematic variation in the specific gravity was observed from the base of the pluton to the upper contact.

Kinsman Quartz Monzonite

General statement.—Two bodies of Kinsman quartz monzonite occur in the Lovewell Mountain quadrangle. The body which occupies the eastern third of the quadrangle is part of a much larger pluton and is referred to in this paper as the Bacon Ledge pluton. The name Huntley Mountain pluton is applied to the smaller tabular body of Kinsman quartz monzonite in the northwestern part of the area.

Bacon Ledge pluton.—In the Bacon Ledge pluton, the Kinsman quartz monzonite is light-gray, coarse-grained, and conspicuously porphyritic. The rocks range from quartz monzonite to quartz diorite with granodiorite predominating. Modes are given in Table 7, columns 1 to 5. In calculating the modes for the porphyritic types, the percentages of phenocrysts were determined at the outcrop by linear measurements. These data were combined with the mineral percentages of the groundmass as determined in thin section to give the bulk modal composition of the rock.

The phenocrysts, composed of potash feldspar, are 3–7 cm. long, 1–3 cm. wide, and 0.5–1.5 cm. thick. They are fairly evenly distributed throughout the body and on the average comprise 10 per cent of the rock, but locally may range from 5 to 25 per cent. The phenocrysts are euhedral and are commonly oriented parallel to one another. Except in a few places where the rock has suffered late deformation, the large feldspar crystals show no signs of strain. Under the microscope the phenocrysts are seen to be microcline-microperthite. The chemical analysis given in Table 9 indicates that the feldspar is fairly low in soda with only 14 per cent of the albite molecule. Within some of the phenocrysts there are small grains of quartz, plagioclase, and biotite. These inclusions are irregularly distributed throughout the phenocrysts and generally occur in amounts less than 1 per cent.

Large garnets, 1–3 cm. in diameter, constitute 1 to 5 per cent of the rock. Although garnets are found throughout most of the pluton, their distribution at many outcrops is highly variable mainly because of the alteration of the garnet to biotite. There is a complete gradation in the alteration from fresh garnet to aggregates of biotite pseudomorphous after garnet. The chemical analysis of the garnet given in Table 9 indicates that it is largely almandite with 16 per cent of the pyrope molecule.

The groundmass of the Kinsman quartz monzonite is hypidiomorphic granular and somewhat granoblastic. Biotite-rich portions of the quartz monzonite are schistose and commonly have cataclastic textures and augen structures. The grain-size ranges from 0.05 to 8 mm. The groundmass is composed largely of quartz, oligoclase-andesine, biotite, and muscovite with minor amounts of magnetite, sillimanite, cordierite, graphite, calcite, apatite, zircon, and sphene. In only a very few rocks has potash feldspar been found in the groundmass. Normally it occurs in crystals many times larger than the other constituent minerals.

The plagioclase ranges from calcic oligoclase (An_{23}) to andesine (An_{38}) in different specimens. The plagioclase grains are 3–8 mm. in diameter and are generally larger than the other minerals in the groundmass. The plagioclase is slightly to moderately altered to sericite and kaolin with the cores more highly altered than the margins. Some blebs of potash feldspar

TABLE 7.—ESTIMATED MODES OF THE KINSMAN QUARTZ MONZONITE AND SCHIST INCLUSIONS, BACON LEDGE PLUTON

	1	2	3	3a	4	5	6	7	8	9
Number of thin sections	2	14	1		2	5	1	1	1	1
Phenocrysts and Porphyroblasts										
Microcline	13	11	14	14.0	11	11			5	
Garnet	2	2	3	3.4*		2				
Groundmass										
Quartz	30	29	28	32.0	31	29	80	26	49	35
Microcline	7	tr						25		36
Albite										25
Oligoclase									20	
Oligoclase-andesine		47				44				
Andesine	37		36	31.8	51		4	12		
Biotite	9	10	16	14.0	7	7	8	25	18	
Muscovite	2	1	3	3.0*	tr	tr	1		8	4
Chlorite		tr			tr					
Garnet					tr		3			
Cordierite						7				
Sillimanite	tr	tr	tr	0.7		tr	4	12		
Myrmekite	tr	tr	tr		tr	tr				
Graphite		tr								
Pyrite		tr	tr	0.1	tr	tr			tr	
Magnetite	tr	tr	tr	0.1	tr	tr	tr	tr	tr	tr
Ilmenite				0.3						
Apatite	tr	tr	tr	0.3	tr	tr			tr	
Zircon	tr	tr	tr		tr	tr	tr	tr	tr	tr
Sphene		tr	tr	0.3*						
Calcite		tr	tr	0.3	tr					
Tourmaline								tr		
Per cent of anorthite in plagioclase	36	35	34	34	32	35		33	28	10
Size of phenocrysts and porphyroblasts in mm	10–50	10–70	10–50		15–40	10–60			8–30	
Size of groundmass in mm	0.2–8.0	0.05–8.0	0.2–5.0		0.5–10.0	0.5–9.0	0.1–1.0	0.1–5.0	0.05–0.8	0.05–6.0

* Assumed to be equal to amount observed in thin section.

1. Porphyritic quartz monzonite.
2. Porphyritic granodiorite.
3. Porphyritic granodiorite, specimen LM1.

3a. Porphyritic granodiorite, calculated from chemical analysis, specimen LM1.

4. Porphyritic granodiorite (nongarnetiferous).
5. Cordierite bearing granodiorite.
6. Quartz-mica schist inclusion.
7. Feldspathized schist inclusion.
8. Porphyroblastic schist inclusion.
9. Altered phase of the Kinsman quartz monzonite.

are common in some of the plagioclase. A large plagioclase grain mantled by microcline was observed in one section. The rim of microcline was about 2 mm. thick and had nearly the same orientation as the core of plagioclase. No case of plagioclase mantling microcline has been found. Myrmekite is common along the borders of the microcline phenocrysts especially where the microcline is in contact with plagioclase. The plagioclase in the myrmekite is generally in optical continuity with the adjacent plagioclase in the rock. The myrmekite is undeformed and apparently grew late.

Quartz has highly sutured borders and shows undulatory extinction, but it is not greatly deformed except in the rocks which have been subjected to granulation. It has a strong tendency to embay other minerals, especially plagioclase and biotite. Most of the quartz contains many tiny needles of sillimanite. The fact that these needles are limited to quartz in most sections aids greatly in distinguishing quartz from plagioclase.

The biotite flakes are generally randomly oriented and in most specimens occur in 5 mm. aggregates. Normally the biotite is undeformed, but in the rocks which have undergone deformation, it is bent and shredded. In thin section the biotite is typically brown, but some of the biotite which has altered from garnet is green. A chemical analysis of the brown biotite is given in Table 9. In some places, biotite has altered to chlorite and muscovite. Muscovite is not as abundant as biotite and normally constitutes less than 3 per cent of the rock except in the highly altered specimens.

Cordierite is fairly common near the western contact of the pluton between South Stoddard and Camp Merriewoode. The cordierite generally comprises 3–7 per cent of the rock with local concentrations of 15 per cent not uncommon. Most of the crystals are anhedral, but some have a pseudohexagonal outline. They range in size from 8 to 20 mm. The fresh cordierite has a vitreous luster and is grayish-blue. It is normally darker than quartz, but where quartz is dark because of strain the two minerals cannot be distinguished megascopically with certainty. Most of the cordierite is highly altered to sericite.

Although sillimanite is widespread as tiny needles within quartz, it generally constitutes less than 1 per cent of the rock. Larger concentrations of sillimanite are found in the reworked inclusions. In these rocks, it normally occurs as small needles in mica, but large porphyroblasts of sillimanite are present in some of the inclusions.

Inclusions of metasedimentary rocks in the Kinsman quartz monzonite range in size from a few inches to several thousand feet. The inclusions are generally more abundant near the contacts, but the largest inclusion, which is south of Goodhue Hill in Hancock, is several miles from the contact. Inclusions in all stages of digestion may be observed. The inclusions which have been subjected to considerable reworking are mineralogically and texturally similar to the quartz monzonite but have a greater content of biotite. Modes of representative schist inclusions are given in Table 7, columns 6, 7, and 8.

Porphyroblasts of microcline and oligoclase-andesine are commonly well-developed in the inclusions. The feldspar crystals in many of the inclusions are the same size as in the quartz monzonite. Even where the porphyroblasts are small, the relative size of the microcline and the plagioclase is the same as in the enclosing rock. Included grains within the porphyroblasts of microcline are no more abundant than in the microcline of the quartz monozonite. The included biotite flakes within the porphyroblasts are randomly oriented and coarser than in the matrix of the inclusions. Evidently the biotite is not simply a relic within the porphyroblasts but has recrystallized and grown into larger flakes. There is apparently no increase in the amount of garnet in the inclusions and the size of the individual crystals is small compared to the garnets in the Kinsman quartz monzonite. Cordierite has not been found in any of the inclusions.

The matrix of some of the inclusions has an average grain size of 0.07 mm. and is thus finer-grained than any of the schist in the area. The origin of these inclusions is not clear. Their fine-grained texture is probably not due to late granulation because the feldspar porphyroblasts are largely undeformed. It is also unlikely that the grain size would have become smaller during recrystallization within the magma.

Possibly these inclusions are fragments of fine-grained schists which were brought in from outside areas.

A portion of the Kinsman quartz monzonite in the vicinity of Goodhue Hill in Antrim has been hydrothermally altered and injected by light-colored aplitic material. The highly altered rock is light-gray to white and is composed of albite, microcline-microperthite, and muscovite (Table 7, column 9). The microperthite occurs in large grains and appears to have replaced much of the albite. The plagioclase in the microperthite is albite and comprises about 25 per cent of the microperthite. It forms coarse blebs up to 1 mm. long. The muscovite occurs in aggregates composed of many tiny flakes.

Huntley Mountain pluton.—The Kinsman quartz monzonite in the southern portion of the Huntley Mountain pluton is essentially nonporphyritic and contains little potash feldspar and garnet. Quartz diorite is the predominant rock-type. Except for a slightly finer grain size, this phase is similar to the groundmass of the rocks in the Bacon Ledge pluton (Table 8, columns 1 and 2). Inclusions range in length from a few feet to several tens of feet and generally are unaltered. Small concordant bodies of Kinsman are common in the adjacent country rock.

From Tinker Pond to Huntley Mountain in Marlow, the Kinsman quartz monzonite contains relatively small phenocrysts of microcline. Generally the phenocrysts are less than 2 cm. long and comprise from 3 to 8 per cent of the rock. Garnets are uncommon and occur in small crystals. Granodiorite is the predominant rock-type but there are some phases of quartz monzonite (Table 8, columns 3 and 4). From Huntley Mountain to the northern boundary of the quadrangle, the quartz monzonite is conspicuously porphyritic and is similar in most respects to the types in the Bacon Ledge pluton (Table 8, column 5). However, no cordierite has been observed in the Huntley Mountain pluton.

In the eastern third of the Huntley Mountain pluton from Symonds Pond in Marlow to May Pond in Washington, the phenocrysts of microcline have largely altered to quartz, muscovite, and oligoclase-andesine. In some outcrops all stages in the alteration may be observed, but generally most of the microcline has been completely replaced. A mode of one of the pseudomorphs after microcline is given in Table 8, column 7. The groundmass of this rock is essentially unaltered and is similar to the groundmass of the normal porphyritic types. The alteration of the microcline apparently involved an introduction of soda and lime, but a loss of potash.

Minor bodies.—Many small bodies of Kinsman quartz monzonite occur in the metasedimentary rocks near the larger plutons, and a few bodies have been found over a mile from the main contacts. Although some of the masses are cross-cutting, most of them are concordant and are only a few tens of feet thick. They are generally composed of quartz diorite similar to the nonporphyritic phases of the Huntley Mountain pluton, but small phenocrysts of microcline occur in some types (Table 8, columns 8 and 9). The bodies in the southern part of the area have sharp contacts, whereas those in the northern portion of the May Pond and Dakin Hill members tend to have gradational contacts. In the northern area, the nonporphyritic phases of the Kinsman quartz monzonite are not greatly different from the feldspathic types of paragneiss.

Concord Granite

The body of Concord granite in the northwestern corner of the Monadnock quadrangle (Fowler-Billings, 1949) is believed to extend a short distance into the Lovewell Mountain quadrangle. Although the only outcrops in the southwestern corner of the area consist of pegmatites, the prevalent float of Concord granite suggests that a body of this granite lies below the drift.

Miscellaneous Dike Rocks

Small dikes, 1–18 inches thick, are common throughout the area, especially in the bodies of Kinsman quartz monzonite. The rocks are light gray, fine-grained to medium-grained, and range from quartz monzonite to quartz diorite. Most phases have a granitic texture but some are porphyritic with microcline phenocrysts 0.5–2 cm. long. Essential minerals are quartz,

TABLE 8.—ESTIMATED MODES OF THE KINSMAN QUARTZ MONZONITE AND MISCELLANEOUS DIKE ROCKS

	Kinsman quartz monzonite									Miscellaneous dike rocks	
	Huntley Mountain pluton							Minor bodies			
	Type										
	1	2	3	4	5	6	7	8	9	10	11
Number of thin sections	2	1	4	1	1	3	1	1	2	1	2
Phenocrysts and porphyroblasts											
Microcline			4	11	7						
Garnet					2						
Groundmass											
Quartz	38	29	33	25	21	35	40	23	28	36	36
Microcline	tr	8	5	8			3	5		32	
Oligoclase										24	53
Oligoclase-andesine			48								
Andesine	43	50		37	59	50	23	56	53		
Biotite	13	9	8	15	8	13		15	17	4	7
Muscovite	3	2	2	4	1	2	30		1	2	4
Chlorite			tr		tr						tr
Garnet	1	1	tr		2	tr			1	tr	tr
Sillimanite	2		tr		tr		3	tr	tr		
Myrmekite	tr	1	tr				1	1		2	tr
Pyrite	tr	tr			tr			tr			
Magnetite	tr	tr	tr	tr	tr	tr		tr	tr	tr	tr
Apatite	tr	tr	tr	tr	tr	tr		tr	tr	tr	tr
Zircon	tr	tr	tr	tr	tr	tr		tr	tr	tr	tr
Sphene			tr			tr					
Per cent of anorthite in plagioclase	37	34	31	37	33	35	32	34	33	23	24
Size of phenocrysts and porphyroblasts in mm			8.0–10	8.0–30	8.0–60						
Size of groundmass in mm	0.05–6.0	0.1–6.0	0.1–8.0	0.5–4.0	0.5–4.0	0.1–6.0	0.1–6.0	0.01–4.0	0.04–4.0	0.1–4.0	0.1–3.0

Kinsman quartz monzonite.
- Huntley Mountain pluton.
  1. Quartz diorite.
  2. Nonporphyritic granodiorite.
  3. Porphyritic granodiorite.
  4. Porphyritic quartz monzonite.
  5. Garnetiferous granodiorite.
  6. Groundmass of granodiorite with altered phenocrysts.
  7. Pseudomorph after microcline phenocryst.
- Minor bodies.
  8. Granodiorite.
  9. Quartz diorite.

