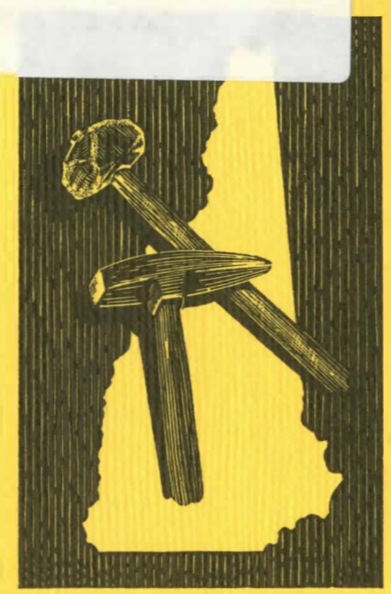

Geology of the GORHAM QUADRANGLE New Hampshire - Maine

By Marland P. Billings and
Katharine Fowler-Billings

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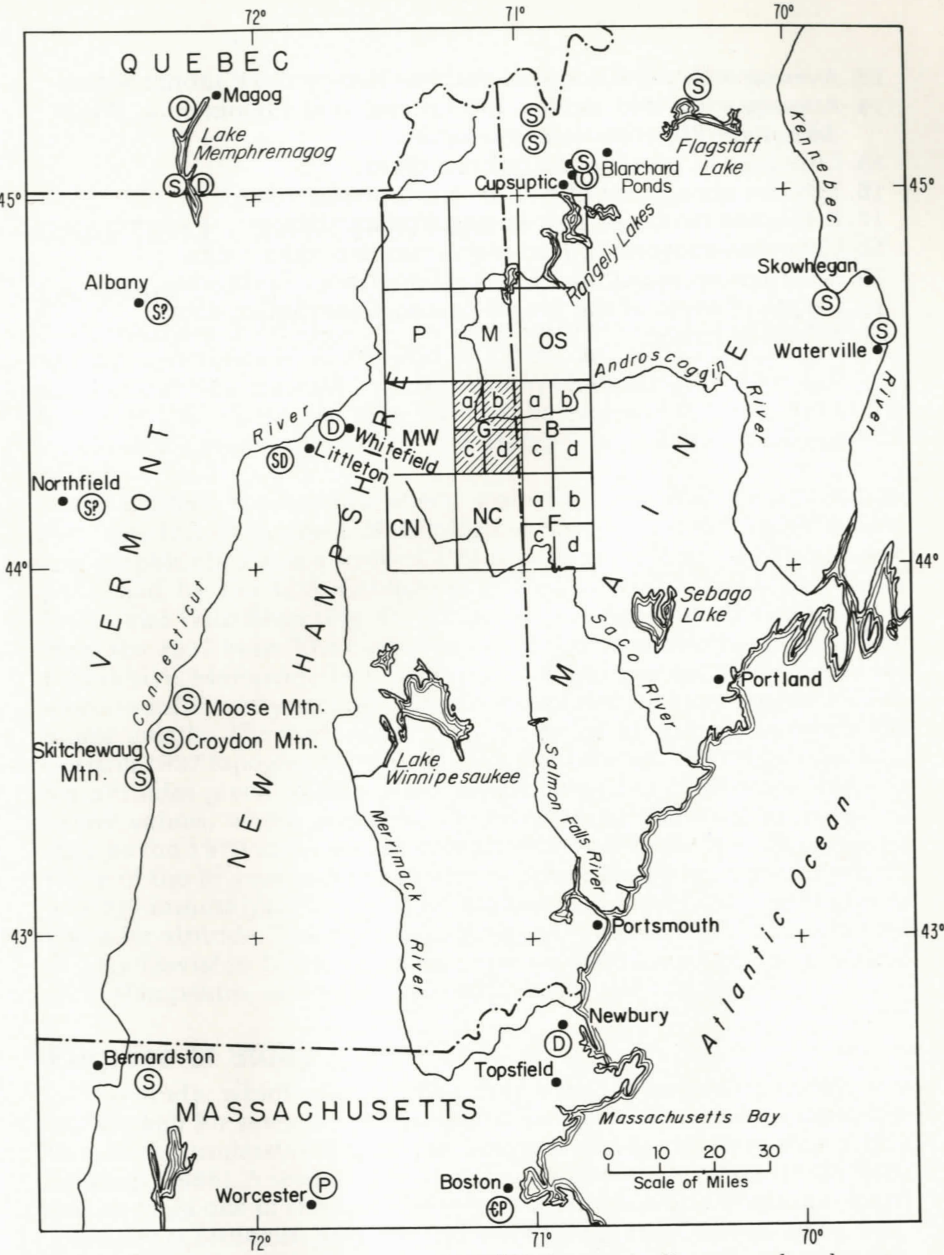

Figure 1. Index Map. Shows location of Gorham and adjacent quadrangles. Names of 15-minute quadrangles, with names of 7½-minute quadrangles in parentheses: P-Percy, M-Milan, OS-Old Speck, MW-Mt. Washington, G-Gorham (a-Berlin, b-Shelburne, c-Carter Dome, d-Wild River), B-Bethel (a-Gilead, b-Bethel, c-Speckled Mtn., d-East Stoneham), CN-Crawford Notch, NC-North Conway, F-Fryeburg (a-Center Lovell, b-North Waterford, c-Fryeburg, d-Pleasant Mountain). Letters enclosed in circles are ages of fossil localities: €Cambrian, O-Ordovician, S-Silurian, D-Devonian, P-Pennsylvanian.

CHAPTER I. INTRODUCTION

Location

The Gorham Quadrangle, bounded by latitudes N.44°15' and N. 44°30' and by longitudes W.71°00' and W.71°15' covers 216 square miles in east-central New Hampshire and western Maine (Fig. 1). The state line trends N.3°W. about one mile west of the eastern border of the quadrangle; 202 square miles are in New Hampshire, 14 square miles are in Maine.

The Gorham topographic sheet, scale 1/62,500, contour interval 20 feet, was issued by the U.S. Geological Survey in 1937. In 1970 new topographic sheets on a scale of 1/24,000, contour interval 20 feet, were published by the U.S. Geological Survey: Berlin, Shelburne, Carter Dome, and Wild River (Fig. 1). The accompanying geological map (Pl. 1) is on the 1937 base. The cost of publishing on the new bases would be prohibitive. Moreover, the topography and drainage as shown on the old map are sufficiently accurate. Even the road system has changed only in minor details. There are minor discrepancies in altitude between the Gorham 1937 topographic map and the 1970 sheets. To avoid confusion, the altitudes given in this paper are those on the 1937 maps, but the newer values, where available, are given in parentheses. In many instances the 1970 maps do not give a precise altitude; in such cases the value of the highest contour shown is given. For those areas for which new 7½-minute quadrangles have not been published, only one figure is given for altitude. The regional setting is shown on the U.S. Geological Survey Lewiston 1/250,000 map, covering 6900 square miles in Maine, New Hampshire, and Vermont, contour interval 100 feet.

Purpose of Study

This study, which is concerned only with the bedrock geology, was undertaken for several reasons. One objective was to make a contribution to the understanding of the bedrock geology of New Hampshire (Billings, 1956). A second objective (Fig. 1), obviously related to the first, was to forge one of the links between the Silurian and Devonian fossil localities at Littleton, New Hampshire (Billings and Cleaves, 1934; Boucot and Arndt, 1960), and the Silurian localities at Waterville, Maine (Osberg, 1968). A third purpose was to continue the investigation of the relations between tectonics, plutonism, and regional metamorphism. A fourth objective was to determine whether the geological structure — and hence the stratigraphy — of such an area could be deduced from the minor structures alone without recourse to the map pattern shown by the lithologic units.

Topography

The Gorham Quadrangle is a maturely dissected mountainous region in the northeastern part of the White Mountains. The highest point is Carter Dome, 4843 (4832) feet, in the southwestern part of the quadrangle; the lowest point, 670 (685) feet, is where the Androscoggin River leaves the quadrangle along its eastern margin. The total relief is thus 4173 (4147) feet. The local relief is 1500 to 3000 feet. The area is heavily forested, and although there are some barren ledges and summits, the entire area is below timber line. Most of the southern half of the quadrangle is in the White Mountain National Forest, but the rest is privately owned, much of it by the Brown Company, owners of pulp and paper mills in Berlin, New Hampshire.

The trend of the topography is northeasterly with the valley of the Androscoggin River cutting across it. There are three principal mountain ranges in the Gorham quadrangle.

The Mahoosuc Range extends southwesterly from the northeast corner of the quadrangle for 12 miles, where it is cut off by the Androscoggin River. The summit of Goose Eye, 3860 feet, lies just north of the northeast corner of the quadrangle. The highest point in the Mahoosuc Range in the quadrangle is Mt. Success, 3590 (3565) feet. Pine Mountain, 2404 (2400+) feet, continues the topographic trend southwesterly to the Presidential Range, the eastern flanks of which lie in the southwest corner of the quadrangle.

The Carter-Moriah Range extends from the southwest corner of the quadrangle in a northeasterly direction for 14 miles to the Androscoggin River. Carter Dome, 4843 (4832) feet, is the highest summit.

A third range, which, for lack of any accepted designation, may be called the Royce Range, trends northeasterly across the southeast corner of the quadrangle. The highest point in this quadrangle is West Royce 3202 (3200+) feet. North Baldface, 3591 feet, lies half a mile south of the quadrangle boundary. This range continues northeasterly into the Bethel quadrangle and southwesterly into the North Conway quadrangle.

Drainage

All but five percent of the quadrangle is in the drainage basin of the Androscoggin River, which enters the north edge of the quadrangle at an altitute of 1100 (1090±) feet, flows southerly through Berlin and Cascade for 8 miles, then turns east at Gorham Upper Village, leaving the quadrangle 10 miles to the east at an altitude of 670 (685) feet. The average gradient is 24 feet per mile.

The principal tributaries entering the Androscoggin from the southwest are Moose River (northwest of Pine Mountain), Peabody River (between Pine Mountain and the Carter-Moriah Range), and Wild River (between the Carter-Moriah and Royce Ranges). Numerous brooks drain the northwest and southeast slopes of the Mahoosuc Range.

Five percent of the area drains southerly to the Saco River. An area of

1.6 square miles on the south flanks of Wildcat Mountain and Carter Dome drains into Wildcat Brook in the North Conway quadrangle. Ten and a half square miles in the southeast corner of the quadrangle, on the southeast flank of the Royce Range, drains into the southerly flowing Cold River, thence to the Saco River.

Accessibility

Much of the area can be reached only on foot. Two first-class paved highways cross the quadrangle. Route 16 extends the entire length of the western part of the quadrangle from Pinkham Notch in the southwest corner through Gorham, Cascade, and Berlin to the north edge of the quadrangle. Route 2 extends east-west across the center of the quadrangle on the south side of the Androscoggin River and crosses Route 16 in Gorham. Because of additional roads, some of which are paved, most parts of the quadrangle are within three miles of roads, but some localities are as much as six miles away. Locally there are temporary lumber roads, but the number and their condition varies from year to year; recent air photographs are the best way to locate them.