Miscellaneous dike rocks.
  10. Quartz monzonite.
  11. Quartz diorite.

oligoclase, microcline, biotite, and muscovite Modes are given in Table 8, columns 10 and 11. These rocks are somewhat similâr to the Concord granite but are poorer in potash feldspar than most phases of this rock.

Age of the New Hampshire Magma Series

The Bethlehem gneiss and Kinsman quartz monzonite must be younger than lower Devonian because they cut schists of the Littleton formation. Blocks of binary granite similar to the Concord granite, which is the youngest member of the New Hampshire magma series, have been found in the Moat volcanics (Billings, 1928, p. 99–100). The Moat volcanics are considered to be Mississippian (Billings, 1941, p. 918); hence the New Hampshire magma series is middle or late Devonian. Furthermore, uraninite from pegmatites genetically related to the Bethlehem gneiss in the Cardigan quadrangle was found to be of Devonian age (Shaub, 1938, p. 339).

The age relations between the Bethlehem gneiss and the Kinsman quartz monzonite are not clear because these two members have not been observed in contact. However, the Bethlehem gneiss is slightly more deformed than the Kinsman quartz monzonite and is therefore probably older.

MINERALOGY

General Statement

Many detailed studies of the minerals occurring in western New Hampshire have been made in recent years. The following discussion is mainly limited to new data on the occurrence and properties of these minerals.

Potash Feldspar

Orthoclase and orthoclase-microperthite occur as large porphyroblasts in the metamorphosed argillaceous rocks in the high-intensity portion of the high-grade zone (Fig. 8). Microcline is common in the lime-silicate rocks and is a minor constituent of the impure quartzites. These rocks crop out in the vicinity of Marlow Hill in the low-intensity portion of the high-grade zone. In the plutonic rocks, the potash feldspar is microcline and microcline-microperthite.

An analysis of orthoclase-microperthite which occurs as porphyroblasts in paragneiss (Specimen LM6) is given in Table 9, column 1. Significant data could not be obtained for the soda feldspar component because the lamellae were extremely small. The following optical data refer to the aggregate effect of the two feldspar components:

$$\alpha = 1.521 \quad (-)2V = 70^\circ$$
$$\beta = 1.525 \quad Z = b$$
$$\gamma = 1.527 \quad X \wedge a = 7^\circ$$

The chemical formula for the orthoclase-microperthite is as follows:

$$(K^{0.74}Na^{0.21}Ca^{0.01}Ba^{0.01})_{0.97}Al_{1.10}Si_{2.93}O_8$$

The molecular composition in weight per cent is: $Or_{77}Ab_{21}An_1Cn_1$.

An analysis of microcline-microperthite which occurs as phenocrysts in the Kinsman quartz monzonite (Specimen LM3A) is given in Table 9, column 2. In this specimen the microperthitic structure is also very fine. The following optical data, therefore, refer to the aggregate effect of the two feldspar components:

$$\alpha = 1.520 \quad (-)2V = 80^\circ$$
$$\beta = 1.523 \quad \text{Extinction on (010)} = 6^\circ$$
$$\gamma = 1.525 \quad \text{Extinction on (001)} = 13^\circ$$

The chemical formula may be written:

$$(K^{0.80}Na^{0.14}Ca^{0.02}Ba^{0.01})_{0.97}Al_{1.06}Si_{2.96}O_8$$

The molecular composition in weight per cent is: $Or_{83}Ab_{14}An_2Cn_1$

The microcline-microperthite is fairly low in soda, but is only slightly less sodic than the average potash feldspar from the granodiorites of southern California (Larsen, 1948, p. 160). Compared to the orthoclase-microperthite from the paragneiss (LM6), the microcline-microperthite is poorer in soda. This is probably due to differences in the amount of soda available for the potash feldspar, although differences in temperature and pressure may have had some effect.

Plagioclase

The composition of the plagioclase was determined from the value of the β index of refraction. The plagioclase in all rocks, except the lime-silicate granulites and the hydrothermally

TABLE 9.—CHEMICAL ANALYSES OF MINERALS FROM THE LOVEWELL MOUNTAIN QUADRANGLE

	1	2	3	4	5	5A
SiO_2......	63.90	63.94	35.34	36.97	46.87	47.33
Al_2O_3.....	20.46	19.48	19.10	21.66	32.57	32.59
Fe_2O_3 }	0.09	0.06	0.79	0.77	0.15	0.15
FeO }....			18.45	33.68	8.09	8.49
MnO.....	0.00	0.00	0.03	0.98	0.06	0.06
MgO......	0.08	0.18	9.05	4.48	7.69	8.07
CaO......	0.16	0.36	0.10	1.13	0.09	0.09
Na_2O.....	2.38	1.64	0.27	0.10	0.51	0.53
K_2O......	12.61	13.48	9.15	0.08	0.93	0.48
H_2O^+.....	0.12	0.30	3.21	0.08	1.97	1.88
H_2O^-.....	n.d.	n.d.	0.17	n.d.	0.19	0.20
TiO_2......	0.00	0.04	3.28	0.31	0.02	0.02
P_2O_5......	n.d.	n.d.	0.03	n.d.	0.05	0.05
F.........	n.d.	n.d.	0.71	n.d.	n.d.	n.d.
V_2O_3......	n.d.	n.d.	0.10	n.d.	n.d.	n.d.
BaO......	0.36	0.39	n.d.	n.d.	n.d.	n.d.
Less O for F.......	—	—	-0.30	—	—	—
	100.16	99.87	99.48	100.24	99.19	99.94
S.G.......	2.55	2.55	3.06	4.10	2.63	—

1. Orthoclase-microperthite from porphyroblastic orthoclase gneiss (LM6), 0.1 mile south of the junction of Highways 10 and 123 in Marlow. F. A. Gonyer, analyst.
2. Microcline-microperthite, phenocrysts in Kinsman quartz monzonite (LM3A), Franklin Pierce Highway 300 feet north of B. M. 1285, Stoddard, N.H. F.A. Gonyer, analyst.
3. Biotite from Kinsman quartz monzonite (LM1), Forest Road 300 feet east of Nelson-Antrim town-line. L.C. Peck, analyst.
4. Garnet from Kinsman quartz monzonite (LM1), Forest Road 300 feet east of Nelson-Antrim town-line. L.C. Peck, analyst.
5. Cordierite from Kinsman quartz monzonite (LM3A), Franklin Pierce Highway 300 feet north of B. M. 1285, Stoddard, N.H. L.C. Peck, analyst.

5A. Same as 5, recalculated after subtracting 4 per cent sericite.

altered rocks, is surprisingly uniform, either calcic oligoclase or sodic andesine. In the schists and paragneisses, the composition of the plagioclase ranges from An_{25} to An_{32} and averages An_{29}. The plagioclase in the lime-silicate granulites and associated rocks is very calcic (An_{87} to An_{93}). The plagioclase in the Bethlehem gneiss ranges from An_{27} to An_{33} and averages An_{31}; in the Kinsman quartz monzonite the range is from An_{30} to An_{37} and the average is An_{34}.

The average plagioclase in the middle-grade schists of the Bellows Falls quadrangle is calcic oligoclase (An_{27}) (Kruger, 1946, p. 199) and is thus similar to the plagioclase in the high-grade schists and paragneisses of the Lovewell Mountain quadrangle. This suggests that plagioclase does not become appreciably more calcic with increasing metamorphism.

Amphibole

Amphibole occurs in the lime-silicate granulites and amphibolites in the Hubbard Hill member. The amphibole in the lime-silicate granulites has a β index of 1.637 and according to Winchell's curves (1933, p. 246) it is actinolite with approximately 75 per cent of the tremolite molecule. The amphibole in the amphibolites has an average β index of 1.670 and complete optical data indicate that it is probably common hornblende.

Pyroxene

Pyroxene occurs only in the lime-silicate granulites. The β index of the pyroxene in all specimens is close to 1.690. According to Winchell's curves (1933, p. 226), the pyroxene is diopside-hedenbergite with approximately 25 per cent of the hedenbergite molecule.

Muscovite

Muscovite occurs in the schists and paragneisses except in the west-central part of the area where orthoclase is present. Much of the muscovite is late and lies across the foliation. In the plutonic rocks, it is difficult to determine what proportion of the muscovite is secondary. The muscovite that is pseudomorphic after microcline in the Kinsman quartz monzonite is obviously secondary; yet this muscovite occurs in large flakes similar to those in the groundmass. It is therefore possible that much of the muscovite in the groundmass is also secondary. The β index of the muscovite is very close to 1.598 in all rocks. From the rock analysis of Specimen LM358 (Table 15, column 3), it is estimated that the muscovite contains about 2 per cent soda. The analyzed muscovite reported by Barth (1936, p. 780) also contains an appreciable amount of soda and is similar in optical properties to the muscovite from the Lovewell Mountain quadrangle.

Biotite

Biotite is common in nearly all the metamorphic and plutonic rocks. An analysis of biotite from the garnetiferous phase of the Kinsman quartz monzonite (LM1) is given in Table 9, column 3. The optical properties of this biotite are as follows:

$\alpha = 1.595$	$2V = 2° - 7°$; negative
$\beta = 1.650$	X = light yellowish brown
$\gamma = 1.650$	$Y = Z$ = dark reddish brown
	$X < Y = Z$

The chemical formula for the biotite is:

$$K_{0.9}(Fe^{1.2}Mg^{1.0}Al^{0.4}Ti^{0.2})_{2.8}(Si^{2.7}Al^{1.3})_{4.0}O_{10}(OH^{1.8}F^{0.2})_{1.8}$$

According to Winchell's classification (Winchell, 1933, p. 267), the biotite contains 45 per cent siderophyllite, 40 per cent eastonite, 8 per cent annite, and 7 per cent phlogopite. The refractive indices of the biotite are somewhat higher than those given by Winchell (1933, p. 274) for biotite of this composition.

In the Kinsman quartz monzonite and the Bethlehem gneiss the values for the β index of the biotite generally range from 1.645 to 1.653 and average 1.647. The composition of the biotite in most of the plutonic rocks is therefore probably similar to that of the analyzed biotite.

The values for the β index of biotite in all the metasedimentary rocks except those associated with the lime-silicate granulites range from 1.635 to 1.650 and average 1.640. The biotite in these rocks apparently has a higher magnesium-iron ratio than the biotite in the plutonic rocks. The β index of the biotite in the schists interbedded with lime-silicate rocks averages 1.625. The phlogopite-eastonite molecules probably comprise 60 per cent of this biotite (Winchell, 1933, p. 274).

Garnet

Garnets are common in nearly all of the metasedimentary rocks except the pyritiferous gneisses. Apparently insufficient iron was available for the formation of garnet in most of the pyritiferous gneisses because of the large proportion of iron held in pyrite. Garnet is rare in the Bethlehem gneiss and in the Kinsman quartz monzonite in the western part of the area; however garnet comprises 1–5 per cent of the Kinsman quartz monzonite in the eastern two-thirds of the area. An analysis of garnet from the Kinsman quartz monzonite is given in Table 9, column 4. The physical properties of this garnet are as follows:

Refractive index = 1.803
Specific gravity = 4.10
Size of unit cell, a = 11.50 Å.

The chemical formula of the garnet is:

$$(Fe^{2.26}Mg^{0.54}Ca^{0.10}Mn^{0.06})_{2.96}Al_{2.04}Si_{2.97}O_{12}$$

The molecular composition in weight per cent is:

	Per cent
Almandite	81
Pyrope	16
Spessartite	2
Grossularite	1

In all of the rocks except the schists interbedded with lime-silicate granulites, the values for the refractive indices of the garnets range from 1.801 to 1.808 and average 1.805. The garnets in the metasedimentary rocks were small and contained many inclusions so that it was difficult to measure their specific gravities. Carefully selected garnet from one of the biotite gneisses was found to have a specific gravity of 4.12. The length of the edge of the unit cell was 11.50 Å. Apparently the composition of the garnets in most of the metasedimentary rocks is similar to that of the analyzed garnet in the Kinsman quartz monzonite. The garnets in the biotite schists interbedded with lime-silicate rocks have an average index of 1.788 and are therefore probably richer in the pyrope and grossularite molecules.

Cordierite

Cordierite has been observed in only two specimens of the metasedimentary rocks (Table 5, columns 1 and 9). It comprises 2 per cent or less of the rock and is highly altered to green mica (probably magnesium-rich biotite) and light-brown isotropic matrial. Cordierite is fairly common in the Kinsman quartz monzonite near the western contact of the Bacon Ledge pluton between South Stoddard and Camp Merriewoode. Conant (1935) has described cordierite from this area, but no detailed optical or chemical studies have been made. Cordierite generally comprises 3–7 per cent of the Kinsman quartz monzonite in this zone and is moderately to highly altered to sericite (pinite). Some of the sericite occurs as fine shreds in the cordierite so that an entirely uncontaminated sample could not be obtained for chemical analysis. The analyzed cordierite which contained about 4 per cent sericite is given in Table 9, column 5. By subtracting 4 per cent sericite and correcting to 100 per cent the calculated composition of the pure cordierite given in column 5A was obtained.