The railroads in general follow the same routes as the principal highways. The Canadian National Railroad, a main line between Portland and Montreal, follows the Androscoggin River from the east edge of the quadrangle as far as Berlin, whence it goes northwest along the Dead River. The Boston and Maine Railroad enters the west-central edge of the quadrangle, follows Moose River to Upper Gorham Village, crosses the Androscoggin, and continues on the east side of the river to Berlin, where the line ends. The Berlin Railroad, about 3 miles long on the east side of the Androscoggin River, services the mills of the Brown Company.

The gondola at the Wildcat Ski Area near Pinkham Notch operates much of the year, providing accessibility to the upper slopes of Wildcat Mountain.

The mountains are readily reached by a network of trails maintained by the U.S. Forest Service, the Appalachian Mountain Club, and other organizations. The Appalachian Trail follows the crest of the Carter-Moriah and Mahoosuc Ranges. As the location and condition of the trails change from year to year, the most recent edition of the White Mountain Guide, published by the Appalachian Mountain Club, should be consulted. Many of the trails shown on the 1937 topographic map no longer exist.

There are two overnight shelters in the Mahoosuc Range, one at Gentain Pond and one on the slopes of Mt. Carlo. Imp Shelter is in the Carter-Moriah Range near Imp Mountain, Blue Brook Shelter is in the Royce Range north of Mt. Meader, and Spruce Brook Shelter is on the Wild River. Overnight lodging may be obtained at the Carter Notch Hut and at Pinkham Notch Camp, both operated by the Appalachian Mountain Club or at numerous motels along the highways.

Culture and Industry

The principal city in the area is Berlin, population 15,050 in 1973. Gorham is a village in the township of the same name; the population of the township was 3,058 in 1973; Shelburne is a village in the township of the same name; the population of the township was 208 in 1973; and Cascade is a village, partially in Berlin, partially in Gorham.

Two industries dominate the economy: paper mills and tourism. The Brown Company operates the paper mills at Berlin and Cascade. Not only are people employed in the mills, but some pulp wood is cut in the adjoining forests. Much of the pulp wood is transported by truck from distant forests.

Tourism has been an important industry for many decades. There are four public campgrounds. Three are operated by the U.S. Forest Service: Cold River, Wild River, and Dolly Copp Campgrounds; the fourth is in Moose Brook State Park. Numerous motels and inns are available. Whereas most tourist activity was formerly concentrated in the summer and fall months, in recent decades skiing has become increasingly important. During the winter, Wildcat Ski Area attracts thousands of people, and even in summer many tourists ride the gondolas to Wildcat Ridge to obtain a view of the spectacular glacial cirques on the east slopes of the Presidential Range. What was perhaps the first ski jump in the United States was built a century ago a few miles north of Berlin by Scandinavians who came to work in the paper mills.

Field and Laboratory Work

The field work was started in 1947 and has continued to the present. However, most of the field work was done in the summers of 1951, 1952, and 1953. Field assistants in the summer of 1952 were James Maddock and Constance Schilling. Field assistants in the summer of 1953 were William B.N. Berry and Lawrence DeMott. Since then additional investigations have been made by the authors in this and adjacent quadrangles — especially the Percy, Milan, North Conway, and Crawford Notch Quadrangles.

For a base map the U.S. Geological Survey topographic maps of the Gorham Quadrangle (1937) was enlarged three times to a scale 1/20,833 (1 inch = 1736 feet). Locality numbers as well as representative lithological and structural data were plotted on this map; but generally far more data were obtained than could be recorded on this scale; consequently much additional information was recorded in the field notebooks. All highways, roads, lumber roads, trails, and railroads were searched for outcrops. Cliffs and other obvious exposures were investigated. But the most rewarding traverses were those in the stream beds, where running water has incised valleys 5 to 50 feet deep through glacial till to encounter bed rock. Some streams have long stretches with 50 percent or more outcrop; others may be devoid of outcrops for as much as a mile. Interstream traverses were run in places where they seemed desirable. Pace and compass traverses,

on an average scale of 1" = 200', were used occasionally in the search for outcrops in critical areas. Satisfactory air photographs, which in any case would be of limited value in such heavily forested terrane, were not available at the time of the field work. About 15 nights were spent in the various shelters and six nights were spent at the now defunct Evans Notch Hut of the Appalachian Mountain Club in the southeast corner of the quadrangle.

Office and laboratory work occupied much of the fall, winter, and spring months between 1951 and 1955, and again between 1971 and 1973. Four hundred thin sections were studied under the petrographic microscope. Eleven wet chemical analyses of rocks were made, six at the University of Minnesota, five by Hirashi Haramura of Tokyo Institute of Technology, Japan. Microprobe analyses of some of the minerals were made by graduate students in the Department of Geological Sciences at Harvard University: barkevikite from three camptonite dikes by Peter Lyttle and 28 minerals, representing 12 species, from the Ammonoosuc Volcanics by Richard Sanford.

Adjacent Areas

The study of the geology of the Gorham Quadrangle has been greatly facilitated by work in other pertinent quadrangles in New Hampshire and Maine. Work done prior to 1953 includes: North Conway Quadrangle (Billings, 1928), Percy Quadrangle (Chapman, R.W., 1935, 1942, 1948, 1949), Littleton-Moosilauke area (Billings, 1937), Franconia Quadrangle (Williams and Billings, 1938), Mt. Washington Quadrangle (Billings, 1941; Billings et al., 1946), and Crawford Notch Quadrangle (Henderson, 1949). Work completed since 1953 includes the Whitefield Quadrangle (Arndt, unpublished), Bethel Quadrangle (Fisher, 1962), Old Speck Quadrangle (Milton, 1961), northern part of the Milan Quadrangle (Milton, 1968), and Bryant Pond Quadrangle (Guidotti, 1963, 1965). The excellent Preliminary Geologic Map of Maine, 1/500,000 (Doyle **et al.**, 1967) has been of tremendous aid in relating the geology of the Gorham Quadrangle to that of western and central Maine.

CHAPTER II. LITHOLOGY OF ORDOVICIAN, SILURIAN (?), AND EARLY DEVONIAN ROCKS

Introduction

The lithology of the Gorham Quadrangle is summarized in Figure 2. Three stratigraphic units are present: (1) the Middle Ordovician Ammonoosuc Volcanics; (2) the Early Devonian (and possibly in part Late Silurian) Littleton Formation; and (3) the Quaternary deposits. The Ammonoosuc and Littleton Formations have been regionally metamorphosed, mostly in the sillimanite zone, but partially in the staurolite zone. Three groups of plutonic and hypabyssal rocks are present: (1) the Middle Ordovician Oliverian Plutonic Series; (2) the Middle Devonian New Hampshire Plutonic Series; and (3) the Early Jurassic White Mountain Plutonic-Volcanic Series. Two groups of dike-rocks are present. The biotite granofels are younger than the orogeny, essentially contemporaneous with the regional metamorphism, and older than the New Hampshire Plutonic Series. The younger dikes are part of the White Mountain Plutonic-Volcanic Series. The Oliverian Plutonic Series has been intensely deformed, is characterized by a granoblastic texture, and is generally foliated and locally lineated. The New Hampshire Plutonic Series in this area is characterized by a hypidiomorphic granular texture and is post-tectonic.

Two major unconformities are present. The older is the Taconic unconformity, resulting from a series of tectonic events in Ordovician time. The younger unconformity represents the great interval of time between the Devonian Acadian revolution and the Pleistocene glaciation. The lower units of the Littleton Formation were deposited in a sea transgressing toward the northwest. Because of the great vertical exaggeration Figure 2 is highly diagrammatic.

In the ensuing pages of this chapter the lithology of the Ammonoosuc Volcanics, Oliverian Plutonic Series, and Littleton Formation will be described in chronological order. The structure of these rocks is analyzed in Chapter III.

Ammonoosuc Volcanics

General Statement. The Ammonoosuc Volcanics are confined to the northwest portion of the quadrangle. One long band extends from the center of the west edge of the quadrangle in a general northeasterly direction. It passes through that part of Berlin east of the Androscoggin River and extends to the center of the north edge of the quadrangle. This belt is about 13 miles long. A second belt extends northeasterly from

Sugar Mountain and passes through that portion of Berlin west of the Androscoggin River. This arcuate band is about five miles long. The appearance of some outcrops is shown in Figures 3, 4, 5, and 6, especially where the formation is entangled with rocks of the Oliverian Plutonic Series. The Ammonoosuc Volcanics of the Gorham Quadrangle lie in the staurolite and sillimanite zones of regional metamorphism, but neither of these distinctive minerals is present here in the Ammonoosuc because of its composition. The most abundant minerals are plagioclase, quartz, biotite, and amphiboles. The rocks may be best classified as gneisses, schists, and amphibolites. Some of them may have been flows. Many outcrops are homogeneous and consist of one rock. In others the various rocks are in alternating layers an inch to many feet thick; this is

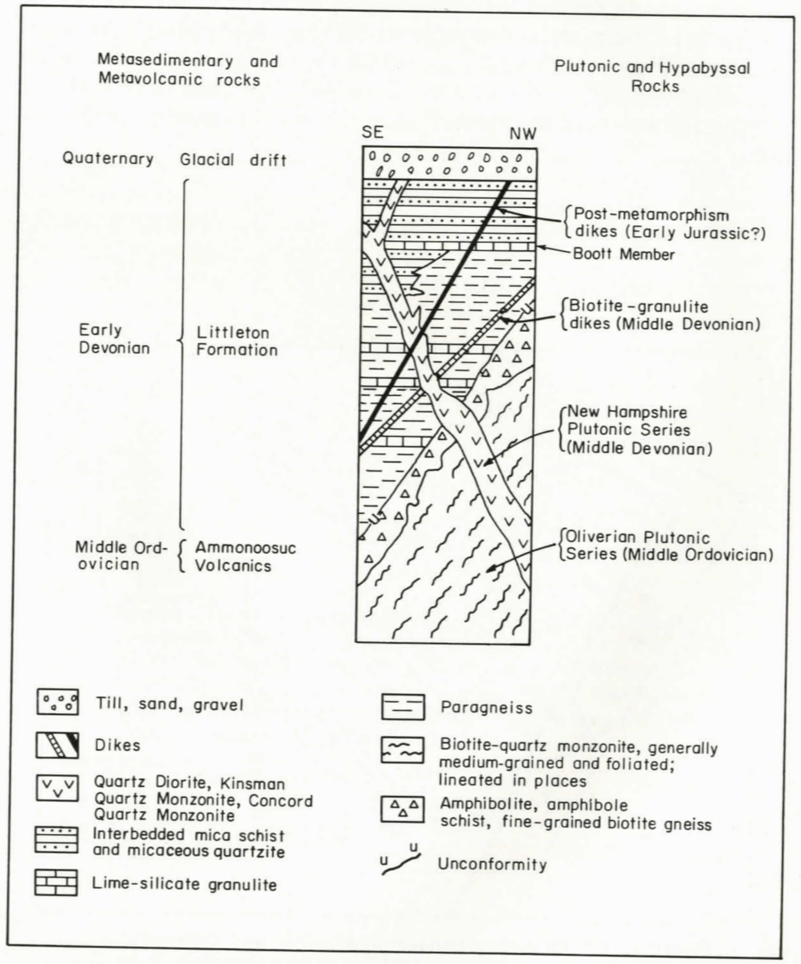

Figure 2. Columnar Section for Gorham Quadrangle.

obviously bedding and the original rocks were volcanic tuffs that may have been reworked by water. The interbedding is especially conspicuous where dark- and light-colored rocks are associated.

Between altitudes of 1170 and 1470 feet on Cascade Brook, a distance of 1200 feet, pyroclastic rocks and volcanic conglomerates are conspicuous. In one variety the matrix is amphibolite, but the clasts are mostly amphibolite with lesser amounts of light-colored biotite gneiss. In another variety both the matrix and clasts are light-colored biotite gneiss. The clasts are ellipsoidal in shape, the long axes ranging from 2 to 6 inches, and plunging gently NE. These pyroclastic beds in Cascade Brook may not be very thick, as the stream is parallel to the strike and there is much repetition due to folding.

Between altitudes of 950 and 1170 feet on Tinker Brook some of the biotite gneisses are definitely pyroclastics. Since the clasts are the same composition as the matrix, the fragmental character here is hard to see.

The Ammonoosuc Volcanics are intensely folded and minor folds are readily observed in many places. This folding makes it difficult to deduce the thickness of the formation, but it is presumed to be thousands of feet.

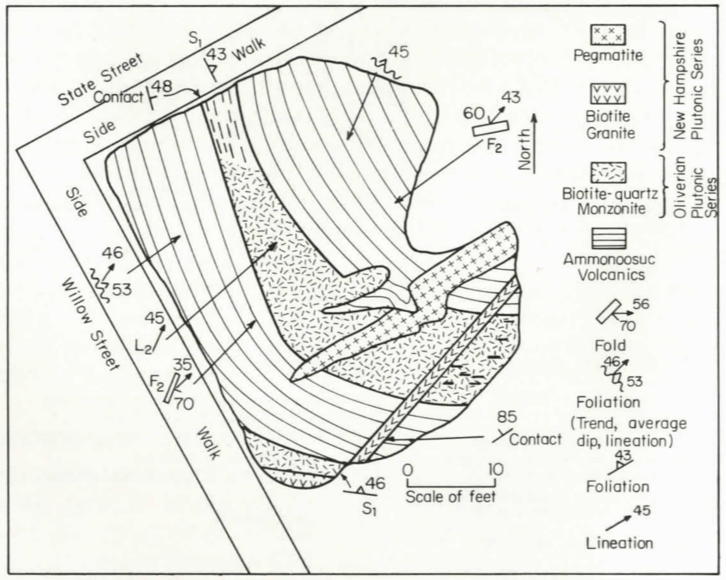

Figure 3. Intermixture of Ammonoosuc Volcanics and Oliverian Plutonic Series. S1 foliation deformed by **F2** folds and **L2** lineation. State and Willow Streets, Berlin.

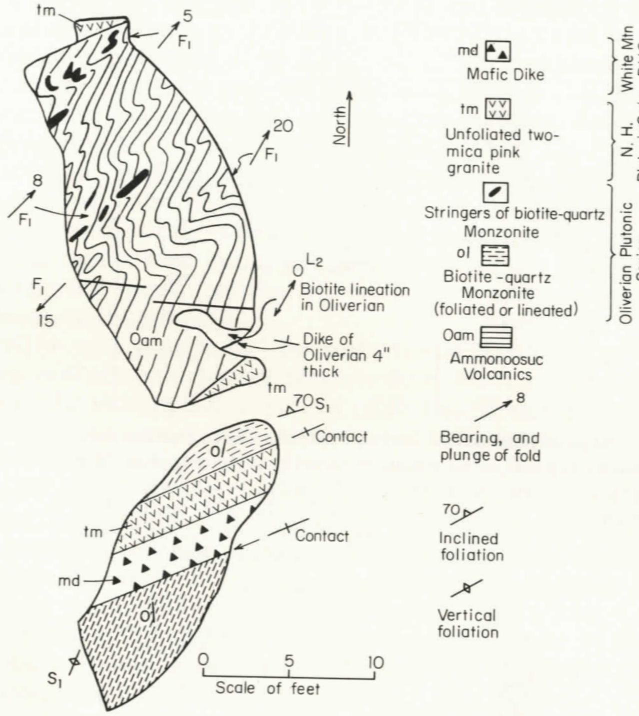

Figure 4. Folded Ammonoosuc Volcanics Cut by Granite and Mafic Dike. F1 folds in Ammonoosuc Volcanics cut by unfoliated two-mica pink granite of New Hampshire Plutonic Series and mafic dike of White Mountain Plutonic-Volcanic Series. West side of Route 16, 3500 feet north of Gorham-Berlin town/city line.

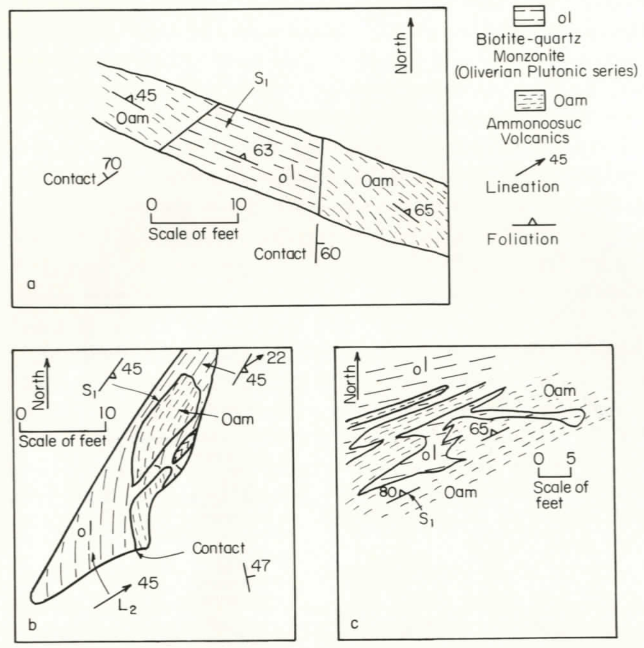

Figure 5. Dikes of Foliated Oliverian Plutonic Series Cutting Ammonoosuc Volcanics. a. S1 foliation cuts the Oliverian and Ammonoosuc. One mile northwest of Mt. Jasper. **b. S1** foliation in Ammonoosuc and Oliverian is deformed by **F2** fold. Berlin Mills R.R. one mile north of Cascade. **c. S1** foliation cuts Ammonoosuc and Oliverian. Berlin, 2000 feet southwest of City Hall.

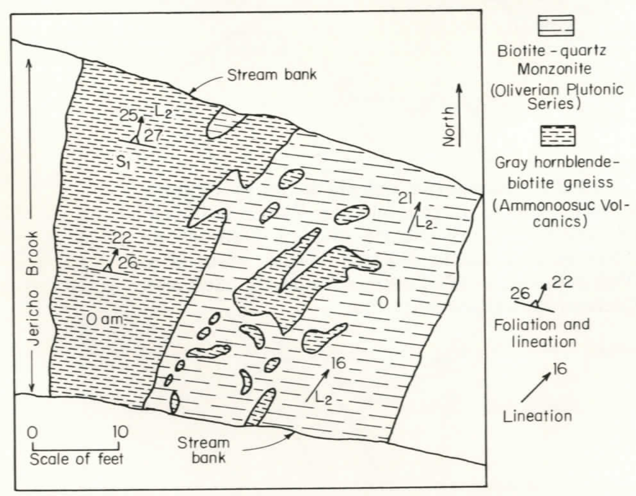

Figure 6. Plutonic Breccia. Xenoliths of Ammonoosuc Volcanics in Oliverian Plutonic Series; **S1** foliation in both units. Jericho Brook, altitude of 1150 feet in Milan Quadrangle.

Mineralogy. Before describing the rocks it is essential to discuss the mineralogy. Initially the minerals were identified by their optical properties in thin sections. Subsequently the minerals in six specimens were studied by the electron probe. The chemical composition of 154 points was determined, from which the compositions of 28 minerals representing 12 different species (Tables 1 and 2) were calculated. The study was made by Mr. Richard Sanford, graduate student at Harvard University, using polished carbon-coated thin sections on an Applied Research Laboratories (EMX) microprobe. Nine element analyses were obtained using the methods of Bence and Albee (1968) and Albee and Ray (1970) for an accelerating potential of 15 KV. Neither the partitioning of the oxides among the minerals nor the structural sites occupied by the elements are discussed here. It is anticipated that Mr. Sanford will analyze these subjects in a forthcoming paper.

The following minerals are abundant (over 10%) in many of the rocks: quartz, plagioclase, biotite, and amphibole (anthophyllite, gedrite, cummingtonite, and hornblende). Minerals that do not exceed 10% or are confined to one or two hand specimens, are garnet, augite, potash feldspar, magnetite, ilmenite, and pyrite. Minor accessories include apatite, sphene, and carbonate.

Anthophyllite and gedrite in thin section show parallel extinction, basal parting, and are colorless or pleochroic in weak shades of yellow and lavender. The variety that is yellow or clove-colored in hand specimens and in which gamma is less than 1.66 is called anthophyllite; the variety that is black in hand specimens and in which gamma exceeds 1.66 is called gedrite. Analyses of anthophyllite are given in Table 1, columns 1 and 2. An analysis of alumina-poor gedrite is given in Table 1, column 3. Cummingtonite is tan in hand specimens; in thin section it is colorless, has inclined extinction, and, in contrast to actinolite, is optically positive. Analyses are given in Table 1, columns 4 and 5. Hornblende is black in hand specimens and is pleochroic in shades of yellow, olive-green, and dark-green in thin section. Analyses are given in Table 1, columns 6, 7, and 8.

The chemical composition of other minerals is given in Table 1, columns 9-14, and in Table 2. These minerals were initially identified by standard petrographic methods. The plagioclase averages An_{33}, ranging from An_{25} to An_{41}.

The Holden mineral collection in the Department of Geological Sciences contains a specimen of cordierite-gedrite gneiss, specimen number 97469, from Cascade Mountain, Gorham, New Hampshire. Although a precise location is not given, the specimen is undoubtedly from the Ammonoosuc Volcanics.

Rocks. Because so many variables are involved — mineralogy, grain size, and texture — a large variety of rocks are present. Twenty-eight thin sections were studied, but in order to keep the descriptions to reasonable lengths, the rocks have been assigned to 13 varieties. Estimated average modes for these 13 varieties are given in Table 3. The reader should realize, of course, that a table such as this tends to overemphasize the unusual types, as these are the ones that the field geologist collects.

The Ammonoosuc Volcanics are exceptionally well displayed in four places: (1) Cascade Alpine Brook, between altitudes of 1000 and 1500 feet; (2) Mt. Carberry in Berlin; (3) Bean Brook, between altitudes of 1300 and 1470 feet; and (4) the brook that rises between Cascade Mountain and Mt. Hayes.

A discussion of the composition of the protolith will follow the description.