TABLE 10.—OPTICALLY POSITIVE CORDIERITES

	1	2	3	4	5	6	7
SiO_2	48.37	50.15	50.09	48.19	47.96	47.69	47.33
Al_2O_3	29.22	33.07	31.78	33.45	31.56	32.52	32.59
Fe_2O_3	2.20	1.52	0.78	0.55	1.03	0.63	0.15
FeO	7.07	2.22	8.71	8.40	3.24	8.04	8.49
MnO	0.42	0.12	0.00	0.18	1.09	0.04	0.06
MgO	9.54	11.01	6.69	7.95	12.16	7.56	8.07
CaO	1.92	0.29	0.00	0.17	0.00	0.52	0.09
Na_2O	n.d.	0.14	0.00	0.22	0.33	0.53	0.53
K_2O	n.d.	0.08	0.07	0.02	tr	0.42	0.48
H_2O^+	1.84	1.37	1.43	0.67	2.80	1.85	1.88
H_2O^-	n.d.	0.09	n.d.	0.01	n.d.	0.55	0.20
TiO_2	n.d.	0.38	0.00	0.01	0.00	tr	0.02
P_2O_5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.05
	100.58	100.44	99.55	99.82	100.17	100.35	99.94
S.G.	2.598	2.588	2.650	2.631		2.64	2.63
α	—	1.527	1.543	1.544	1.534	1.538	1.543
β	—	1.532	1.548	1.550	—	1.542	1.549
γ	—	1.538	1.553	1.556	1.543	1.547	1.555
$2V$	85°–99°	88°	88°	85°–99°	76°	84°	80°

1. From cordierite gneiss, India (Krishman, 1924) M. S. Krishman, analyst.
2. From anthophyllite gneiss, Attu (Pehrman, 1932) G. Pehrman, analyst.
3. From veined gneiss, Illmajoki (Pehrman, 1932) G. Pehrman, analyst.
4. From gneiss, Great Slave Lake area (Folinsbee, 1941b) R. E. Folinsbee, analyst.
5. From gneiss, Antarctica (Tilley, 1940) A. P. White, analyst.
6. From argillaceous hornfels, Belhelvie (Stewart, 1942) F. H. Stewart, analyst.
7. From Kinsman quartz monzonite, Lovewell Mountain quadrangle. Corrected analysis of cordierite after subtracting 4 per cent sericite. L. C. Peck, analyst.

The optical properties of the analyzed cordierite are as follows:

$$\alpha = 1.543 \quad 2V = 80°$$
$$\beta = 1.549 \quad \text{positive}$$
$$\gamma = 1.555$$

The chemical formula for the cordierite may be written:

$$(Mg^{1.27}Fe^{0.74})_{2.01}Al_{4.03}Si_{4.97}O_{18}$$

This cordierite is unusual because it is optically positive. Thirteen occurrences of optically positive cordierite have been reported but only six complete analyses of optically positive cordierite are available (Table 10). The range in composition of these cordierites is about the same as for optically negative cordierites. The

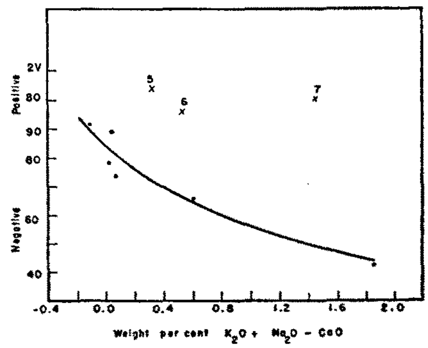

FIGURE 4.—RELATION BETWEEN AXIAL ANGLE AND $K_2O + Na_2O - CaO$ FOR CORDIERITE

Curve given by Folinsbee (1941b) based on points shown by dots. Crosses represent the cordierites which have been analyzed since Folinsbee's study. Numbers are the same as in Table 10.

most recent attempt to correlate the size of the axial angle of cordierite with chemical composition was made by Folinsbee (1941b). He obtained the curve given in Figure 4 by plotting axial angle against $K_2O + Na_2O - CaO$. The three crosses representing the cordierites which have been analyzed since Folinsbee's study fall far from his curve. The writer agrees with Stewart (1942) that sufficient data are not available to determine the relation between axial angle and chemical composition of cordierite. As in the case of the potash feldspars, it is barely possible that the thermal history of cordierite may have had some influence on the size of the axial angle.

Distribution of Constituents in Garnet, Biotite, and Cordierite

The analyzed garnet, biotite, and cordierite (shown by crosses in Figure 5) from the Kinsman quartz monzonite have been plotted against molecular per cent FeO, MgO, and Al_2O_3. Although the analyzed biotite and garnet were not obtained from a cordierite-bearing specimen, the optical properties of the biotite and garnet indicate that the composition of these minerals is the same as that of the garnet and biotite in the cordierite-bearing rocks. For comparison, the garnet, biotite, and cordierite from a hornfels from Belhelvie (Stewart, 1942) and garnet and cordierite from a gneiss from the

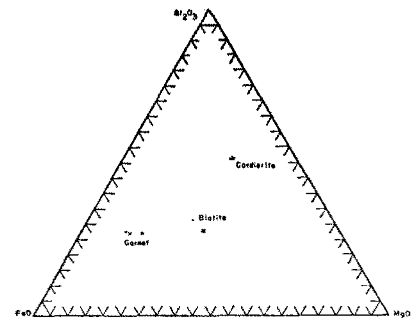

FIGURE 5.—DISTRIBUTION OF FeO, MgO, AND Al_2O_3 IN GARNET, BIOTITE AND CORDIERITE

Crosses = minerals from the Kinsman quartz monzonite, Lovewell Mountain quadrangle; dots = minerals from hornfels, Belhelvie (Stewart, 1942); open circles = minerals from gneiss, Great Slave Lake (Folinsbee, 1941a).

TABLE 11.—DISTRIBUTION OF MnO AND TiO_2 IN GARNET, BIOTITE, AND CORDIERITE

	Garnet	Biotite	Cordierite
MnO	1. 0.98	0.03	0.06
	2. 1.81	0.02	0.04
	3. 0.66	—	0.18
TiO_2	1. 0.31	3.28	0.02
	2. 0.51	5.12	tr
	3. 0.03	—	0.01

1. Kinsman quartz monzonite, Lovewell Mountain quadrangle.
2. Hornfels, Belhelvie (Stewart, 1942).
3. Gneiss, Great Slave Lake area (Folinsbee, 1941a).

Great Slave Lake area (Folinsbee, 1941a) are plotted in Figure 5. The selective distribution of FeO, MgO, and Al_2O_3 in the minerals in these rocks is about the same. The garnets are very rich in iron oxide, the cordierites are rich in magnesia, and the biotites contain nearly equal amounts of iron oxide and magnesia. It is also to be noted that although the biotites and garnets carry about the same amount of alumina, the cordierites are much richer in alumina. The distribution of MnO and TiO_2 is given in Table 11. The MnO is largely concentrated in the garnets and most of the TiO_2 occurs in the biotites.

Heavy Minerals

A study of the heavy minerals from the metasedimentary and plutonic rocks was undertaken in the hope that systematic differences between the mineral assemblages in the two types of rock might be found and perhaps furnish data on the origin of these rocks. Heavy minerals were separated by heavy liquids and magnets from 14 specimens. The distribution of the minerals in weight per cent of the bulk sample is given in Table 12. Although the same heavy minerals are found in all rocks, zircon, monazite, and sphene are slightly more abundant in the plutonic rocks. The percentage of apatite reported in the plutonic rocks and schists is probably lower than it should be because some of the tiny grains in the biotite may easily have been overlooked. In the paragneisses, on the other hand, the apatite occurs in relatively large crystals and could be readily separated.

TABLE 12.—HEAVY MINERALS FROM METASEDIMENTARY AND PLUTONIC ROCKS IN WEIGHT PER CENT OF BULK SAMPLE

	Metasedimentary Rocks				Plutonic Rocks			
	1	2	3	4	5	6	7	8
Biotite	12.	27.	31.	14.	17.	16.	19.	8.
Garnet	0.3	0.8	6.	2.	0.05	2.	0.3	0.4
Sillimanite	0.0	1.	1.	4.	tr	0.03	0.0	0.03
Kyanite	0.0	tr	0.4	0.01	0.0	tr	0.0	0.0
Tourmaline	0.02	0.5	0.0	0.0	tr	0.0	0.0	0.0
Chlorite	0.0	0.0	0.0	2.	0.0	0.1	0.0	0.0
Apatite	0.03	0.05	0.8	0.1	0.2	0.1	0.03	0.03
Zircon	0.002	0.008	0.004	0.008	0.003	0.05	0.01	0.02
Monazite	0.002	0.002	0.0	0.004	0.005	0.02	0.002	0.009
Sphene	0.0	0.005	tr	0.02	0.04	0.1	0.0	0.04
Magnetite	0.06	0.07	1.	0.5	0.1	1.	0.03	0.1
Pyrite	0.0	0.0	0.0	2.	0.05	0.1	0.0	0.0
Unidentified opaques	0.3	0.3	0.5	0.2	0.2	0.3	0.2	0.3
Maximum length of zircon in mm	0.1	0.2	0.06	0.07	0.2	0.3	0.2	0.3
Maximum ratio of length to thickness of zircon	2:1	6:1	2:1	2:1	10:1	6:1	7:1	6:1

Littleton formation, middle-grade zone, Keene area.
1. Mica schist (average of 2 specimens).

Littleton formation, high-grade zone, Lovewell Mountain quadrangle.
2. Mica-quartz schist, Hubbard Hill member (average of 2 specimens).
3. Biotite gneiss, Dakin Hill member.
4. Pyritiferous gneiss, Dakin Hill member (average of 2 specimens).

Plutonic Rocks.
5. Bethlehem gneiss.
6. Kinsman quartz monzonite, Bacon Ledge pluton (average of 3 specimens).
7. Kinsman quartz monzonite, small pod in schist.
8. Granodiorite from late dikes (average of 2 specimens).

Sufficient phosphorus was available in most of the rocks for the formation of both monazite and apatite. The monazite is pale yellowish green and has a β index of 1.795. The ω index of the apatite is 1.632, indicating that it is probably fluorapatite. Tiny zircon inclusions are common in the apatite.

The zircon is colorless and its refractive indices are the same in all rocks (ω = 1.915 – 1.918). The zircons in the metasedimentary rocks are stubby, but have apparently recrystallized even in the middle-grade schists because they are euhedral and show no signs of rounding. The zircons in the plutonic rocks are larger and much more elongate. In the Kinsman quartz monzonite, the cores of some of the zircons have a "dusty" appearance, whereas the outer portions are clear. This may be due to zonal crystallization or to growth around detrital grains. One possibility is that these grains were derived from schist inclusions. However, if the Kinsman has formed by partial solution of preexisting sediments, the zircons, in part, may be relics of these rocks.

From this study no significant differences between the heavy mineral assemblages in the various types of rocks were found except for the slightly larger amount of zircon, sphene, and monazite in the plutonic rocks.

Structural Features

General Statement

In the Lovewell Mountain quadrangle, folded metamorphosed sediments have been intruded by three members of the New Hampshire magma series. Northeasterly and northerly strikes are characteristic and dips are generally steep southeasterly or easterly except in the northwestern part of the area where dips are gentle easterly (Pl. 4). For purposes of description, the structure of the metasedimentary and plutonic rocks will be considered separately.

Metasedimentary Rocks

General Statement.—The metasedimentary rocks occur in fairly regular belts trending north-northeast in the northern part of the area and approximately north-south in the southern portion. The strata are on the east limb of a large anticline the axis of which is in the Bellows Falls quadrangle to the west; the axis of the syncline may be in the eastern part of the Lovewell Mountain quadrangle or in the area to the east. Inasmuch as the structural features of the various members of the Littleton formation are somewhat different, the individual members will be considered separately.

Hubbard Hill member.—The Hubbard Hill member forms the most westerly belt of metasedimentary rocks in the area. The Bethlehem gneiss has been emplaced within the northern portion of this member. The schists below the Bethlehem strike nearly north-south and dip very gently to the east. The schists above the Bethlehem strike consistently N 30° E and dip 55° to 80° SE. In the west-central part of the area, the Kinsman quartz monzonite cuts across the Hubbard Hill member, and the schists assume an east-west strike. The schists in the southwestern part of the quadrangle strike north-northwest and dip 55° to 75° NE.

Major folding in the Hubbard Hill member has apparently been unimportant. The lime-silicate granulites and interbedded quartz conglomerates have a simple outcrop pattern (Pl. 1), and the fact that they are exposed in only one belt indicates that there is no significant repetition of beds due to folding or faulting. Reliable data on drag folds could not be obtained in all portions of the Hubbard Hill member because of poor exposure or the vagueness of bedding. In the vicinity of Marlow Hill, however, it was possible to measure the drag folds at 17 outcrops. These data indicate that about 5 per cent of the beds face west and are consequently overturned.

Minor folds with wave lengths ranging from a few inches to several feet are common (Pl. 3, fig. 1 and 2). The axial planes of the folds are generally parallel to the schistosity and the axes are parallel to the other linear features in the schists. Contorted quartz veins are conspicuous in some places. The veins were emplaced in the later stages of deformation because they cut across the larger folds in the schists. The fact that the folds displayed by these quartz veins have the same attitude as the earlier folds in the schists indicates that the direction in which the forces acted was constant during these periods of deformation. The veins are commonly highly contorted in the beds of micaceous sillimanite schist (Pl. 3, fig. 3). and are little deformed in the beds of mica-quartz schist. Apparently the arenaceous beds were considerably more competent than the argillaceous beds.