The estimated average modes of the 13 varieties are given in Table 3. Columns 1-5 represent modes that are rich in biotite, but some also contain amphiboles. Columns 6-9 and 11-13 are amphibolites. In the rocks represented by columns 6-9, the amphibole is primarily anthophyllite or gedrite. Columns 11-13 are for rocks in which the amphibole is hornblende. Column 10 is a rock that is low in dark minerals.

Fine-grained biotite gneiss (Columns 1 and 2) is very common in the Ammonoosuc Volcanics throughout New Hampshire, and in the Gorham Quadrangle constitutes about 60% of the formation. These are light-gray foliated rocks in which the grains seldom exceed 0.5 mm in diameter. The foliation is largely due to the parallelism of biotite plates, whereas the quartz and plagioclase are essentially equidimensional grains. In most of the specimens, the feldspar is oligoclase (column 1), but in one specimen there is considerable potash feldspar (column 2).

Coarse biotite-gedrite gneiss (column 3) is a spectacular but rare rock that lacks foliation. The gray granular groundmass is composed of biotite flakes and plagioclase grains that are 1 to 2 mm in diameter. The black gedrite needles range in length from 10 to 30 mm, and from 0.2 to 3 mm in thickness. Many are diversely oriented, but some radiate from a common point. This distinctive rock was found in two localities: (1) in the southeast corner of that part of Cascade west of Route 16 and the Canadian National Railroad and (2) along the Boston and Maine Railroad, 0.4 miles north of the Gorham-Berlin town line. If these are in the same bed, the strike is N 47°E over a distance of half a mile.

Biotite-cummingtonite schist (column 4) is a gray poorly foliated porphyroblastic rock. Conspicuous thin disc-shaped aggregates of biotite, 10 mm in diameter, are composed of a large number of small parallel biotite flakes 0.5 mm across. Colorless needles of cummingtonite, that are 2 mm long and show a slight linear tendency, can be readily observed with a hand lens.

Biotite-hornblende schist (column 5) is a dark-gray schistose rock in which the grains average 0.2 to 0.5 mm in diameter. The hornblende needles range from 0.5 to 2.0 mm in length. The parallelism of the long axes of the biotite flakes and of the hornblende needles produces a lineation.

Anthophyllite gneiss (column 6) is a gray rock characterized by compositional layers 0.1 to 0.5 mm thick. Foliation is parallel to this compositional layering. The grains of plagioclase and quartz range in diameter from 0.1 to 0.3 mm. The tan anthophyllite needles, from 5 to 10 mm long, lie in planes parallel to the compositional layering. Some of the needles

are parallel to one another, others display a fan-shaped pattern.

Fine-grained light-gray anthophyllite gneisses (column 7) are light-gray lineated rocks, some of which also possess a foliation. Whereas the grains of the matrix (plagioclase) average 0.4 to 1 mm in diameter, the dark-gray anthophyllite needles are 2 to 4 mm long. In thin section the anthophyllite needles are slightly pleochroic X = light yellow, Y = yellow, Z = light bluish-gray.

Anthophyllite amphibolites (column 8) are gray rocks with both a foliation and lineation. The minerals of the groundmass average 0.2 to 0.5 mm in diameter. The anthophyllite needles range in length from 3 to 6 mm. They are a light-clove color.

Anthophyllite-cummingtonite amphibolite (column 9) is a light-gray fine-grained rock lacking both foliation and lineation. The matrix has a grain size of 0.1 to 0.3 mm. The amphiboles are colorless both in hand specimen and thin section. Diversely oriented, they are 1 to 4 mm long.

White fine-grained anthophyllite gneiss (column 10) is a rather rare white foliated rock. The color is due to the paucity of dark minerals and the corresponding abundance of quartz and plagioclase. The minerals of the matrix average 0.2 mm in diameter. The anthophyllite needles are 5 to 20 mm long, are light-tan, and lie in the plane of foliation; some are straight, others are curved.

Hornblende amphibolites (column 11) are black rocks. Some are foliated, some are lineated, and some are granoblastic. The grain size differs greatly in different specimens. In some, the grains do not exceed 0.1 mm, but at the other extreme the hornblende needles average 2 mm and some are 5 mm. The principal minerals are hornblende and plagioclase.

Hornblende-cummingtonite amphibolites (column 12) are black rocks, one of which is massive, a second is foliated, and a third is lineated. The minerals of the matrix average about 0.5 mm in diameter, in some specimens they show a lineation, in others they are diversely oriented in the plane of foliation. One specimen contains porphyroblasts of biotite 1 to 4 mm across.

Coarse hornblende-augite amphibolite (column 13) is black and shows weak compositional layers that average about 1 mm in thickness. The grains range from 0.2 to 1.5 mm in diameter. The distinctive feature of this rock is the presence of augite in addition to the hornblende. Two samples of this rock were collected on Cascade Brook, one at an altitude of 1120 feet, the other at 1170 feet. If these are from the same bed, the strike is N 50°E over a distance of 300 feet.

The cordierite-gedrite gneiss in the Holden collection is a coarse rock consisting of blue cordierite up to 10 mm across, black gedrite stubs up to 10 mm long, granular white plagioclase 1 to 2 mm across, and flakes of graphite 0.5 mm across.

Protolith. As pointed out in the general statement, most of the rocks in the Ammonoosuc Volcanics are believed to be pyroclastic rocks rather than flows. Undoubtedly there was a great deal of reworking by running water. The fine-grained biotite gneisses (column 1) were initially tuffs and breccias with the composition of soda rhyolites or dacites. The fine-grained biotite gneiss with orthoclase was a quartz latite tuff. The biotite-hornblende schist (column 5) was probably andesite. The hornblende amphibolite (column 11) and hornblende-augite amphibolite (column 13) were basalts, either flows or pyroclastics.

The rocks containing fair amounts of anthophyllite, gedrite, and cummingtonite pose a special problem. There is insufficient lime for the original mafic mineral to have been clinopyroxene or amphibole. Possibly it was orthopyroxene (hypersthene) and the rocks were hypersthene andesite. It is also possible that it was clinopyroxene but that weathering has removed some of the lime from the rock. The presence of gedrite suggests that this weathering also produced excess alumina. The anthophyllite amphibolite (column 8), the anthophyllite-cummingtonite amphibolite (column 9), and the coarse biotite-gedrite gneiss may be the result of metamorphism of somewhat weathered basalt. Similarly, the biotite-cummingtonite schist (column 4), the anthophyllite gneiss (column 6), and the fine-grained light-gray gedrite gneiss (column 7) may be metamorphosed latite tuffs.

Thickness. The calculation of the thickness of the Ammonoosuc Volcanics must utilize structural data given in Chapter III. The belt that extends from the west-central edge of the quadrangle to the north-central edge is 5000 feet wide; the thickness cannot exceed this value. Since there is much tight and isoclinal folding, the thickness must be considerably less. The F1 minor drag folds (Billings, 1972, p. 90-93) indicate that one third of the strata top to the northwest, two-thirds to the southeast. For every two beds topping to the southeast, one tops to the northwest. Thus the true thickness is one third the apparent thickness, or 1700 feet. Obviously this figure is only an approximation.

Age. Although no fossils have been found in the Ammonoosuc Volcanics in New Hampshire, correlation with fossil localities in Quebec and Maine, show that the formation is Middle Ordovician (Billings, 1956; Harwood and Berry, 1967).

Oliverian Plutonic Series

Introduction. The Oliverian Plutonic Series occupies about 25 square miles in the northwest corner of the Gorham Quadrangle. The main part of the body lies west of the Androscoggin and Dead Rivers, but a long band extends northeasterly through Berlin to and beyond the north-central edge of the quadrangle.

Before describing the rocks constituting the Oliverian Plutonic Series, a few important facts should be emphasized. Further southwest in New England some geologists have difficulty separating the Oliverian from the lighter-colored gneisses of the Ammonoosuc because of the more intense recrystallization of the latter in those areas. But in the Gorham Quadrangle the two are readily separated, because the Ammonoosuc is fine grained and is locally fragmental and bedded. Contacts between the Ammonoosuc and Oliverian are knife-sharp (Figs. 3, 5, 6, 10, 11, 12, 13,

14, and 15). Dikes of Oliverian intrude the Ammonoosuc (Figs. 4, 5), and inclusions of the latter are found in the former (Figs. 6, 10, 11, and 12).

Megascopic description. The many varieties of the Oliverian Plutonic Series in the adjacent Mt. Washington quadrangle have been described elsewhere (Chapman, C.A., et al., 1944). In the Gorham quadrangle ninety percent of the Oliverian is a pink foliated or lineated medium-grained to coarse-grained quartz monzonite composed of quartz, feldspar, some biotite and a little muscovite. The texture is granoblastic, the individual grains ranging from 0.1 to 1 mm in diameter. But these grains are usually in aggregates derived from feldspar and quartz grains that were 2 to 7 mm in diameter. The foliation is due to the parallelism of biotite plates and discoidal or ellipsoidal aggregates of biotite, feldspar, and quartz. Lineation, which is conspicuous in places, may occur where there is no foliation or may be part of the foliation. The lineation is shown by ellipsoidal or spindle-shaped aggregates of biotite, but quartz and feldspar have the same shape.

The foliation in many places is demonstrably traverse to contacts with the Ammonoosuc Volcanics (Figs. 5, 6, 10, 11, 12, 13, and 14). This is of great significance, for it demonstrates that the foliation is secondary, resulting from deformation of the solid granite after its consolidation. Whereas the Oliverian consolidated as a hypidiomorphic granular rock in the Middle Ordovician, it was deformed into a granoblastic foliated and/or lineated rock in the middle Devonian.

In places the foliation is folded (Figs. 13 and 21).

Ten percent of the biotite-quartz monzonite in this quadrangle is gray and somewhat finer grained than the typical variety. Some is foliated, some is massive. Granoblastic texture is typical, but the original grains were only 1 to 4 mm in diameter.

Pink pegmatites form tabular and irregular bodies in the biotite-quartz monzonites (Fig. 3); some are many feet thick. They are composed of pink microcline and perthite, white oligoclase, quartz, biotite, and some muscovite. Feldspar crystals are an inch to 12 inches across. Many are massive, but some are poorly foliated. Most are partially granulated, especially along contacts; moreover, along such contacts a weak foliation may extend into the pegmatites. They are considered to be a late phase of the Middle Ordovician hypidiomorphic granular granitic rocks that were later subjected to Middle Devonian deformation.

In places the foliated biotite-quartz monzonites of the Oliverian Plutonic Series and the associated Ammonoosuc Volcanics are cut by dikes of pink biotite granite (Fig. 3) or pink two-mica granite (Fig. 4). These dikes are believed to belong to the New Hampshire Plutonic Series, although they are pink rather than the usual white color. Some of the pink pegmatites may also belong to the New Hampshire Series.

Microscopic description. In thin section the pink foliated and/or lineated biotite-quartz monzonite comprising 90% of the Oliverian Plutonic Series in this quadrangle is a granoblastic rock composed mainly of quartz, potash feldspar, oligoclase, and biotite, with muscovite and magnetite as minor accessories.

Microcline is readily recognized by quadrille twinning. Oligoclase is easily identified wherever it shows albite twinning; such grains are characterized by a low extinction angle in the zone perpendicular to (010), a gamma index close to omega of quartz, and indices less than that of Canada Balsam. This oligoclase ranges from An_{15} to An_{20}; some untwined plagioclase, An_{20}, has indices close to those of quartz. Much of the biotite is altered to chlorite.

An average mode of this rock, based on 10 thin sections from the Mt. Washington Quadrangle (Billings and Rabbitt, 1947) is given in Table 4, column 1; a mode calculated from a chemical analysis is given in Table 4, column 2.

The gray biotite-quartz monzonite that constitutes 10% of the Oliverian in this quadrangle is very similar mineralogically and texturally to the pink variety, except for its finer grain size. An average mode, based on 4 thin sections from the Mt. Washington Quadrangle, is given in Table 4, column3; a mode calculated from a chemical analysis is given in Table 4, column 4.

Age. The Oliverian Plutonic Series intrudes the Middle Ordovician Ammonoosuc Volcanics. Naylor (1969) says it is unconformably overlain by the Middle Silurian Clough Formation and that radiometric dating indicates a Middle Ordovician age.

Littleton Formation

Introduction. The Littleton Formation covers the largest area in the Gorham Quadrangle, occupying about 150 square miles. It underlies the three highest mountain groups, the Mahoosuc, Carter-Moriah, and Royce Ranges. Throughout most of the quadrangle this formation lies in the sillimanite zone of the regional metamorphism, but in a small area southwest of Dolly Copp Campground the rocks are in the staurolite zone. The most abundant rocks are paragneiss (migmatite), mica schist, and feldspathic quartzite ("impure quartzite"). Lime-silicate rocks, containing diopside, actinolite, phlogopite, and calcic plagioclase, although constituting only a few percent of the formation, belong to four important marker members.

A major synclinal axis trends northeasterly through the northwest flank of Pine Mountain, the village of Gorham, and the Mahoosuc Range. Because the Littleton Formation is transgressive toward the northwest, paragneisses thousands of feet thick on the southeast limb of the syncline are absent on the northwest limb. These relations are shown diagrammatically in Figure 2. The upper part of the formation is Lower Devonian. The lower part may be of this age, but in any case cannot be older than Middle Silurian. This subject is treated more fully in a later section.

General Lithologic Features. The lithology of the various rocks constituting the Littleton Formation will be described first, and in a later section the distribution of these rocks in stratigraphic units will be discussed. The rocks are metamorphosed sediments, and rocks of volcanic origin are absent. The present lithology is not only a function of the composition of the original sediments, but is also a product of the grade of metamorphism and metamorphic history.

The rocks will be described under three major headings: (1) metamorphosed arenaceous and pelitic rocks (exclusive of the paragneisses); (2) paragneisses (migmatites); and (3) lime-silicate rocks.

In Table 5 the rocks to be described are listed and a rough estimate is given of the percentage of the formation that they comprise. In a later section the rocks will be assigned to stratigraphic units.

Schist, Feldspathic Quartzite, and Conglomerate. Average modes of these rocks are given in Table 6. Modes of rocks from west of the Peabody River are taken from an earlier paper (Billings, 1941).

At the Carlo Col Shelter, in the northeast corner of the quadrangle, and extending for 250 feet S 20°E, a conglomerate striking N 20°W and dipping 50°NE is exposed. It is at least 5 feet thick and probably 20 feet thick. The matrix is 90% quartz, 5% biotite, and 5% muscovite. The pebbles are chiefly quartz and quartzite, but some are granite and biotite-rich mica schist. In some beds the pebbles are exclusively quartz. The pebbles attain a maximum dimension of 5 cm. Blocks at the shelter show that they are spherical and ellipsoidal.

A thin bed of quartz conglomerate extends northward from a point ¼ mile east of Emerald Pool to one mile south of Dolly Copp Campground, a total distance of 3 miles. The best exposures are at an altitude of 1650 feet on the ridge extending up to peak 2587 (2584) southwest of Dolly Copp Campground and at an altitude of 1520 feet on the West Branch of Peabody River. The trace of the band of conglomerate is very irregular due to intricate folding, but it lies about 1000 feet east of the Boott Member of the Littleton Formation. The matrix is chiefly quartz; the pebbles, which reach a maximum diameter of 5 cm, are chiefly quartz and quartzite.

"Pure" quartzite, that is, rocks composed largely of quartz, are rare in the Littelton Formation. In the cliffs one mile northwest of Cold River Campground, in the southeast corner of the quadrangle, inclusions of the Littleton Formation in the Concord Quartz Monzonite consist of interbedded spangled mica schist and quartzite; the beds are 2 to 7 cm thick. A mode of one of these quartzites is given in Column 1, Table 6.

Commonly the feldspathic quartzites are interbedded with spangled mica schists, the beds ranging in thickness from a few millimeters to 10 cm. Locally they are several meters thick. One variety is a light-gray granoblastic rock in which the grains range in diameter from 0.2 to 0.5 mm. The principal minerals are quartz and oligoclase, with a few percent each of biotite and muscovite, and locally a little pyrite. An average mode is given in column 2, Table 6. A second variety is somewhat darker, but would be classified as light-gray to medium-gray; it is speckled because of the biotite. Most of these rocks are massive, but some are schistose. The principal minerals are quartz, oligoclase, and biotite, with smaller amounts of muscovite, garnet, and pyrite. An average mode is given in column 3, Table 6.

The spangled mica schists are gray schistose rocks, in many instances characterized by platy muscovite porphyroblasts that are commonly 2 to 10 mm in diameter, but may be as small as 1 mm or as large as 25 mm. They lie in the plane of schistosity and are slightly poikiloblastic, enclosing minerals of the groundmass. Because these muscovite porphyroblasts sparkle in the sunlight, these rocks were commonly referred to in the field as "spangled mica schists." The groundmass minerals are much finer grained, ranging from 0.5 to 1.0 mm in diameter. The principal minerals, in addition to muscovite, are quartz, oligoclase, and biotite. Minor accessories are garnet, sillimanite, chlorite, and pyrite. An average mode is given in column 4, Table 6.

A very distinctive assemblage, consisting of interbedded feldspathic quartzite and spangled mica schist is found throughout the Littleton Formation, but is especially important on Pine Mountain and in the Mahoosuc Range. Generally the alternating beds are 1 to 3 centimeters thick, but may be as thin as one millimeter or as thick as 30 cm. In the field this assemblage was referred to as "the well-bedded Littleton." Locally graded bedding is well developed. Good examples may be seen on Pine Mountain ¼ mile south of the fire tower where beds dip 80°NW with the top to the northwest. This places them on the southeast limb of a syncline.

The shiny fine-grained mica schists are especially well developed in a band 1½ to 2 miles wide west of the Peabody River; they extend southwest from Dolly Copp Campground to the Mt. Washington Auto Road. Fresh surfaces are gray, but weathered surfaces are brown due to limonitization of pyrite. The essential minerals are muscovite, biotite, and quartz. The schistosity, which parallels the bedding, displays a well defined lineation due to the alignment of the long axes of oval flakes of biotite, or to small crinkles with a wave length of 2 to 3 mm and an amplitude of 0.2 to 0.5 mm. In some specimens muscovite porphyroblasts 2 to 3 mm in diameter lie in the plane of schistosity and resemble the spangled mica schists. A mode is given in column 5, Table 6.

Schists with conspicuous sillimanite are rare in the Gorham Quadrangle, but some sillimanite may be seen with a hand lens or in thin sections.

Some sillimanite schist is found west of the Peabody River in the same area as the shiny fine-grained mica schist described above. In the Mt. Washington report (Billings, 1941, p. 890) these rocks were described as "shiny fine-grained pseudo-andalusite schist." The general appearance is similar to that of the shiny fine-grained mica schist. Schistosity is parallel to bedding. Small ellipsoidal knots are 5 to 10 mm long, 2 to 4 mm wide and 0.5 to 1.0 mm thick. The long and intermediate axes lie in the plane of schistosity. In many localities the long axes of these knots are parallel giving the rock a distinct lineation. Although in places these knots consist exclusively of sillimanite, more commonly they are composed of sericite with lesser amounts of sillimanite and muscovite. These knots were considered to be pseudomorphs after andalusite (Billings, 1941). The grains of the groundmass are 0.1 to 0.3 in diameter. An average mode is given in column 6, Table 6. Specimens of similar rocks have been collected from that branch of the Baldface Circle Trail on the flanks of Eagle Crag, altitude of 2675 feet, and at an altitude of 1520 feet on the branch of Leadmine Brook that crosses the Mahoosuc Trail at 1900 feet.

In a small area west of the Glen House, extending up the Mt. Washington Auto Road to an altitude of 2400 feet, the rocks have been called sillimanite granofels because they lack schistosity. The average grain size is several millimeters. The essential minerals are muscovite (in conspicuous flakes), biotite, and quartz. Sillimanite, in stubby crystals 4 to 8 mm long, is prominent in some specimens and locally displays a distinct lineation. Retrograde processes are indicated by sericitization of the sillimanite and chloritization of the biotite. An average mode is given in column 7, Table 6.

Southwest of Dolly Copp Campground, in an area extending ½ mile east and one mile north, south, and west from summit 2587 (2584), the Littleton Formation contains staurolite schist. Small euhedral to subhedral porphyroblasts of staurolite, 1 to 5 mm long, occur in a light-gray to dark-gray matrix. Cruciform twins on (032) give a rectangular cross and on (232) give a cross at 60 degrees. Rarely the staurolite is surrounded by a thin shell of sericite 0.1 mm thick.

Some specimens contain andalusite or pseudomorphs after andalusite 1 to 10 cm long and 4 to 8 mm wide. Some crystals have a core of gray andalusite surrounded by a shell of pink andalusite, outside of which is a replacement shell composed of muscovite, staurolite and grains of quartz 1 to 3 mm long. In many places the andalusite has been completely replaced by this aggregate. The gray shiny groundmass of these schists is biotite, muscovite, quartz, and a little garnet. A mode is given in column 8, Table 6.

Hard resistant spherical to ellipsoidal bodies from a few inches to 4 feet in maximum dimension are considered metamorphosed concretions. Some show concentric zoning. The principal minerals are quartz, plagioclase, garnet, hornblende, and diopside. A mode of such a concretion from near Trident Pass is given in column 9, Table 6. These bodies are metamorphosed calcareous concretions.

Paragneiss (migmatite). These rocks are gneisses of sedimentary origin (shales or siltstones), hence are called paragneiss. The paragneisses comprise most of the Carter-Moriah and Royce Ranges, and are extensively developed on the southeast and northwest flanks of the Mahoosuc Range. They are gray, coarse-grained rocks, locally relatively homogeneous, but in most places composed of dark portions rich in biotite and light portions composed largely of quartz and feldspar. They may be called "migmatites," using the term in a strictly descriptive sense without any implication of metasomatism. The dark and light portions may be distributed to give a variety of patterns (Fig. 7). In the "layered gneisses" the dark and light portions are in alternating layers 1 to 3 centimeters thick. In the "pod gneisses" small light-colored pods, 2 to 20 cm long, are enmeshed in a dark matrix. In the "wispy gneisses" small patches of dark material are surrounded by the light-colored matrix.