Schistosity is well-developed throughout the Hubbard Hill member except in beds that are deficient in micaceous minerals. The most prominent schistosity is of the axial plane type. Because most folds are isoclinal, this schistosity is parallel to bedding except at the noses of folds. Schistosites of both the axial plane and bedding type may be observed at the noses of some folds. The bedding schistosity, which is weakly developed, apparently formed before the period of tight folding and was not completely obliterated during the formation of the axial plane schistosity.

A cleavage banding has developed in some of the thin-bedded sillimanite schists at the noses of folds. The banding is parallel to the axial planes of the folds and consists of alternating 5 mm. layers of fine-grained arenaceous material and coarse micaceous material. The banding apparently results from flow of material from the beds of mica-quartz schist into the beds of sillimanite schist along the planes of schistosity.

In the Hubbard Hill member, lineation is expressed by the parallelism of prismatic minerals, streaks of minerals, elongated pebbles, and crinkles. The linear features apparently have a common origin because they are parallel to one another over fairly large areas. They are also generally parallel to the axes of the folds. In the schists east of the Bethlehem gneiss, the lineation plunges steeply southeast (Pl. 4). The lineation in the beds west of the Bethlehem plunges gently northeast. In the southwestern part of the area, the lineation plunges 40° to 65° northeast.

The stretched pebbles in the quartz conglomerates form the most striking linear feature (Pl. 3, fig. 4). The longest and intermediate axes of the pebbles lie in the plane of schistosity, whereas the shortest axis is perpendicular to the schistosity. The pebbles are elongated parallel to the axes of the minor folds. The average axial ratios of the pebbles are 1:2:8, but they range from 1:2:4 to 1:3:16. On the basis of the average axial ratios, the extension along the long axes of the pebbles is approximately 200 per cent.

May Pond member.—The May Pond member lies stratigraphically above the Hubbard Hill member. A tabular body of Kinsman quartz monzonite separates the two members in the northern half of the quadrangle. The May Pond member is composed of fairly well-banded paragneisses which show few traces of bedding. Wherever preserved, bedding is parallel to the foliation and the banding in the gneiss. The northern portion of this member strikes fairly uniformly N 30° E, but toward the south the strike is nearly east-west. Although the gneisses generally dip steeply to the east, in the vicinity of Moose and Whittemore Hills in the southwestern part of Marlow they have an average dip of 75° NW. Drag folds indicate that these beds face southeast and are thus overturned toward the southeast. This interpretation is in harmony with the theory that the younger members of the Littleton formation lie to the east.

It is difficult to determine the intensity of deformation in the May Pond member because horizon markers are lacking and bedding is obscure in most places. Generally the foliation is highly contorted and porphyroblasts of feldspar are drawn out into augen. The folds are normally small with wave lengths ranging from a few millimeters to several centimeters. The lack of cataclastic textures indicates that recrystallization accompanied or followed deformation.

Dakin Hill member.—The Dakin Hill member, which lies stratigraphically above the May Pond member, is composed of rather massive paragneisses which show practically no trace of bedding. Foliation is poorly developed, but its attitude is moderately uniform over large areas. In the southern portion of this member, the foliation strikes approximately north-south and dips steeply to the east or west. In the north, the strike is north-northeast and the dip ranges from 50° SE to vertical and averages 70° SE. The folding shown on Plate 1 is necessarily diagramatic.

Bethlehem Gneiss

Mt. Clough pluton.—The Mt. Clough pluton, named from the type locality in the Moosilauke quadrangle (Billings, 1937), is a large tabular mass of Bethlehem gneiss approximately 80 miles long and half a mile to 7 miles wide. The southern extremity of the body is exposed in the northwestern part of the Lovewell Mountain quadrangle and the northeastern part of the Bellows Falls quadrangle. The body is 6 miles wide at the northern boundaries of these quadrangles and 6 miles to the south in the Lovewell Mountain quadrangle tapers to a point. The eastern contact is relatively straight and on the average strikes north-northeast and dips 40°–70° SE. The western contact is more sinuous and trends approximately north-south and dips 10°–30°E. The irregular course of the contact on Gates Mountain is due to the effects of topography on a gently dipping contact. The attitudes of the contacts as observed at seven localities are given in Table 13. The fact that the contacts of the Bethlehem gneiss appear to be approximately parallel to the bedding in the adjacent schists suggests that the body is concordant. The western contact of the body, however, is actually cross-cutting on a large scale. The base of the Mt. Clough pluton near its southern extremity is about 5000 feet above the Clough formation. Ten miles to the north, in the Claremont quadrangle, Chapman (1942, p. 914) found that the lower contact of the pluton was at the base of the Clough formation. Thus in the southern portion of the Mt. Clough pluton the cross-cutting relations are pronounced when considered over a distance of several miles.

TABLE 13.—ATTITUDE OF THE OBSERVED CONTACTS BETWEEN THE BETHLEHEM GNEISS AND SCHIST

Locality	Attitude		Exposure along strike	Height of vertical face
	Strike	Dip		
			ft.	*ft.*
Western (lower) contact				
200 ft. S60° W of the summit of Gates Mountain	N30° W	13° NE	10	6
1200 ft. S38° E of the summit of Gates Mountain	N10° E	13° SE	8	1
2150 ft. S40° E of the summit of Gates Mountain	N15° W	15° NE	20	2
2300 ft. S37° E of the summit of Gates Mountain	N15° E	15° SE	10	5
2650 ft. S35° E of the summit of Gates Mountain	N27° E	27° SE	15	3
Eastern (upper) contact				
Road cut 1900 ft. south of Marlow Jct.	N35° E	58° SE	2	3
3575 ft. S72° W of Pollards Hill	N28° E	42° SE	6	½

The foliation in the Bethlehem gneiss is well-developed near the margins and is vague in the central part of the pluton. The strike of the foliation ranges from N 30° W to N 30° E and the dip generally ranges from 10° to 30° E; however, near the eastern contact the dip is 40°–70°E and in the northwestern part of the area some of the dips are to the west. Slab-like inclusions in various degrees of digestion are without exception parallel to the foliation. The fact that the foliation is sheared and the shears are filled with pegmatitic material which grades into the groundmass of the gneiss suggests that the foliation is primary. Later movements apparently took place along the foliation planes because quartz aggregates and feldspar phenocrysts are granulated and drawn out into augen parallel to the foliation. Cross-cutting pegmatites are also sheared along planes parallel to the foliation in the gneiss.

Lineation expressed by the alignment of biotite flakes and drawn out inclusions is well-developed near the eastern contact and is vague in other parts of the body. The lineation plunges 20° to 35° SSE near the contact, but decreases to approximately 10° SSE a mile from the contact (Pl. 4). The attitude of the lineation in the Bethlehem gneiss near the contact is approximately the same as in the adjacent schists. The lineation in the schists is parallel to the axes of the folds and its attitude is fairly constant for several miles from the contact of the gneiss. Inasmuch as the lineation in the schists is apparently the result of regional forces, the lineation in the Bethlehem gneiss is probaby secondary and related to these forces rather than to magmatic movement.

Minor bodies of Bethlehem gneiss.—A small concordant body of Bethlehem gneiss, half a mile long and 400 feet wide, is exposed along the Gilsum-Sullivan town line in the southwestern part of the area. The exposure of Bethlehem gneiss west of Wright Hill in Gilsum forms the southeastern prong of a body that extends for 1 mile into the Bellows Falls quadrangle (Fig. 3). Although the contacts of this body are irregular, no cross-cutting relations were observed. The sinuosities of the contact are apparently due to interfingering of the Bethlehem gneiss and schist and to later folding.

The stratigraphic position of the bodies of Bethlehem gneiss in Gilsum suggests that they may be a part of the same sheet that formed the Mt. Clough pluton. If the projected horizon of the Mt. Clough pluton rises in the stratigraphy towards the south at the same rate as it does in the northwestern part of the area, the horizon would lie close to the bodies of Bethlehem gneiss in Gilsum. Thus these bodies may join the Mt. Clough pluton at depth or they may represent detached lenses of a once continuous sheet.

Kinsman Quartz Monzonite

Bacon Ledge pluton.—The western portion of the Bacon Ledge pluton is exposed in the eastern third of the Lovewell Mountain quadrangle. This is probably the largest body of Kinsman quartz monzonite in New Hampshire. It extends southward for 7 miles into the Monadnock quadrangle, eastward for at least 8 miles into the Hillsboro quadrangle, and northward for several tens of miles, probably into the Cardigan quadrangle.

In the Lovewell Mountain quadrangle, the general trend of the western contact is north-south and the dip ranges from 75°E to vertical. In the southern part of the area, the contact was observed at four localities and is parallel to the foliation in the adjacent paragneisses. In the northern part of the area, the actual contact was not observed, but data obtained near the contact indicates moderate interfingering of the Kinsman quartz monzonite and the paragneiss. The extension of the Kinsman into the metamorphic rocks near the village of Stoddard is apparently due to folding. Here the Kinsman quartz monzonite wraps around the nose of a

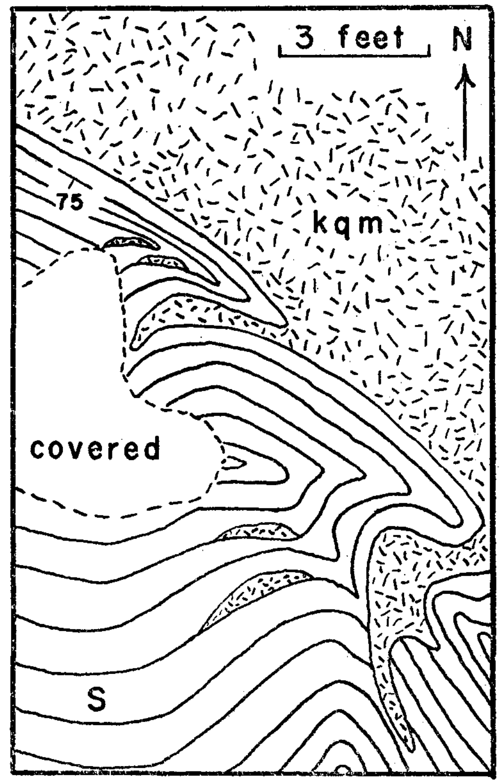

FIGURE 6.—CONTACT BETWEEN INCLUSION OF SCHIST AND KINSMAN QUARTZ MONZONITE

Pitcher Mountain, Stoddard. s = schist; kqm = Kinsman quartz monzonite.

northward-plunging anticline that has a core of paragneiss. The contacts, which were observed at five localities, are generally concordant and nearly vertical on the flanks of the anticline, but dip 55°N on the nose of the anticline (Pl. 4).

Detailed studies at favorable exposures indicated that the contacts are partly concordant and partly discordant. In some places, the Kinsman quartz monzonite is parallel to the foliation in the metasedimentary rocks; in other places it cuts across the structure (Fig. 6).

A planar structure represented by the parallel orientation of microcline phenocrysts and slab-like inclusions is fairly well-developed throughout the pluton. Foliation due to alignment of biotite flakes is generally lacking. The fact that the large feldspar crystals are rigorously parallel to one another in many places and yet show no signs of deformation indicates that the phenocrysts were aligned during the flow stage. In the southeastern part of the area, the planar structures strike approximately north-south and most of the dips range from 75°E to vertical. In the central and northern portions of the pluton, dips as low as 20° east or west are not uncommon (Pl. 4). In this area, the planar features probably were subjected to later folding.

No distinct lineation was observed in the Kinsman quartz monzonite. The elongation of the feldspar phenocrysts is so slight that the attitude of their long axes could be determined only at the most favorable exposures. At these places, there appeared to be no preferred linear orientation.

Inclusions are most numerous along the contacts, especially where the trend of the contact is irregular. However, the largest inclusion, which is south of Goodhue Hill in Hancock, is several miles from any known contact. This inclusion contains beds of schist, quartzite, and lime-silicate granulite which are lithologically similar to the metasedimentary rocks in the Hubbard Hill member.

Huntley Mountain pluton.—The Huntley Mountain pluton lies in the northwestern portion of the quadrangle. It is a large tabular body with a minimum length of 14 miles and an average width of 1¼ miles. The body trends north-northeast in the northern portion of the quadrangle and east-west in the west-central part of the area. It extends into the Bellows Falls quadrangle for 2 miles (Fig. 3) and into the Sunapee quadrangle for an unknown distance.

The contacts are concordant except in the southern portion of the body where the Kinsman quartz monzonite commonly truncates the bedding in the schist (Fig. 7). In this part of the pluton, cross-cutting relationships on a large scale are also pronounced. Near Lake Warren in the Bellows Falls quadrangle the lower contact of the body is about 4000 feet above the base of the Littleton formation; 4 miles to the northeast, at Bald Hill in the Lovewell Mountain quadrangle, it is 10,000 feet above the base of the Littleton formation.

Angular inclusions are more common in this body than in the Bacon Ledge pluton. Possibly

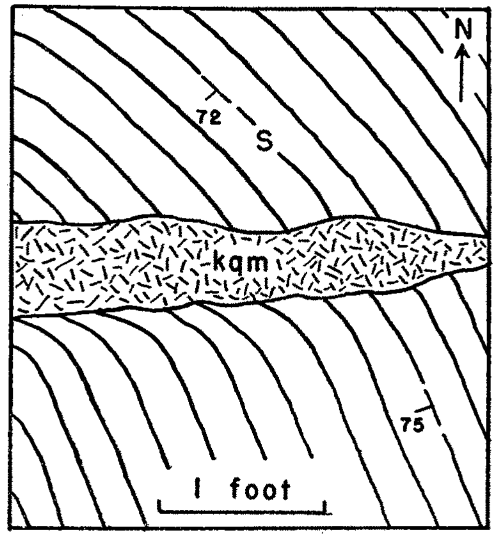

FIGURE 7.—CROSS-CUTTING STRINGER OF KINSMAN QUARTZ MONZONITE

Half a mile north of Tinker Pond, Marlow. s = schist; kqm = Kinsman quartz monzonite.

the rocks adjacent to the Huntley Mountain pluton were more brittle at the time of emplacement than were those next to the Bacon Ledge pluton. In the southern portion of the Huntley Mountain pluton, schist and quartz monzonite occur in nearly equal amounts along some of the contacts. In this area it is difficult to determine whether one is dealing with schist inclusions in the pluton or isolated masses of quartz monzonite in the schist.