Many of these gneisses are foliated due to platy parallelism of biotite flakes and ellipsoidal grains of quartz and feldspar. Elsewhere foliation is absent because the minerals are diversely oriented; recrystallization outlasted deformation. Lineation is rare.

The grains are one to three millimeters in diameter. The mineralogy is comparatively simple, and only four minerals are abundant: quartz, oligoclase, biotite, and muscovite. Minor constituents are garnet, sillimanite, apatite, pyrite, and carbonate; chlorite is a secondary mineral. Modes are given in Table 7. Columns 1 and 2 are from an earlier paper (Billings, 1941); they are based on thin sections. Column 3 is an average mode, assuming that the dark portion (column 1) constitutes 80% of the rock and that the light portion (column 2) constitutes 20% of the rock. Columns 4 to 8 are modes calculated from the chemical analysis in Table 8. These modes are in weight percent. But the correction of one set to the other would entail values less than the probable error in the modes.

In places the paragneisses are "rusty," that is stained by limonite due to the weathering of pyrrhotite. The pyrrhotite may be as much as 5 weight percent of the rock, and even higher. A chemical analysis from the adjacent Bethel Quadrangle shows 3.36 weight percent of sulfur (Fisher, 1962, p. 1399). Contacts between the "rusty" gneisses and the gray gneisses are gradational in many instances, and the two varieties intermingle in a complex way. No effort was made to separate the two in the geological mapping of the Gorham Quadrangle, but in the Bethel Quadrangle Fisher distinguished the two.

The chemical analyses in columns 1 to 5 in Table 8 were prepared to help determine the protolith of the paragneisses and the extent of metasomatism during metamorphism. Columns 6 to 12 are analyses of slates and shales from the low-grade chlorite zone in the Littleton-Moosilauke area (Shaw, 1954 a and b). The problem of preparing satisfactory chemical analyses of the heterogeneous paragneisses has already been discussed by Fisher (1962) and Heald (1950). For each analysis of the paragneisses in Table 8 a block with a volume of about half a cubic foot (20,000± cubic centimeters) was collected. Each block was thus approximately equivalent to a cube 9.5 inches (24 centimeters) on each edge; weight about 84 pounds (38.2 kilograms). The rock was crushed in successive stages to progressively smaller sizes. After each crushing one quarter of the material was crushed again to a smaller size. The last powder, about 1/5 of an ounce (30 grams) was used for the chemical analysis. The similarity of the five analyses indicates that the paragneiss, despite its heterogeneity, is relatively homogeneous if the sample is sufficiently large.

Column 1 of Table 9 is the average of the five paragneisses in Table 8. Similarly column 2 of Table 9 is the average of the seven slates and shales from the Littleton Formation in the low-grade (chlorite) zone. It is apparent that the paragneisses were derived from rocks similar to the slates. The change in water content and state of oxidation of the iron is not unexpected. The only possible significant changes are a decrease in

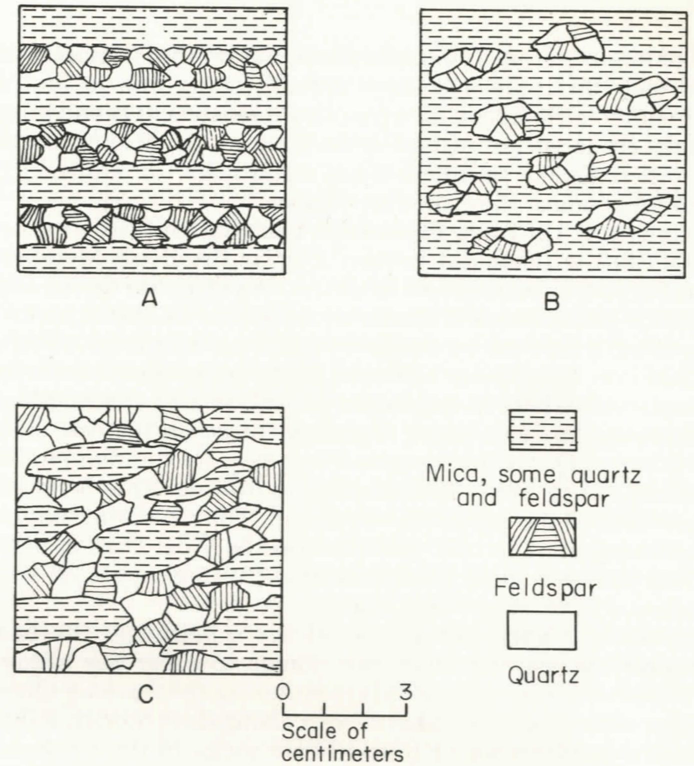

Figure 7. Paragneiss of Littleton Formation. Diagrammatic representation of field terminology. A. Layered gneiss. B. Pod gneiss. C. Wispy gneiss.

alumina and an increase in soda in the paragneisses compared to the slates. Fisher (1962) has studied the paragneisses in the Littleton Formation in the adjacent Bethel area of Maine. From measurements of the size of zircon grains and calculating the hydraulic equivalents in light minerals he has concluded that the paragneisses were derived from siltstones. These could have been composed of quartz, oligoclase, potash feldspar, sericite, chlorite, and alumina-rich clay minerals. The segregation of the paragniess into darker and lighter portions was the result of metamorphic differentiation and is discussed further in the section on metamorphism.

Lime-Silicate Rocks. The lime-silicate rocks are very distinctive, offering a welcome relief from the extensive schists, feldspathic quartzites, and paragneisses that constitute most of the Littleton Formation.

The lime-silicate rocks are in five narrow discontinuous bands that trend northeasterly. Since these bands are so important in interpreting the geologic structure they are described here in detail. They range in breadth of outcrop from 100 to 1000 feet, but no unit is more than a few hundred feet thick, the excessive breadth being due to folding. The bands are not readily traced for a number of reasons: (1) good outcrops of these rocks are largely confined to the streams; (2) discontinuities may result from irregular sedimentation, boudinage, or faulting; and (3) plunging folds cause the bands to zig-zag.

One band (unit 8 of Table 11) extends from the southwest corner of the quadrangle to the northeast corner. This is the Boott Member of the Littleton Formation as mapped in the Mt. Washington Quadrangle (Billings, 1956). The most southwesterly exposure in the Gorham Quadrangle is at Emerald Pool on the Peabody River, where the member is 27 feet thick. From here it may be traced by a very irregular route for three miles northward where it abuts against the Concord Quartz Monzonite. The band reappears five miles to the northeast on the east side of the stock of Concord Quartz Monzonite. From here it extends 11 miles to the northeast by a very irregular route due to folding. This band is on the southeast limb of the Mahoosuc syncline. The excellent exposure between altitudes of 1620 and 1635 feet on the West Branch of the Peabody River has been described elsewhere (Billings, 1941, p. 885); here the member is at least 136 feet thick.

In the extreme northeast corner of the quadrangle the band cuts northwesterly across the Mahoosuc Range to enter the Milan Quadrangle. It then turns southwesterly, reentering the Gorham Quadrangle one quarter mile west of the Maine-New Hampshire border. It is thus the most northwesterly band of lime-silicate rocks in the Gorham Quadrangle, but can be followed for only two miles to the southwest. This band is also unit 8 (Boott Member) of Table 11, but is on the northwest limb of the Mahoosuc syncline. It is absent for 17 miles southwest of the exposure northwest of Mt. Success, but reappears in the Ravine of the Castles in the Mt. Washington Quadrangle (Billings, 1941). From here it trends southerly around the nose of the Mahoosuc syncline to join the Boott Member on the southeast limb.

A third band (unit 6 of Table 11) lies on the southeast flank of the Carter-Moriah Range. The most southwesterly exposures are on Moriah Brook between altitudes of 1700 and 1800 feet. It extends northeasterly for 3¼ miles to a quarter of a mile south of Howe Peak. It is also exposed on the hanging wall of a fault at an altitude of 1300 feet on the west branch of Connor Brook and 200 feet east of the east edge of the quadrangle ½ mile north of the Androscoggin River. It may extend southwest from Moriah Brook, but exposures are poor.

A fourth band (unit 4 of Table 11) lies about ¾ mile northwest of Wild River. The unit is exposed in Moriah Brook, Bull Brook, Martins Brook, and the unnamed brook northeast of it, for a total length of 4½ miles. In this unnamed brook the unit is repeated three times by folding. Due to a lack of outcrops it can not be traced further northeast, but is shown as extending to the east edge of the quadrangle, although Fisher (1962) found no lime-silicate beds in the adjacent parts of the Bethel quadrangle. Southwest of Moriah Brook lime-silicate rocks have not been

found in the quadrangle. But exposures here are very poor. The presumed location of the unit is shown nevertheless. The band is shown with more certainty at the south edge of the quadrangle because of exposures in the North Conway quadrangle, where it can be followed southwesterly for 7 miles, crossing the Ellis River at an altitude of 1090 feet. It probably continues southwesterly to the south flanks of Mt. Parker in the Crawford Notch Quadrangle.

A fifth band (unit 2 of Table 11) lies in the south-central part of the Gorham Quadrangle. It is well exposed on Baldface Brook at an altitude of 1900 feet and at 2050 feet in the unnamed brook to the southwest. From Baldface Brook the band continues northeasterly for six miles to the state line. To the southwest this band is cut out by the Kinsman Quartz Monzonite just south of the quadrangle boundary.

In addition to these five major bands, the lime-silicate rocks appear in five other ways:

(1) Anticlinal uplifts of the Boott Member (unit 8) in the Mahoosuc Range: (a) on Peabody Brook; (b) south of Gentian Pond; and (c) in a brook 3000 feet N 70°W of Carlo Shelter.

(2) A syncline of the Boott Member (unit 8) in the Mahoosuc Range 3000 feet N 70°W of boundary post 77 on the state line.

(3) Thin isolated beds that cannot be traced beyond the limits of one outcrop: (a) Mt. Shelburne Moriah 250 feet west of the summit (diopside granulite); (b) in a stream one-half mile northwest of the summit of Carter Dome; and (c) one mile west of Cold River Campground.

(4) As metamorphosed concretions in the spangled mica schist and paragneisses; these have been described in an earlier section.

(5) As dikes. These are discussed in the chapter on the biotite granofels.

The lime-silicate rocks are characterized by one or more of the following diagnostic minerals: calcic labradorite, diopside, amphibole (actinolite or hornblende), and phlogopitic biotite. These minerals may be associated in various combinations and percentages to form separate beds that range in thickness from a fraction of a millimeter to many meters. The quartz, plagioclase, diopside and even some of the amphibole tend to occur as equidimensional grains less than a millimeter in diameter. These rocks with granular texture are best described as granofels. Diversely oriented biotite flakes are present. Some of the lime-silicate rocks are schistose due to the parallelism of biotite plates and flattened grains of other minerals. Some amphibole occurs as needles several millimeters long; they lie in the plane of schistosity. Additional minerals, present in small amounts, are pyrrhotite and sphene. Microcline is present in a few specimens and in some instances such secondary minerals as chlorite and sericite are abundant.

Quartz occurs as equidimensional grains a millimeter or less in diameter. In thin sections the quartz generally is clear and strain shadows are rare.

Plagioclase forms equidimensional grains a millimeter or less in diameter. The high indices and high extinction angles in zones perpendicular to (010) indicate calcic labradorite or sodic bytownite. In some specimens the plagioclase is sericitized.

Diopside forms equidimensional grains a millimeter or less in diameter. In hand specimens the diopside is white or has a slight green tinge. In thin sections it is colorless and extremely poikiloblastic. In the Mt. Washington Quadrangle (Billings, 1941) it is relatively pure diopside, containing 16 to 22 percent hedenbergite.

Amphibole is black to dark green. In some speciments it occurs as poikiloblastic needles 1 to 5 mm long, but in others it forms equidimensional grains one millimeter in diameter. In some thin sections the amphibole shows a weak pleochroism, X = light yellow, Y = light green, Z = light blue-green. By analogy with the amphibole in the Mt. Washington Quadrangle (Billings, 1941) this is considered to be actinolite, with 80% $CaMg_3Si_4O_{12}$ and 20% $CaFe_3Si_4O_{12}$. But some of the amphibole has a more intense pleochroism: X = tan, Y = olive green, and Z = deep green. This will be called hornblende.

Biotite is pleochroic, X = light yellow, Y = yellow, and Z = light brown. In the Mt. Washingtion Quadrangle (Billings, 1941) such biotite is 72% phlogopite in rocks containing diopside and/or actinolite. In the associated rocks it is 60% phlogopite.

Pyrrhotite forms 5% or more of some of the rocks. In some rocks it is concentrated in discontinuous layers a millimeter or less thick and parallel to the bedding. Weathering to limonite, it produces a rusty outcrop. In the field these were called "rusty quartzite," but this is a misnomer, as minerals other than quartz, notably diopside and amphibole, may be abundant.

Sphene forms typical wedge-shaped crystals a millimeter or less in size.

Quartz and plagioclase are present in large amounts in most of these rocks. The differences are largely due to variations in the amounts of biotite, amphibole, diopside, and sulfide. A secondary factor is the degree of development of foliation. Most of the rocks have a granoblastic texture and granofels is the more appropriate name. But some are schists.

Table 10 gives semi-quantitative modes. Although based on estimates, they give a general idea of the manner in which the various minerals are combined. The modes are based on 46 thin sections, but since some of these sections contain more than one bed, 60 modes were used in obtaining the averages in Table 10. All the rocks are called granofels, but some are more appropriately designated schists.

In Table 10 the rocks are classified on the relative abundance of the mafic minerals. The number of specimens averaged for each of the 13 entries is not necessarily an indication of their relative abundance. As usual, few thin sections are made of the more common types. A rough estimate of the relative abundance of the various rocks is incorporated in the table.

The biotite-rich rocks are black granofels or schists. Those composed of phlogopitic biotite, calcic labradorite and quartz constitute at least a third of the lime-silicate members. An average mode is given in column

1, Table 10. Many of the black biotite-rich rocks contain such minerals as actinolite, hornblende, diopside, and potash feldspar. Average modes are given in columns 2, 3, 4, 5, and 12 of Table 10. Such rocks comprise 25% of the lime-silicate rocks.

The actinolite granofels (column 6, Table 10) are light-greenish-gray rocks in which green actinolite needles are set in a white matrix composed of quartz and plagioclase.

The diopside granofelses (column 8, Table 10) are white granoblastic rocks that can be mistaken for quartzite; the principal minerals are quartz, calcic plagioclase, and diopside, which may be distinguished from the other minerals by its slight green tinge. Other diopside-rich rocks contain one or more of the following minerals: actinolite, hornblende, biotite, and potash feldspar (columns 7, 9, and 10 of Table 8).

The rocks containing potash feldspar have been separately listed in Table 10 (colums 11, 12, and 13). Many of the lime-silicate and associated rocks contain pyrrhotite (Table 10). In some instances this comprises 5% of the rock, which consequently weathers to a dark rusty brown.

Consideration was given to comparing and contrasting the rocks in the various bands. But a statistical study to establish criteria in order to try to distinguish the various bands would not be justified. More thin sections would be necessary and, more important, the exposures are not adequate.

The original sedimentary rocks are believed to have ranged from calcareous shales to arenaceous dolomites, with numerous transitional varieties.

Stratigraphy. The rocks constituting the Littleton Formation have been described in the preceding sections. Their arrangement in stratigraphic units will now be discussed. In Table 11 the Littleton Formation has been divided into nine members — four lime-silicate members alternating with the five metamorphosed arenaceous-pelitic members. The members are given numbers rather than locality names, primarily because many of them probably cannot be identified beyond the limits of the quadrangle. There are a few exceptions. Unit 8 is the Boott Member, so named in the Mt. Washington Quadrangle (Billings, 1956). Moreover, unit 9 can be followed into the Mt. Washington Quadrangle, where it holds up the high peaks of the Presidential Range. It also extends far to the northeast in Maine. Unit 4 can be followed far to the southwest in the North Conway and Crawford Notch Quadrangles.

Units 1, 3, 5, and 7, although largely paragneiss (migmatite), locally contain bodies of micaceous quartzite and spangled mica schist similar to that in unit 9 in the Mahoosuc Range. Such bodies are shown on the geological map (Pl. 1).

Many units in the southeast limb of the Mahoosuc syncline are absent on the northwest limb. Units 9, 8, and 7 are found on the northwest limb. But whereas unit 7 is typical paragneiss northeast of Horne (Mollywocket) Brook, to the southwest it becomes interbedded feldspathic quartzite and spangled mica schist (Pl. 1). This lithology continues for 10 miles to the southwest. In the Mt. Washington Quadrangle unit 7 again becomes paragneiss. Similarly, unit 8 (Boott Member) disappears at Horne Brook, to reappear in the Ravine of the Castles 15 miles to the southwest. Units 6 to 1 are absent from the northwest limb of the syncline. These relations are shown diagrammatically in Figure 2.

Thickness. In Chapter III it is shown that, despite all the minor folding, the average regional dip of the four lime-silicate members is 22°NW. The thicknesses shown in Table 11 are calculated using this value and the breadth of outcrop.

Age and Correlation. Two related questions concern the location of the base of the Littleton Formation in the Gorham Quadrangle and the age of the strata.

The interbedded feldspathic quartzites and spangled mica schists constituting unit 9 of the Littleton Formation in the Gorham Quadrangle, that is, the rocks above the Boott Member, may be correlated with the interbedded sandstones and slates in the upper part of the Littleton Formation at the type locality. Twenty-five hundred feet of strata, mostly slate, consitute the lower part of the formation at the type locality. Unit 7 in the Gorham Quadrangle may be reasonably correlated with these slates. Units 6 to 1 may be stratigraphically lower and chronologically older than any unit in the Littleton Formation at the type locality. New formation names might appropriately be proposed for these units. This seems undesirable at the present time. Hence all the units in Table 11 have been assigned to the Littleton Formation. Fisher (1962) in the adjacent Bethel Quadrangle followed the same policy.

In the type locality the upper part of the formation contains Lower Devonian (Oriskany or Schoharie fossils (Billings and Cleaves, 1934). The lower part overlies the Middle Silurian Fitch Formation. Hence the lower part could be as old as Middle Silurian. Similarly, the paragneisses below the Boott Member in the Gorham Quadrangle may be traced northeasterly across the Bethel Quadrangle into the Bryant Pond Quadrangle where they overlie lime-silicate rocks (Guidotti, 1965) that have been correlated with fossiliferous Middle Silurian rocks of the Waterville region in Maine (Osberg, 1968). Thus the rocks below unit 8 are Early Devonian or Late or Middle Silurian.

CHAPTER III. STRUCTURE OF ORDOVICIAN, SILURIAN (?), AND LOWER DEVONIAN ROCKS

Introduction

Structural geology is concerned with the geometry of folds, foliation, joints, faults, plutons, and dikes, as well as their chronological development and mechanics of their formation.

The Gorham Quadrangle is located within that portion of the Appalachian geosyncline dominated by the Bronson Hill Anticline and the Merrimack Synclinorium. More specifically, the northwest corner of the quadrangle around Berlin lies on the southeast flank of the Jefferson Dome, one of the many domes in the Bronson Hill Anticline. The rest of the quadrangle lies in the northwest part of the Merrimack Synclinorium, the axial trace of which lies in the Gorham Quadrangle, where it is known as the Mahoosuc Syncline. If the limits of the synclinorium are arbitrarily defined as the base of the Siluro-Devonian, the northwest border of the Merrimack Synclinorium is only a mile or two northwest of the axial trace and passes northwest of Gorham and southeast of Berlin. But the southeast border lies near the Maine coast, 70 miles to the southeast. Whereas the Siluro-Devonian rocks on the northwest limb do not exceed 5000 feet in thickness, those on the southeast limb are tens of thousands of feet thick (Fig. 2).

The folding was Middle Devonian. Plutonic and hypabyssal rocks play an important role in the structure of the Gorham Quadrangle. The core of the Jefferson Dome is composed of rocks belonging to the Ordovician Oliverian Plutonic Series. These rocks are so intimately involved in the Acadian folding that their lithology has been described in the previous chapter and their structure will be analyzed in this chapter. The lithologic descriptions and structural analyses of the other map-units (dikes of biotite granofels, New Hampshire Plutonic Series, and White Mountain Volcanic-Plutonic Series) is deferred to later chapters.

Analytical Methods

Structural analysis involves the integration of observations made at thousands of outcrops. The kind of data recorded and the methods of analysis are reasonably well standarized (Billings, 1972) and need not be discussed in any detail. But the emphasis given to the various methods in the study of the Gorham Quadrangle needs elucidation.

One standard method, plotting on a map the attitudes of the bedding at various localities (Billings, 1972, p. 75-77), cannot be used here to deduce the larger structures. The rocks are so crumpled by minor folds that individual strikes and dips cannot be utilized in this way. Locally, individual beds, with a relatively uniform attitude, may be followed for hundreds of thousands of feet. Of course, the final interpretation must be consistent with the attitude of the bedding. One important type of information is the map-pattern (Billings, 1972, p. 77-80). Critical contacts of major value in this area are (1) the Oliverian-Ammonoosuc contact; (2) the Ammonoosuc-Littleton contact; and (3) the contacts of the lime-silicate units in the Littleton Formation. Locally other metasedimentary contacts are helpful.

In places, despite all the minor folding, it is possible to construct the "fold mirror," that is, the plane tangent to the crests of all the minor anticlines (or tangent to the troughs of the minor synclines). Along some brooks and ridges where exposures are very good, it is possible to construct the fold mirror (Fig. 8).

The three-point method (Billings, 1972, p. 502-560) has been of great value in the southern half of the quadrangle. The lime-silicate units are exposed in regions where the relief is hundreds of feet. If, despite all the minor folding, the contacts over large areas can be treated as planar surfaces, a regional strike and dip can be obtained. That is, the attitude of the fold mirror is calculated. The use of this method is elaborated in a later section.