Planar structures, represented by the parallelism of biotite flakes, feldspar phenocrysts, and slab-like inclusions, are well-developed except in the small apophyses which extend into the surrounding rocks. In the southern portion of the Huntley Mountain pluton, the foliation is evidently primary, because it wraps around the larger wedge-shaped inclusions. Primary movements were also important in the northern portion of the pluton because undeformed phenocrysts of feldspar show a marked parallelism. However, later movements apparently took place in this area, because a secondary foliation, parallel to the planar structures in the Kinsman, is conspicuous in many of the cross-cutting pegmatite veins.

Progressive Metamorphism

In the Bellows Falls quadrangle, Kruger (1946, p. 166) has shown that there is an in-

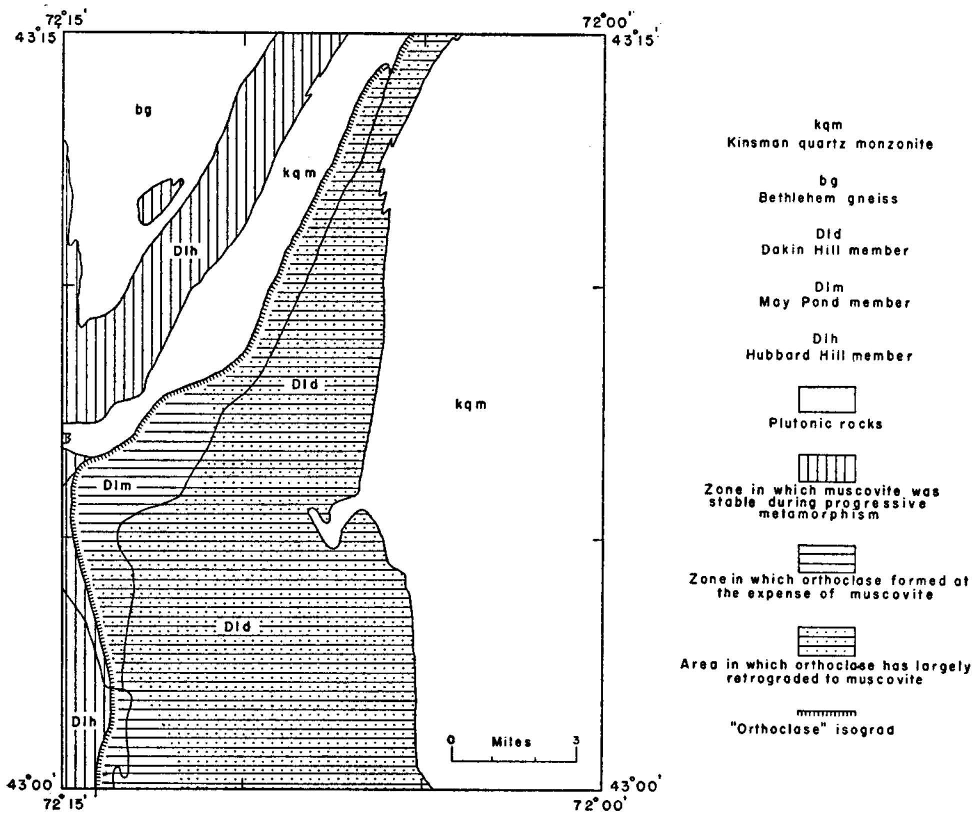

FIGURE 8.—METAMORPHIC SUBZONES IN THE LOVEWELL MOUNTAIN QUADRANGLE

METAMORPHISM OF THE METASEDIMENTARY ROCKS

General Statement

All the metasedimentary rocks and some of the plutonic rocks in the Lovewell Mountain quadrangle have been metamorphosed under high-grade conditions. In general, the intensity of the metamorphism increases from west to east. Orthoclase formed at the expense of muscovite under the highest intensity conditions; however, the orthoclase has altered to muscovite where retrograde metamorphism has occurred. Changes in chemical composition during metamorphism have not been great although locally alkalies were probably introduced or removed.

crease in the grade of metamorphism from the Connecticut River toward the east. The sillimanite isograd, which is the boundary between the middle-grade and high-grade zones, trends nearly north-south and lies about 4 miles west of the western margin of the Lovewell Mountain quadrangle. Although the high-grade zone occupies the entire Lovewell Mountain quadrangle, there is evidence that the intensity of metamorphism increases from west to east.

In the western part of the area (as shown by vertical ruling in Fig. 8) sillimanite and muscovite occur in the metasedimentary rocks and potash feldspar is lacking except in the lime-silicate rocks. East of this area, the metasedimentary rocks contain either orthoclase or aggregates of muscovite and quartz which appear to be pseudomorphous after orthoclase

(Fig. 8). The boundary between the metamorphosed argillaceous rocks which lack orthoclase and those which contain orthoclase or pseudomorphs after orthoclase is referred to as the "orthoclase" isograd. In the rocks which contain orthoclase, muscovite is lacking except where retrograde metamorphism has occurred. (See modes in Table 4, columns 1 and 2, and Table 5, columns 1 and 11.) This suggests that the orthoclase formed largely at the expense of muscovite. The fact that fine sillimanite needles commonly penetrate biotite in the gneisses east of the "orthoclase" isograd indicates that some of the potash for the orthoclase may have been derived from biotite.

Retrograde Metamorphism

In most of the metasedimentary rocks in the central portion of the quadrangle, the orthoclase porphyroblasts have been partially or completely replaced by muscovite and quartz (Fig. 8). Apparently the alteration of orthoclase occurred under high-grade conditions throughout most of this zone because sillimanite is prevalent and appears to be in equilibrium. The degree of alteration of the orthoclase increases from west to east. In the western portion of the area of retrograde metamorphism, all stages in the transition from orthoclase to aggregates of muscovite and quartz may be seen. In the partially altered porphyroblasts, muscovite occurs along cleavage planes in the orthoclase and shells of muscovite and quartz commonly surround the orthoclase. Although orthoclase is rare in the central part of the area, the form of the aggregates of muscovite and quartz indicates that they are actually pseudomorphs after orthoclase porphyroblasts.

The retrograde metamorphism was probably facilitated by solutions which were genetically related to the Kinsman quartz monzonite. Inasmuch as the pseudomorphs after orthoclase in the May Pond member contain considerable plagioclase, soda and lime were probably introduced in this zone. Throughout most of the area the orthoclase has simply been replaced by muscovite and quartz. A part of the potash in the original orthoclase was probably removed from the limits of the pseudomorphs because some of the pseudomorphs contain as little as 5 per cent muscovite. However, the occurrence of muscovite in the matrix of the gneiss indicates that the potash may have migrated only a short distance. The fact that the specimen of gneiss which has undergone retrograde metamorphism (LM 125, Table 15, column 2) contains only 0.2 per cent less potash than the specimen of orthoclase gneiss (LM6, Table 15, column 1) suggests that little if any potash was removed during the retrograde metamorphism.

In the Hubbard Hill member, sillimanite has altered to muscovite in many of the schists which are west of the "orthoclase" isograd. This alteration is not necessarily the result of retrograde metamorphism in the sense that it occurred during declining intensity conditions. Muscovite was apparently stable in these schists during the entire period of metamorphism, because orthoclase or pseudomorphs after orthoclase are lacking. Thus the alteration of sillimanite to muscovite may have occurred during progressive metamorphism as a result of the introduction of potash.

The development of chlorite in various parts of the area indicates that some retrograde metamorphism occurred under low-intensity conditions. Biotite has been most susceptible to chloritization although garnet has undergone slight alteration. Inasmuch as chlorite-bearing rocks are found sporadically throughout the area, the chloritization was probably unrelated to the alteration of the orthoclase.

Origin of the Paragneisses

The paragneisses are largely limited to the May Pond and Dakin Hill members. The chemical analyses of specimens LM6 and LM125 (Table 15, columns 1 and 2) suggest that the gneisses were originally shales. The homogeneity and lack of bedding in the gneisses indicate that the initial shales probably formed a thick series with few sandstone beds. The gneisses apparently recrystallized after most of the deformation because they are not well-foliated.

The graphite-bearing pyritiferous gneisses represented by the analyzed specimen of LM358 (Table 14, column 1) are believed to have been black shales. It is generally accepted (Twenhofel, 1939, p. 304) that the presence of carbonaceous matter and sulphur in sediments implies that there was poor circulation of the

TABLE 14.—ANALYSES OF ROCKS CONTAINING CARBON

	1	2	3	4	5	6
SiO_2	59.56	51.03	49.13	59.70	56.38	61.52
Al_2O_3	17.45	13.47	13.92	16.98	15.27	17.59
Fe_2O_3	3.10	8.06	1.35	1.31	2.81	1.54
FeO	3.84	—	1.87	4.88	3.23	4.86
MnO	0.07	—	0.25	0.16	0.09	0.04
MgO	2.67	1.15	5.11	3.23	2.84	2.76
CaO	0.21	0.78	8.73	1.27	4.23	2.04
Na_2O	0.79	0.41	0.20	1.35	1.30	1.74
K_2O	3.79	3.16	4.25	3.77	3.51	3.55
H_2O^+	2.98	—	4.69	3.82	4.09	1.96
H_2O^-	0.38	0.81	1.52	0.30	0.77	0.65
CO_2	0.00	—	6.93	1.40	3.67	0.00
TiO_2	1.10	—	0.66	0.79	0.78	0.64
ZrO_2	—	—	0.00	—	tr	—
P_2O_5	0.13	0.31	0.03	0.16	0.17	tr
SO_3	0.65	—	—	—	—	—
F	0.06	—	—	—	—	—
S	2.19	7.29	0.46*	0.63*	0.92*	0.49
C	1.20	13.11	2.00	0.46	0.59	0.87
BaO	—	—	0.00	0.08	0.08	—
Hydrocarbons	—	3.32	—	—	—	—
Total	100.17	102.90	101.10	100.29	100.73	100.25
Less O for S and F	0.86	2.73	0.18	0.24	0.34	
	99.31	100.17	100.92	100.05	100.39	

* The sulphur here given was computed from the FeS_2 reported in the original analyses. The iron in the FeS_2 was computed as Fe_2O_3. These adjustments were made so that the analyses in which FeS_2 was reported could be directly compared to the analyses in which sulphur was given separately.

1. (LM358) Pyritiferous muscovite gneiss, Lovewell Mountain quadrangle, N. H. For mode see Table 5, column 10. L. C. Peck, analyst.
2. Bituminous shale, Dry Gap, Ga. (Clarke, 1924, p. 552). L. G. Eakins, analyst.
3. Shale, Hermosa, N. M. (Clarke, 1914, p. 256). G. Steiger, analyst. 0.86 per cent pyrite reported in the original analysis.
4. Black slate, Benson, Vt. (Clarke, 1924, p. 554). W. F. Hillebrand, analyst. 1.18 per cent pyrite reported in the original analysis.
5. Black roofing slate, Slatington, Penn. (Clarke, 1914, p. 252). W. F. Hillebrand, analyst. 1.72 per cent pyrite reported in the original analysis.
6. Mica schist of the Orfordville formation, middle-grade zone, Mt. Cube area, N. H. (Hadley, 1942, p. 122). W. H. Herdsman, analyst.

water during deposition. The lack of arenaceous beds and the general massiveness of the Dakin Hill member indicates that the conditions of deposition were quiet.

Few complete analyses of black shales are available. Analyses of black slates are more common, but most of the specimens analyzed were roofing slates and are therefore probably not representative of the group. Several analyses of black shales and black slates together with the analyses of the pyritiferous gneiss from the Lovewell Mountain quadrangle are given in Table 14. The composition of the gneiss is not greatly different from that of the shales and slates except that it is richer in sulphur than most of the other rocks. However, the bituminous shale (Table 14, column 2) contains considerably more sulphur than does the gneiss; therefore it is possible that all the sulphur in the gneiss is original.

Carbonaceous rocks are not common in the low-grade and middle-grade zones of the Littleton formation, but black schists are fairly abundant in the middle-grade zone of the Orfordville formation. An analysis of one of the carbonaceous schists from the Orfordville formation in the Mt. Cube area is given in Table 14, column 6. Chapman (1939, Table 1) reported as much as 3 per cent pyrite in some of the black schists from the Orfordville formation in the Mascoma quadrangle. Thus the amount of pyrite in some of the middle-grade schists of the Orfordville formation is as great as in the high-grade gneisses of the Littleton formation.

If sulphur has been added to the pyritiferous gneisses, it probably was not introduced through simple pyritization, because the gneisses do not contain more iron than the nonpyritiferous types. Goldschmidt (1922) has suggested that carbon and sulphur may be introduced through the process of "carbon metasomation," in which introduced CS_2 or COS reacts with iron-rich silicates to form graphite, pyrite, and quartz. However, evidence that iron-silicates have been altered in the gneiss is lacking. From the general massiveness of the gneiss and its similarity in chemical composition to some of the black shales, it is concluded that the carbon and sulphur are primary constituents and that the gneiss was originally a black shale.

The light-colored nodules and bands in the gneisses are believed to have formed by replacement and segregation rather than by magmatic injection. In some gneisses, well-formed porphyroblasts of orthoclase have cores of unreplaced gneiss. Even where the orthoclase is in the form of augen, there is generally evidence that the orthoclase grew by replacement. In the gneisses containing relatively thin lenses of orthoclase, it is difficult to determine whether the lenses represent highly drawn out porphyroblasts or concentrations of a former liquid phase. In the gneisses which have not undergone retrograde metamorphism, the lenses commonly contain over 90 per cent orthoclase and less than 10 per cent quartz. One would not expect a low-temperature liquid phase to be as rich in potash. In any case, the light-colored lenses probably do not represent introduced material. The analyzed specimen of orthoclase gneiss (LM6, Table 15, column 1) actually contains slightly less potash than the analyzed slates from the low-grade zone of the Littleton

TABLE 15.—CHEMICAL ANALYSES OF METAMORPHOSED ARGILLACEOUS ROCKS FROM THE LITTLETON FORMATION

	1 LM6	2 LM124	3 LM358	4 W219	5 L489
SiO_2	62.04	58.94	59.56	58.92	58.14
Al_2O_3	18.29	18.10	17.45	18.55	21.00
Fe_2O_3*	0.33	0.49	3.10	0.94	0.33
FeO	8.45	10.04	3.84	6.63	6.32
MnO	0.22	0.25	0.07	0.08	0.06
MgO	3.23	3.45	2.67	3.24	3.41
CaO	0.45	0.89	0.21	0.48	0.32
Na_2O	0.77	1.20	0.79	1.49	1.10
K_2O	3.54	3.34	3.79	3.74	3.85
H_2O^+	0.99	1.73	2.98	3.90	4.47
H_2O^-	0.09	0.06	0.38	0.11	n.d.
CO_2	0.01	0.00	0.00	0.25	0.00
TiO_2	1.11	1.44	1.10	0.93	0.65
ZrO_2	n.d.	n.d.	n.d.	n.d.	0.04
P_2O_5	0.08	0.05	0.13	0.14	0.00
SO_3	n.d.	n.d.	0.65	n.d.	n.d.
Cl	0.00	0.01	0.00	n.d.	n.d.
F	0.10	0.10	0.06	n.d.	n.d.
S	0.03	0.15	2.19	0.17	0.09
C	n.d.	n.d.	1.20	n.d.	n.d.
Less O for S and F	−0.06	−0.12	−0.86	−0.06	—
Total	99.67	100.12	99.31	99.51	99.78
S.G.	2.85	2.88	2.72	2.75	2.777

* Includes iron in pyrite.

1. (LM6) Porphyroblastic orthoclase gneiss, Dakin Hill member, 0.1 mile south of the junction of Highways 10 and 123 in Marlow, Lovewell Mountain quadrangle. L. C. Peck, analyst.
2. (LM125) Biotite gneiss, Dakin Hill member, on road 0.5 mile west of Spruceland Camps at Granite Lake, Lovewell Mountain quadrangle. L. C. Peck, analyst.
3. (LM358) Pyritiferous muscovite gneiss, Dakin Hill member, on road 1.1 miles north of Ellisville, Lovewell Mountain quadrangle. L. C. Peck, analyst.
4. (W219) Slate, quarry at Slate Ledge, approximately 2.75 miles west of Littleton, N. H. (Billings, 1941, Table 10). G. Kahn, analyst.
5. (L489) Slate, quarry at Slate Ledge, approximately 2.75 miles west of Littleton, N. H. (Billings, 1937, p. 556). F. A. Gonyer, analyst.

formation (Table 15, columns 4 and 5). Furthermore, the amount of potash in the orthoclase gneiss is about the same as in the two analyzed gneisses which contain no potash feldspar (Specimens LM125 and LM358,

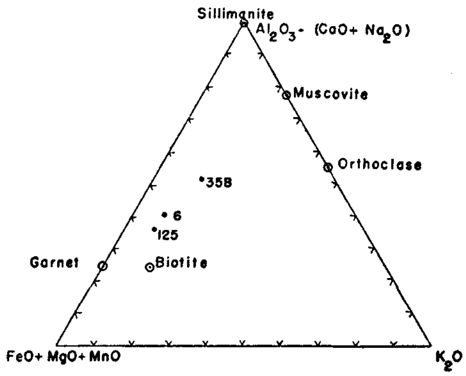

FIGURE 9.—PROJECTION OF ANALYZED PARAGNEISSES

Numbers same as in Table 15. Composition of the garnet, biotite, and orthoclase based on analyses given in Table 9. Composition of the muscovite calculated from the rock analysis of specimen LM358.

Table 15, columns 2 and 3). In Figure 9, the analyzed gneisses are plotted against molecular per cent K_2O, Al_2O_3 − (CaO + Na_2O), and FeO + MgO + MnO. It is significant that the point representing the orthoclase gneiss (LM6) falls in the same general area in the diagram as do the points for the gneisses which lack orthoclase (LM125 and LM358). The physical conditions rather than the chemical composition have been the important factors in the formation of orthoclase in the gneisses.

The origin of the light-colored lenses in the gneisses which have undergone retrograde metamorphism is not entirely clear. In the northern portion of the May Pond member, the lenses are composed mainly of muscovite, quartz, and oligoclase. One interpretation is that the lenses represent injections of magmatic material. However, in the same area there are aggregates of muscovite, quartz, and oligoclase which appear to be pseudomorphs after orthoclase porphyroblasts, suggesting that the light-colored lenses may represent altered orthoclase lenses. Except for slight additions of lime and soda, no change in composition occurred. In the Dakin Hill member, the light-colored lenses are composed almost wholly of quartz and muscovite. Many of these lenses also probably represent altered orthoclase lenses.

Changes in Chemical Composition

General Statement.—An exact determination of the changes in composition during metamorphism was not possible because the original differences in composition between the rocks being compared were not precisely known. However, the fact that the composition of the schists and the paragneisses in the area is similar to the composition of the two analyzed slates from the Littleton formation in the Littleton-Moosilauke area (W219 and L489, Table 15) suggests that no major changes in composition occurred during metamorphism.

Hubbard Hill member.—Although no analyses of the schists from the Hubbard Hill member are available, the modes of these rocks indicate that their composition is not greatly different from that of the slates in the low-grade zone. The average schist contains 10 per cent plagioclase, about 0.8 per cent soda, and about 0.6 per cent lime. The two analyzed slates from the Littleton-Moosilauke area (W219 and L489, Table 15) average 1.30 per cent soda and 0.40 per cent lime. A few of the schists from the Hubbard Hill member contain as much as 30 per cent plagioclase. Small amounts of soda and lime may have been added to these rocks or their original composition may have been slightly different from that of the slates. If material was added, it was probably introduced by dilute solutions or vapors rather than by magmatic injection, because the light-colored constituents are evenly distributed throughout the rock. In the pseudo-sillimanite schists some potash was probably introduced during the muscovitization of the sillimanite. It is unlikely that the potash was derived from other minerals in the rock. Orthoclase is eliminated as a possible source of potash because pseudomorphs after orthoclase are lacking. Potash was not obtained from the biotite because there is no evidence that biotite has been replaced by garnet or chlorite. The fact that accessory tourmaline is fairly common in the pseudo-sillimanite schists suggests that boron may have been introduced perhaps at the same time as the potash. In the west-central portion of the

Hubbard Hill member, thin lime-silicate beds rich in lime and magnesia are closely associated with normal argillaceous rocks. Probably these compositional differences would have been eliminated if solutions had been effective in moving large amounts of material.

Some of the gneisses in the Hubbard Hill member in the southwestern part of the area contain light-colored bands rich in andesine. In general, the total amount of andesine in the gneiss is about the same as in the average schist so that the banding may be the result of segregation without addition of material. Soda and lime may have been added locally where the gneiss contains 20 to 30 per cent andesine.

May Pond and Dakin Hill members.—In the gneisses of the May Pond and Dakin Hill members, bands and nodules of light-colored minerals are common; however, the similarity in composition between the analyzed gneisses (Table 15, columns 1, 2, and 3) and the analyzed slates (Table 15, columns 4 and 5) suggests that no large changes in composition occurred during the metamorphism. In the analyzed orthoclase gneiss, Specimen LM6, orthoclase porphyroblasts comprise 8 per cent of the rock; yet the gneiss is no richer in potash than are the analyzed slates. Specimens LM6 and LM358 are slightly poorer in soda than are the slates. However, the analyzed gneisses contain only about 3 per cent plagioclase, whereas the average gneiss carries about 10 per cent plagioclase and about 1 per cent soda. Thus the soda-content of the gneiss is generally about the same as that of the low-grade rocks. Locally, where the gneiss contains as much as 35 per cent plagioclase, appreciable amounts of soda and lime may have been introduced.

Summary of Metamorphism

All the metasedimentary rocks in the area have been metamorphosed under high-grade conditions. Orthoclase developed at the expense of muscovite in the paragneisses during the peak of metamorphism. The orthoclase in the central portion of the quadrangle was largely replaced by quartz and muscovite during a period of retrograde metamorphism. Most of the metasedimentary rocks were probably derived from shales without any appreciable changes in composition during metamorphism. In portions of the Hubbard Hill member, however, potash was apparently introduced during the alteration of sillimanite to muscovite. In the few rocks which contain as much as 35 per cent plagioclase, soda and lime were presumably added.

Origin of the Plutonic Rocks

General Theory

Several lines of evidence indicate that most of the bodies of Kinsman quartz monzonite have intruded the surrounding rocks. In the case of the Bethlehem gneiss the field relations are not as conclusive, but they do demonstrate that most of the gneiss moved as a magma. Definite conclusions could not be drawn regarding the origin of the granitic material which formed these bodies. Magma rising from great depth may have entered certain favorable horizons and formed the huge sill-like masses now exposed. Some features suggest that the granitic material originated at a comparatively shallow depth by the solution or partial solution of favorable beds. The mobilized material may have moved along approximately the same stratigraphic horizon at which it originated to form the intrusive sheets.

Evidence of Intrusion

General statement.—The data pertinent to the problem of the origin of the plutonic rocks are assembled in Table 16. This material has been described in detail in the sections on plutonic rocks and structure.

Kinsman quartz monzonite.—Field evidence clearly demonstrates that most portions of the Kinsman quartz monzonite are intrusive into the surrounding rocks. In the case of some of the small nonporphyritic masses of Kinsman quartz monzonite in the northern part of the area, the data are inconclusive as to whether the rock was injected or formed essentially in place. The evidence which indicates an intrusive mode of emplacement is as follows:

1. Beds in the schist have been forced apart and disrupted by the Kinsman quartz monzonite at some of the contacts. This relation is clearly shown in the exposures at Sand Pond (Fig. 10). Many of the lenticular pods of

TABLE 16.—CHARACTERISTICS OF THE KINSMAN QUARTZ MONZONITE AND THE BETHLEHEM GNEISS

Chemistry: Kinsman quartz monzonite—granite to quartz diorite, granodiorite predominating. Facies with large percentages of microcline phenocrysts generally granites; nonporphyritic facies generally quartz diorites. Average 4 per cent normative corundum. (For chemical analyses see Table 19.)

Bethlehem gneiss—quartz monzonite to quartz diorite, granodioritie predominating.

Mineralogy: Oligoclase-andesine, microcline, quartz, biotite, and muscovite; sillimanite and garnet in the bodies of Kinsman quartz monzonite in the eastern two-thirds of the quadrangle. (For modes see Tables 6, 7, 8.)

Texture: Kinsman quartz monzonite—hypidiomorphic granular; coarse-grained, largely porphyritic with large crystals of microcline 1 to 8 cm. long. Nonporphyritic phases more common in the small bodies.

Bethlehem gneiss—granoblastic texture; medium-grained with a few augen of microcline 1–2 cm. long.

Structure: Bodies strikingly concordant but with some large scale cross-cutting relationships; small scale cross-cutting relationships common along many of the contacts of the Kinsman quartz monzonite.

Dikes rare.

Contacts generally sharp but in some places very gradational.

Foliation fairly well-developed in the Bethlehem gneiss; poorly developed in the Kinsman quartz monzonite; phenocrysts with parallel orientation common in the Kinsman quartz monzonite. Planar structures generally parallel to contacts.

Slab-like inclusions parallel to foliation; most inclusions in the Bethlehem gneiss considerably reworked; in the Kinsman quartz monzonite some inclusions unaltered, others highly reworked.

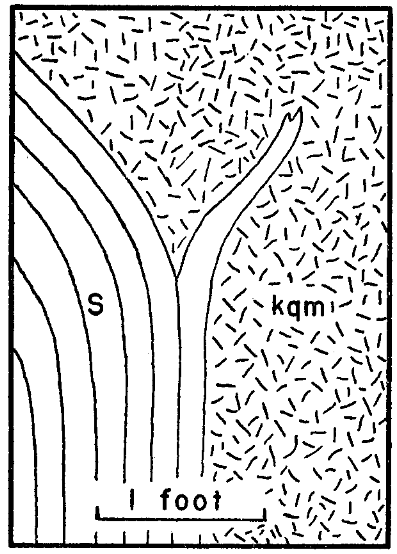

FIGURE 10.—CONTACT BETEEN SCHIST AND KINSMAN QUARTZ MONZONITE

Exposed in cliff at north end of Sand Pond, Lempster. Beds in the schist (s) have been wedged apart and disrupted by the intrusion of the Kinsman quartz monzonite (kqm.).

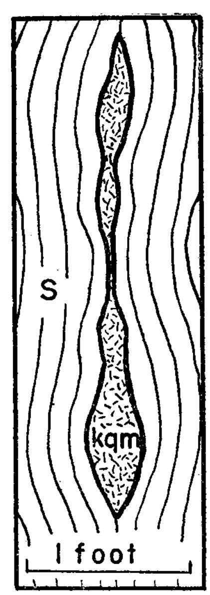

FIGURE 11.—PODS OF KINSMAN QUARTZ MONZONITE IN SCHIST

Exposed in cliff at north end of Sand Pond, Lempster. s = schist; kqm = Kinsman quartz monzonite.

Kinsman in the schists appear to be the result of intrusion. These pods are probably not boudinages because evidence of granulation and plastic deformation within the pods is lacking. Furthermore the pods are not blunt, but taper to relatively sharp points (Fig. 11).

2. Dikes of Kinsman quartz monzonite are found in the paragneisses several miles from the main plutons. A 3-foot dike is well-exposed 1 mile southwest of Big Pond in Marlow.

3. Where the Kinsman quartz monzonite cuts across the bedding of the schist inclusions,

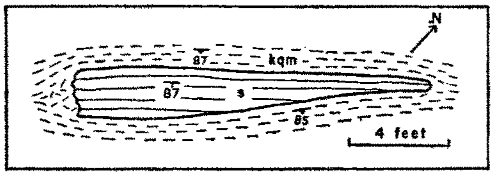

FIGURE 12.—INCLUSION OF SCHIST IN THE KINSMAN QUARTZ MONZONITE

0.3 mile west of Mack Hill, Marlow. On the southeast side of the inclusion of schist (s), the Kinsman quartz monzonite (kqm) cuts the bedding at an angle of about 10°. The foliation in the Kinsman is parallel to the contacts except at the blunt end of the inclusion where foliation is lacking.

the foliation in the Kinsman is commonly parallel to the walls of the inclusions (Fig. 12). The foliation in these cases is obviously a flow structure and not an inherited feature.

4. In the Bacon Ledge pluton, the large feldspar crystals have a parallel orientation whereas the biotite flakes are randomly oriented. If the alignment of the feldspar crystals were due to replacement along former planes of schistosity one would expect that the biotite flakes would also show a parallel orientation. The fact that the feldspar crystals are euhedral and show no signs of granulation rules out the possibility that they were oriented by differential forces acting after the solidification of the magma. The feldspars were probably oriented during the late stages of magmatic flow. Because of the large size of the feldspar crystals, they were more readily oriented than the smaller biotite flakes.

5. Although there is a gradation from quartz monzonite to schist in a few places, most of the contacts are sharp (Fig. 13). Some of the inclusions of schist near the sharp contacts, however, are highly reworked. The original composition of many of these inclusions was apparently similar to that of the wall rock. In a body which formed by replacement, one would expect the wall rock to be altered if many of the slabs of schist near the contacts are highly reworked.

6. In the middle-grade zone of the Keene quadrangle, Moore (1949) found that the Kinsman quartz monzonite was rimmed by a belt of silimanite schist which was only a few

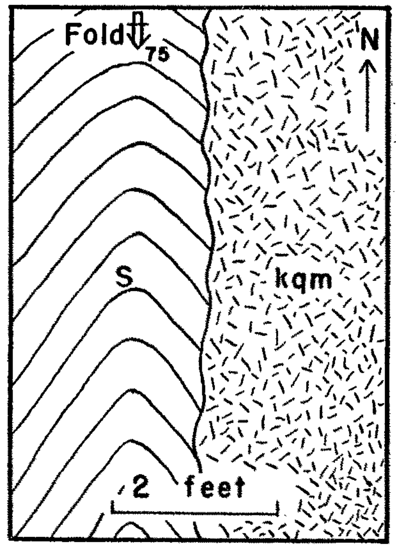

FIGURE 13.—CONTACT BETWEEN SCHIST AND KINSMAN QUARTZ MONZONITE

Half a mile northwest of Pumpkin Hill, Marlow. Bedding in schist (s) is truncated by the Kinsman quartz monzonite (kqm.).

hundred feet wide. The fact that the high-grade schists in the central part of this area are confined to narrow border zones along the pluton suggests that the Kinsman quartz monzonite intruded these rocks and furnished the heat necessary for the more intense metamorphism of the schists.

Bethlehem gneiss.—Although some of the Bethlehem gneiss may have formed in place, the following evidence indicates that large masses of the gneiss moved as a magma:

1. The fact that the schists diverge at the southern extremity of the Mt. Clough pluton (Pl. 4) indicates that they were probably intruded by the Bethlehem gneiss and wedged apart.

2. Although most of the Mt. Clough pluton is concordant, the southern portion cross-cuts the lower part of the Littleton formation. Over a distance of 10 miles, the base of the pluton rises 5000 feet in the stratigraphy.

3. Cross-cutting contacts between the Bethlehem gneiss and schist have been observed in the Mt. Cube area (Hadley, 1942, p. 165).

Evidence of Replacement

Kinsman quartz monzonite.—Evidence that large portions of the Kinsman quartz monzonite formed by replacement *in situ* is lacking. The paragneisses that have porphyroblasts of orthoclase are texturally somewhat similar to the porphyritic phases of the Kinsman, but the porphyroblastic paragneisses can not be considered as intermediate phases in a process of granitization of argillaceous rocks because their chemical composition does not approach that of the Kinsman quartz monzonite. The porphyroblastic paragneisses are as rich in alumina and as poor in soda and lime as the slates in the low-grade zone (Table 15).

Some of the nonporphyritic phases of the Kinsman quartz monzonite which occur in small bodies in the northern portions of the May Pond and Dakin Hill members are not greatly different from the paragneisses which are rich in plagioclase (Table 5, column 6). Inasmuch as cross-cutting relations have not been observed and some of the contacts are gradational, the Kinsman quartz monzonite may have originated at a comparatively shallow depth through processes analogous to those which formed the paragneiss. However, compelling evidence against an intrusive origin for these bodies is lacking.

Bethlehem gneiss.—There is no conclusive evidence that any of the Bethlehem gneiss formed in place, but some features suggest that replacement processes may have been locally important. Relatively fine-grained layers which are a few inches thick occur in the gneiss within 1500 feet of the upper (eastern) contact of the Mt. Clough pluton in the northern part of the quadrangle. Microscopic study of one of these layers indicated that it was mineralogically similar to the enclosing gneiss except for a lack of potash feldspar. It is unlikely that the fine-grained layers are younger sill-like injections because they are poorer in potash feldspar than the older rock. Another possibility is that the layers represent highly reworked inclusions. Some of the layers are only a few inches thick and are at least several tens of feet in length. One would not expect inclusions of these dimensions to remain intact if the enclosing rock moved appreciably. The fine-grained layers may represent relic beds in a portion of the gneiss which formed essentially in place. The fact that the upper contact is gradational in some places is in harmony with this idea, although the gradational contacts could have resulted through the action of solutions emanating from a magma.

Conclusions

From the evidence considered, it is concluded that at least the main portions of the Kinsman quartz monzonite and Bethlehem gneiss are intrusive into the surrounding rocks. For purposes of discussion this injected material will be referred to as magma although it may never have been entirely liquid.

Syntectonic Nature of Intrusion

The evidence in the Lovewell Mountain quadrangle supports the conclusion reached by Billings (1937, p. 537, 538) that the Bethlehem gneiss and the Kinsman quartz monzonite were intruded during the orogeny. Apparently deformation preceded the intrusion because the inclusions in the plutonic rocks are schistose. The secondary foliation that has developed in some of the pegmatites which cut the plutonic rocks indicates that deformation continued after intrusion. The Bethlehem gneiss was apparently intruded slightly earlier than the Kinsman quartz monzonite because the Bethlehem is more granulated and a secondary lineation has been imposed on it.

Metamorphism of the Plutonic Rocks

Although the Bethlehem gneiss and the Kinsman quartz monzonite were probably intruded near the close of the orogeny, they have undergone some metamorphism. In the Bethlehem gneiss, the microcline phenocrysts and large quartz grains have been drawn out into augen; however, mortar and cataclastic textures are not as common as in the Bethlehem gneiss of the Littleton-Moosilauke area (Billings, 1937, p. 506).

The Kinsman quartz monzonite in the eastern part of the area has also been affected by the metamorphism. Although sillimanite generally comprises less than 1 per cent of the Kinsman, it is widely distributed except in the southern portion of the Huntley Mountain pluton. Some of the sillimanite needles may be magmatic or relics from incorporated schist inclusions, but the following evidence indicates that at least part of the sillimanite is metamorphic:

1. Undeformed sillimanite needles commonly extend across granulated quartz grains.

2. Sillimanite needles are concentrated in myrmekite at the margins of microcline phenocrysts which are essentially free of sillimanite.

3. The pseudomorphs after microcline in the eastern portion of the Huntley Mountain pluton contain as much as 3 per cent sillimanite. The microcline probably was altered during regional metamorphism, because the orthoclase in the nearby paragneisses of the May Pond member is similarly altered.

Garnets comprise 1–5 per cent of the Kinsman quartz monzonite in the eastern two-thirds of the quadrangle. The garnets may have originated by (1) mechanical incorporation from schist, (2) crystallization from magma, or (3) later metamorphism.

Simple mechanical incorporation of the garnets from the wall rock seems unlikely because the garnets in the Kinsman quartz monzonite are much larger than in the metasedimentary rocks.

The possibility that the garnets in the Kinsman quartz monzonite crystallized from a magma cannot be entirely ruled out; however the following evidence is against a magmatic origin:

1. In the garnetiferous phases of the Kinsman quartz monzonite, the garnets are fairly evenly distributed throughout the rock and are not concentrated in or near inclusions. If the garnets formed as a result of reaction with inclusions, one would expect them to be spatially related to the inclusions. Furthermore, reworked inclusions are common in the western part of the quadrangle; yet most of the rock is nongarnetiferous.

2. Pyrogenetic garnets in granitic rocks are generally poor in pyrope and contain appreciable amounts of spessartite (Fig. 14). The garnet from the Kinsman quartz monzonite (indicated by a cross in Fig. 14) is relatively rich in pyrope and poor in spessartite.

3. The composition of the garnetiferous Kinsman quartz monzonite is approximately the same as that of the nongarnetiferous types

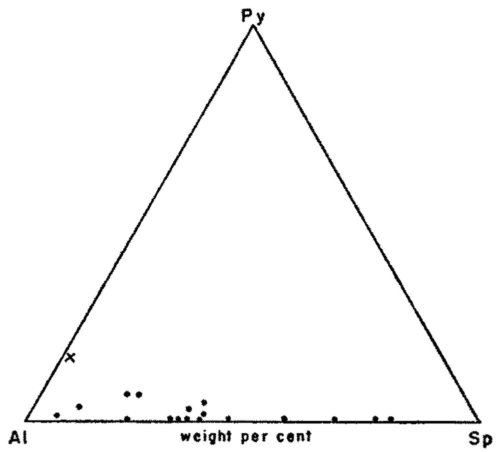

FIGURE 14.—COMPOSITION OF GARNETS FROM GRANITES

Shown by dots. Al = almandite; Sp = spessartite; Py = pyrope. Data from Wright (1938) and Hintze (1899). Cross represents the analyzed garnet from the Kinsman quartz monzonite (Table 9).

(Table 17). If the garnets are of magmatic origin, it is difficult to understand why they formed in one magma and not in another of the same composition.

The evidence which supports a metamorphic origin for the garnets is as follows:

1. As nearly as can be determined from physical properties, the garnets in the Kinsman quartz monzonite are identical in composition with those from the metasedimentary rocks in the area. Furthermore, the proportion of the major molecules in the average garnet from biotite schist in weight per cent is: 78.5% almandite, 15% pyrope, and 6.5% grossularite (Wright, 1938, p. 441). The proportion of these molecules in the garnets from the Kinsman is: 83% almandite, 16% pyrope, and 1% grossularite.

2. The garnetiferous phases of the Kinsman quartz monzonite lie in the high-intensity portion of the high-grade zone; the nongarnetiferous types generally occur in areas of less intense metamorphism.

TABLE 17.—CHEMICAL ANALYSES OF KINSMAN QUARTZ MONZONITE

	1	2	3
	Specimen No.		
	LM1	L556	L585
SiO_2	66.60	66.74	65.52
Al_2O_3	15.86	15.70	16.72
Fe_2O_3	0.35	0.85	0.60
FeO	4.48	4.30	4.75
MnO	0.06	0.06	0.06
MgO	1.50	1.50	1.55
CaO	2.64	1.96	1.94
Na_2O	2.61	2.60	2.76
K_2O	3.58	4.48	3.68
H_2O^+	0.59	0.79	1.21
H_2O^-	0.00	—	—
CO_2	0.08	0.00	0.00
TiO_2	0.95	0.70	0.70
ZrO_2	0.06	n.d.	n.d.
P_2O_5	0.23	0.11	0.23
Cl	0.01	n.d.	n.d.
F	0.08	n.d.	n.d.
S	0.14	0.10	0.19
Less O for S and F	−0.10	—	—
Total	99.72	99.89	99.91
S.G.	2.70	2.738	2.774

1. (LM1) Kinsman quartz monzonite, porphyritic granodiorite facies, Bacon Ledge pluton, Forest Road 300 feet east of Nelson-Antrim town-line, Lovewell Mountain quadrangle. L. C. Peck, analyst.
2. (L556) Kinsman quartz monzonite, porphyritic type, Kinsman Notch, outlet of Beaver Pond, Moosilauke quadrangle. (Billings, 1937, p. 556). F. A. Gonyer, analyst.
3. (L585) Kinsman quartz monzonite, nonporphyritic type, Kinsman Notch, on highway half a mile east of B. M. 1814, Moosilauke quadrangle. (Billings, 1937, p. 556). F. A. Gonyer, analyst.

For these reasons it is believed that the garnet in the Kinsman quartz monzonite formed during metamorphism, probably at the expense of biotite. No analyses of biotite from the nongarnetiferous phases of the Kinsman are available. A computation based on the rock analysis of the nongarnetiferous phases of the Kinsman quartz monzonite from the Littleton-Moosilauke area (Table 17, Specimen L585) indicates that the ratio FeO:MgO in the biotite is 1.6. In the Lovewell Mountain quadrangle, a biotite of this composition may have reacted with some of the muscovite to form the garnet (FeO:MgO = 4.2) and the biotite (FeO:MgO = 1.1) which are now found in the Kinsman.

The exact factors which caused the metamorphism of the Kinsman quartz monzonite are not known, but it is probable that moving solutions played an important part. The fact that the garnetiferous phases of the Kinsman quartz monzonite are limited to the eastern two-thirds of the quadrangle suggests that the solutions were related to the late phases of crystallization of the deeper portions of the Bacon Ledge pluton.

Origin of the Large Feldspar Crystals in the Kinsman Quartz Monzonite

The large crystals of microcline in the Kinsman quartz monzonite are probably of magmatic origin and not the result of replacement. The evidence which supports this conclusion is as follows:

1. In many places the microcline crystals show a parallel orientation; yet they are euhedral and exhibit no signs of deformation. Apparently the crystals were aligned while the magma was still partially fluid. In many places the biotite flakes in the Kinsman are randomly oriented whereas the microcline crystals show a marked parallelism. Is is therefore unlikely that the microcline crystals are porphyroblasts which grew along planes of schistosity.

2. The microcline crystals are commonly smaller in the small bodies of the Kinsman quartz monzonite. This suggests that the microcline is magmatic and that the size of the microcline crystals was influenced by the rate of cooling of the magma.

Several lines of evidence indicate that the microcline crystals are not intratelluric but grew in the later stages of the crystallization of the magma.

1. In almost every specimen, the microcline occurs only as large crystals and is not found in the groundmass. If the phenocrysts were intratelluric, a second generation of microcline would normally occur in the groundmass.

2. The fact that the phenocrysts are gener-

ally smaller in the small bodies of Kinsman quartz monzonite indicates that the growth of the crystals was probably controlled by conditions existing in the body at the time of its final emplacement.

3. Metacrysts of microcline are found in inclusions of mica-quartz schist in the Kinsman quartz monzonite. Metacrysts of potash feldspar do not occur in the mica-quartz schists outside of the plutonic bodies; therefore, the microcline must have grown after the schist had been incorporated in the magma. Presumably the inclusions were picked up at a relatively shallow depth.

4. The fact that the microcline phenocrysts contain inclusions of the other constituent minerals suggests that the formation of the microcline did not precede the growth of the other minerals.

The available data on the physical chemistry of the siliceous rocks also indicate that potash feldspar would not be the first mineral to crystallize in a quartz monzonite or granodiorite. Complete agreement regarding the position of the field boundary in the orthoclase-plagioclase equilibrium diagram is lacking (Bowen, 1928; Doggett, 1929; Vogt, 1926, 1930). The diagram proposed by Bowen (1928, p. 231) is largely hypothetical because it is based on limited experimental data. The diagram given by Doggett is based on a statistical study of fine-grained igneous rocks. Vogt (1930) made a similar study but included coarse-grained rocks. His data failed to support Doggett's diagram. The orthoclase-plagioclase equilibrium diagrams proposed by Vogt (1926, 1930) were based on the sequence of crystallization in coarse-grained plutonic rocks and extrusive rocks many of which contained phenocrysts of more than one mineral. His results are open to question because the order of crystallization in some of the rocks which he considered is not entirely clear.

From a consideration of the sequence of crystallization in fine-grained rocks, the writer has deduced the orthoclase-plagioclase diagram given in Figure 15. To eliminate errors in the interpretation of the order of crystallization as far as possible, the study was limited to those fine-grained rocks which had phenocrysts of only one mineral. The data have been obtained from the compilations of rock analyses by Clarke (1914) and by Wells (1937). For the most part, only extrusive rocks were considered; however, information on the mode of occurrence of some of the fine-grained rocks was not available, so that a number of hypabyssal rocks have probably been included. Although the entire field boundary cannot be located accurately, there is fairly good control in the more controversial portions of the diagram. The deduced boundary nearly coincides with that given by Bowen but is in poor agreement with those presented by Vogt.

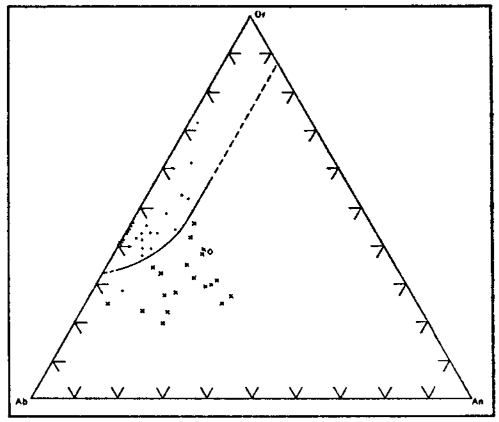

FIGURE 15.—ORTHOCLASE-PLAGIOCLASE EQUILIBRIUM DIAGRAM

Based on the order of crystallization in fine-grained igneous rocks. Dots = rocks in which orthoclase is the only phenocryst; crosses = rocks in which plagioclase is the only phenocryst; open circle = analyzed specimen (LM1) of Kinsman quartz monzonite from the Lovewell Mountain quadrangle.

The composition of Specimen LM1 is believed to be fairly representative of the Kinsman quartz monzonite in the Lovewell Mountain quadrangle. The point corresponding to this specimen (Fig. 15) falls well within the plagioclase field. It is therefore unlikely that potash feldspar would begin to crystallize before plagioclase in a magma of this composition.

Cross (1894), Pirrson (1899), Watson (1901), Pecora (1940), and Nockolds (1946) have cited cases in which the porphyritic growth of potash feldspar apparently occurred after emplacement of the magma but before final crystallization.

From the available data, it is concluded that the large microcline crystals in the Kinsman quartz monzonite are magmatic rather than the result of replacement. Most of the evidence indicates that the large crystals are not of intratelluric origin but formed after the bodies had been partially emplaced. The reason potash feldspar tends to form large crystals in certain magmas is not clear. Most phases of the Bethlehem gneiss and the Concord granite are nonporphyritic; yet the range in composition of these rocks is mainly the same as that of the Kinsman quartz monzonite. The tendency of potash feldspar to form large crystals may be favored by high-water content of magma, although it cannot be proved that the Kinsman was richer in water.

Origin of the Magma

General statement.—As stated in a previous section, several lines of evidence indicate that most portions of the Kinsman quartz monzonite and Bethlehem gneiss are intrusive into the surrounding rocks. Regarding the origin of the magma, the following theories are considered: (1) differentiation of basaltic magma, (2) assimilation of sediments by basaltic magma, (3) "pure melting" of older granitic rocks, and (4) solution of beds at a comparatively shallow depth.

Differentiation of basaltic magma.—As Quinn (1944) pointed out, there is little evidence that the New Hampshire magma series originated by fractional crystallization of basaltic magma. The series is of restricted composition and the siliceous members are far more abundant than the basaltic ones.

Assimilation of sediments by basaltic magma.—Although inclusions of schist are common in the Kinsman quartz monzonite, it is unlikely that assimilation of schist by basaltic magma would in itself account for the observed rock types. The composition of the least amount of material which can be added to the average plateau basalt to produce the Kinsman quartz monzonite is given in Table 18, column 3. The amount of material which must be added is three times the original magma. The calculated addition does not even approximate the composition of most of the metasedimentary rocks in New Hampshire. In general the schists are richer in iron and magnesium than is the Kinsman quartz monzonite so that the simple addition of schist to a mafic magma would not produce the Kinsman. If fractional crystallization accompanied or followed assimilation of the metasedimentary rocks, some of the excess iron and magnesium might have been removed leaving a slightly aluminous magma similar to the Kinsman quartz monzonite. However, it is questionable whether sufficient heat would have been available for an appreciable amount of assimilation or whether the special conditions necessary for the postulated sequence of events would have prevailed.

TABLE 18.—COMPOSITION OF THE LEAST AMOUNT OF MATERIAL WHICH CAN BE ADDED TO AVERAGE PLATEAU BASALT TO PRODUCE THE KINSMAN QUARTZ MONZONITE

	1	2	3
SiO_2	48.80	66.60	73.2
Al_2O_3	13.98	15.86	16.8
Fe_2O_3	3.59	0.35	
FeO	9.78	4.48	2.2
MnO	0.17	0.06	—
MgO	6.70	1.50	0.0
CaO	9.38	2.64	0.6
Na_2O	2.59	2.61	2.6
K_2O	0.69	3.58	4.5
H_2O	1.80	0.59	—
TiO_2	2.19	0.95	—
P_2O_5	.33	0.23	—
S	—	0.14	—

1. Average plateau basalt (Daly, 1933, p. 17).
2. Kinsman quartz monzonite, Specimen LM1 from the Lovewell Mountain quadrangle. L. C. Peck, analyst.
3. Composition of the least amount of material which can be added to average plateau basalt to produce the Kinsman quartz monzonite.

"Pure melting" of older granitic rocks.—The fact that few members of the New Hampshire magma series are mafic suggests that the magma may have formed by the remelting of older granitic rocks. Remelting probably occurs at considerable depth so that evidence for or against this process would be difficult to obtain.

Solution of beds at a comparatively shallow depth.—The magma may have formed by processes analogous to those advocated by Billings (1941, p. 931) for the banded gneisses in the Mt. Washington area. Rocks similar in composition to the slates of the low-grade zone were believed to have been altered to gneiss by moving solutions. By selective fusion or solution of the rock, a liquid phase formed which is now represented by the light-colored streaks in the gneiss. "In the areas of most intense alteration, where 4 or 5 per cent of soda, lime, and potash were introduced, the whole rock became a molten mush similar to magma" (Billings, 1941, p. 931).

TABLE 19.—AVERAGE MODES OF BANDED GNEISS AND BETHLEHEM GNEISS

	1	2
Quartz	37	29
Plagioclase	36	45
Microcline	0	13
Biotite	15	11
Muscovite	11	2
Garnet	1	tr

1. Banded gneiss from the Mt. Washington Area (Billings, 1941, p. 880).
2. Bethlehem gneiss from the Lovewell Mountain quadrangle.

The modal composition of the gneisses formed by these processes is not greatly different from that of the Bethlehem gneiss in the Lovewell Mountain quadrangle. The average modes of the banded gneiss from the Mt. Washington area and the Bethlehem gneiss from the Lovewell Mountain quadrangle are given in Table 19. One of the most striking differences in these modes is the lack of potash feldspar in the banded gneiss. However, potash feldspar is also lacking in some phases of the Bethlehem gneiss and in nearly all the Kinsman quartz monzonite which occurs in small bodies in the metasedimentary rocks. Furthermore, a small addition of potash to the banded gneiss would convert the muscovite to potash feldspar and thus produce a rock quite similar to those phases of the New Hampshire magma series which contain microcline. Although the average banded gneiss is poorer in plagioclase than are the plutonic rocks, some of the light-colored banded gneisses contain up to 50 per cent plagioclase (Billings, 1941, p. 928). Thus in a more advanced stage of the transformation, a magma or essentially liquid mass similar in composition to the Bethlehem gneiss or the Kinsman quartz monzonite might be produced.

It may not be mere coincidence that most of the Mt. Clough pluton occurs at the same stratigraphic horizon as the banded gneiss in the Mt. Washington area. The northeast extremity of the Mt. Clough pluton lies less than 10 miles from the area of banded gneiss. Although the Mt. Clough pluton appears to be largely intrusive, the magma may have formed by the solution of beds which occurred at the same stratigraphic horizon as the pluton. Movement of the magma along this horizon would account for the intrusive features and the remarkable concordance of the body. Some of the bodies of Bethlehem gneiss which lie in areas of middle-grade metamorphism, such as the Bellows Falls pluton in the Bellows Falls quadrangle, are believed to be detached portions of the Mt. Clough pluton (Kruger, 1946, p. 190). The magma which formed these bodies probably originated at least several miles to the east. In the Lovewell Mountain quadrangle, most of the evidence also indicates that the Bethlehem gneiss has undergone movement. However, as pointed out in a previous section some features suggest that the gneiss along the upper portion of the pluton may not have moved far from its place of origin.

Conclusions.—Definite conclusions regarding the source of the magma cannot be drawn because the observed features can be explained by several different theories. Derivation of the magma from basalt by fractional crystallization or by assimilation of sediments seems unlikely, but these theories cannot be entirely ruled out. It is quite possible that the magma formed by the solution of pre-existing rocks. This process may have occurred at a relatively shallow depth because some parts of the Littleton formation have been transformed into gneiss which is chemically somewhat similar to the plutonic rocks. The solution or partial solution of certain favorable strata and movement of the mobilized material parallel to the bedding would account for the sill-like form of the bodies and the intrusive relations.

SUMMARY OF GEOLOGIC HISTORY

The earliest recorded event in the Lovewell Mountain quadrangle was the deposition of the Littleton formation during the lower Devonian. The first deposits consisted of well-stratified shales and sandy shales with a few lenses of impure dolomite, sandstone, and quartz conglomerate. These beds were followed by a thick series of massive shales. The total accumulation in the Lovewell Mountain and Bellows Falls quadrangles was probably 25,000 feet.

During the orogeny in the middle or late Devonian, the strata were steeply tilted to the east forming the east limb of a large anticline, the axis of which is in the Bellows Falls quadrangle. It is not known whether the axis of the syncline is in the eastern part of the Lovewell Mountain quadrangle or in the area to the east. The beds in the central part of the area were thrown into a series of large isoclinal folds. Minor folds with wave lengths ranging from a fraction of an inch to several feet also developed. Schistosities of both the bedding and axial plane types formed in the schists in the western part of the area.

Recrystallization accompanied and followed deformation. In the paragneisses of the Dakin Hill member most of the recrystallization apparently took place after deformation because foliation is poorly developed in these rocks. During the peak of metamorphism, orthoclase formed at the expense of muscovite throughout a large part of the area, but the orthoclase was replaced by muscovite and quartz during declining intensity conditions in most of the eastern two-thirds of the quadrangle. Little change in chemical composition took place during the metamorphism except for a small addition of potash to the pseudo-sillimanite schists and an addition of soda and lime to some of the paragneisses.

Near the close of the orogeny, bodies of Bethlehem gneiss and Kinsman quartz monzonite were emplaced. Definite intrusive relationships along most of the contacts indicate that the granitic material which formed these bodies moved as a magma. The granitic material may have originated at a comparatively shallow depth by the solution or partial solution of pre-existing rocks. During the last stages of the metamorphism, sillimanite and garnet formed in the Kinsman quartz monzonite in the eastern two-thirds of the area.

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