For about 30% of the quadrangle (60 square miles) large-scale maps, 400 feet to the inch, occasionally 200 or 100 feet to the inch, were prepared from the 1/62,500 topographic map. Fifty-four such maps, covering areas as small as ¼ square mile and as large as 4 square miles, were prepared. The main purpose was to permit plotting of the detailed structural data and deduce the details of the folding. Since we were primarily interested in the relative position of outcrops and not their absolute positions, such maps were satisfactory for structural analysis.

A series of stereographic projections of structural data were prepared by computer. Some of these were pi-diagrams of the perpendiculars to such planar features as bedding, foliation, gneissic layering, and dikes (Billings, 1972, p. 190). Others were diagrams of linear features, such as fold hinges and lineation. Initially the quadrangle was divided into 36 areas in order to extract the data from the field notebooks. But in order to keep the number of diagrams to a reasonable figure, the areas were combined into eight districts: Berlin, Dolly Copp, Pinkham, Carter, Moriah, Success, Beans, and Royce (Fig. 9). Separate projections were prepared, where sufficient data were available, for bedding, schistosity, gneissic layering, fold hinges, and lineation. Thirty-nine projections utilizing 6117 field measurements were prepared. But 10 of these projections combined data that were in the other diagrams, and they are not repeated here. Hence only 29 projections are presented in this report.

The pi-diagrams serve two functions. First, they show at a glance the attitude of the planar feature. Secondly, the girdles shown by some of the projections can be used to deduce the bearing and value of the plunge of the larger folds. Other projections show the bearing and value of the

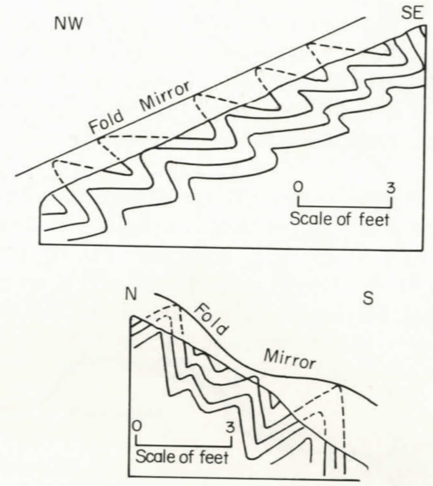

Figure 8. Fold Mirror. Fold mirrors on "cascading" folds of Littleton Formation in Mahoosuc Syncline. **a.** 0.6 mile south of Mt. Surprise on slopes of Peabody River Valley. **b.** Altitude of 1660 feet on south slope of Mt. Hayes.

plunge of the hinges of the minor folds — those a few feet or tens of feet in wave length. These axes may or may not be parallel to the axes of the larger folds. Similarly, the lineation may be an **a** or a **b** lineation, and may or may not be perpendicular or parallel to the hinges of the larger or minor folds.

Beta diagrams (Billings, 1972, p. 107) were not prepared. Pi-diagrams give essentially the same information.

The basic data for these projections were garnered by the senior author in the summer of 1971 from the field notebooks. The study was financed by a grant from the Milton Fund of Harvard University. The work was done on an IBM 5/360 by Mark Davis at the Harvard Computer Center. The program was based on one devised by Jeffrey Warner (1969) modified by Mark Davis for the IBM 5/360. The count is done in the lower hemisphere and the count centers are projected onto the print plane, using a stereographic projection. Inasmuch as the counting is done on equal areas on the surface of the sphere before the projections to the print plane, the latter may be contoured. On this plane, the azimuth directions and plunges are measured as in a stereographic net.

Such diagrams are generally considered a suitable basis for statistical analysis of the field data. But it is not usually recognized that a great deal

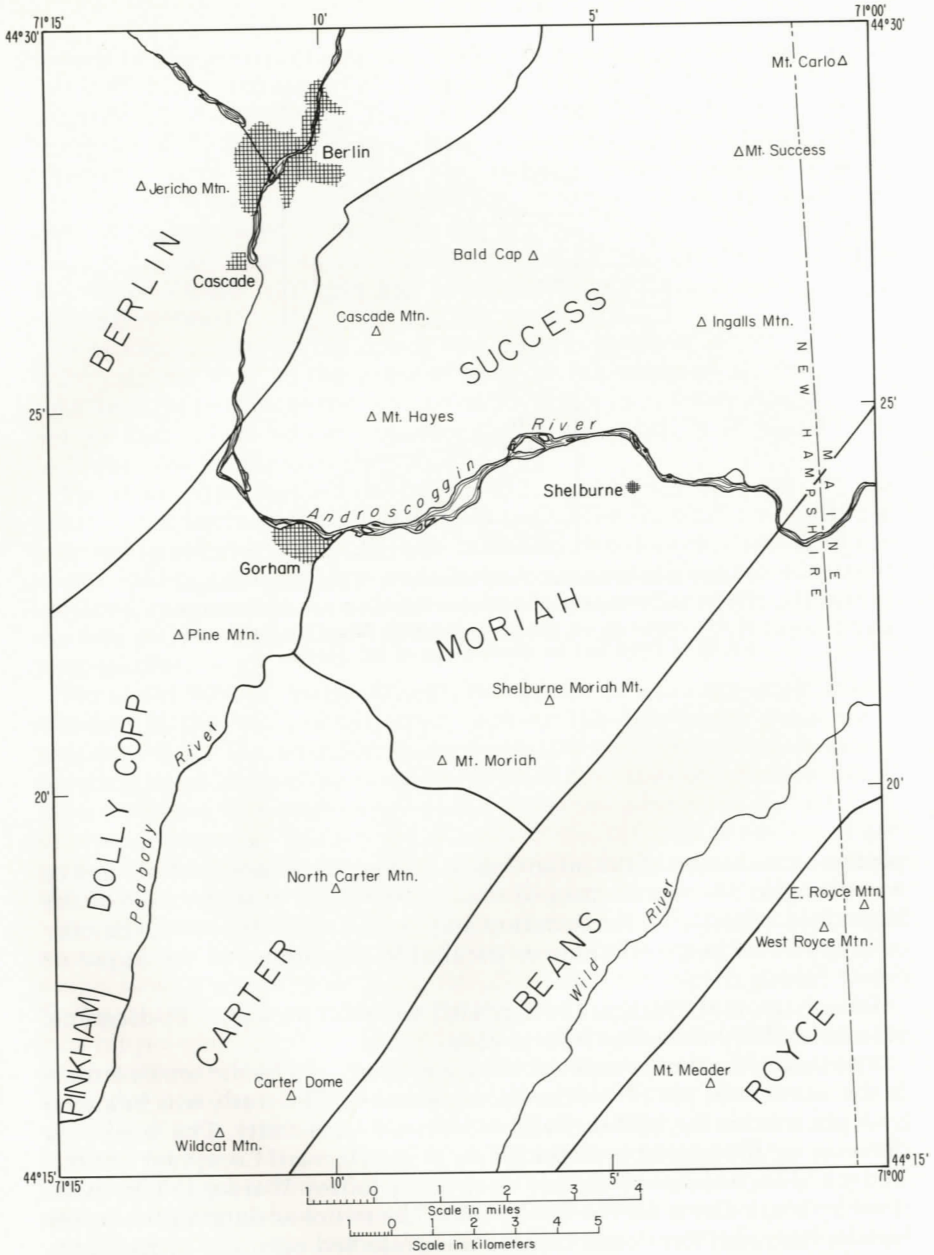

Figure 9. Districts for Stereographic Projections. Districts used in Figures 19, 20, 30, 31, and 34.

of bias may go into the gathering of the field data. This is especially true for joints (Billings, 1972, pp. 149-150) and dikes. There is also a tendency to record higher dips in preference to low dips. Beds with high dips may weather differentially and some beds will project above the general ground level. Another source of bias is the tendency to record unusual attitudes in preference to a long sequence of uniform strikes and dips.

Structural studies by the use of the petrographic microscopic, such as those emphasized in structural petrology, have not been made.

Geophysical maps are available. The relation of the anomalies on an aeromagnetic map of the Berlin area (Bromery, *et al.*, 1957) to the bedrock geology has been discussed elsewhere (Billings, 1972, p. 464-465). Gravity maps (Joyner, 1963; Kane *et al.*, 1972) covering all or large parts of New England are not sufficiently detailed to be utilized in this study.

Structural Stages

The folds, foliation, and lineation may be assigned to four structural stages, D_1 to D_4. All four stages are considered to be part of the Middle Devonian Acadian Revolution. Some minor faults may be contemporaneous with some of these stages, but consideration of the faults is deferred to a later chapter. The silicified zones and post-metamorphism dikes are younger than these stages. Theoretically one would expect to find older stages of deformation associated with the Taconic Revolution. Either there was no such deformation in this area, or all evidence has been obliterated by the Acadian Revolution.

Stage D_1 is represented by northeasterly trending folds that are open, tight, and isoclinal (F_1 folds). It is also marked by foliation (S_1), especially conspicuous in the Oliverian Series, and lineation (L_1). Stage D_2 is shown by folds (F_2) and lineation (L_2) that deforms the S_1 foliation of the Oliverian Series. These folds are coaxial with the F_1 folds. Stage D_3 is represented by northwesterly trending "cross folds." Stage D_4 is represented by "brittle" chevron folds, but no careful study of them was made.

The numerical designations refer to the sequence in which the various structural features were initiated. Evidence is discussed in the chapter on metamorphism that F_1 folds and L_1 lineation continued to form after F_3 folds and L_3 lineation had been initiated.

In the analyses by stereographic projections (Figs. 19, 20, 30, 31, and 34) in general no effort was made to distinguish the various stages before the diagram was prepared; to have done so would have been highly subjective. An exception was a stereographic projection diagram showing the F_2 folds that deform the S_1 foliation in the Oliverian Series (Fig. 19b).

Major Structural Units

Introduction. At the beginning of this chapter it was pointed out that the northwest corner of the quadrangle lies within the Bronson Hill

Anticline, whereas the rest of the quadrangle lies within the Merrimack Synclinorium. More specifically, the northwest corner of the quadrangle lies on the southeast flank of the Jefferson Dome. The southeast boundary of the Jefferson Dome is arbitrarily placed at the base of the Littleton Formation. The Merrimack Synclinorium consists of the Mahoosuc Syncline and the Wild River Homocline. The northwest boundary of the Mahoosuc Syncline is arbitrarily placed at the Littleton-Ammonoosuc contact — some thousands of feet stratigraphically below the Boott Member. The axis of the Mahoosuc Syncline passes through Pine Mountain, Mt. Hayes, Mt. Success, and Mt. Carlo. The southeast boundary of the syncline is arbitrarily placed at the top of lime-silicate unit No. 6, which is about 2 miles southeast of the crest of the Carter-Moriah Range. That boundary corresponds to the southeast boundary of the Carter and Moriah Districts used in the stereographic projections.

Jefferson Dome. As already stated, the southeast margin of the Jefferson Dome is arbitrarily defined as the base of the Littleton Formation. This contact strikes northeasterly and bedding in the adjacent strata indicates that it dips steeply SE 65° to 90°. Several bends in the contact, as well as changes in the direction of dips in the adjacent strata, indicate open drag folds plunging northeasterly.

The dome here consists of two lithologic units — the Ammonoosuc Volcanics and the biotite-quartz monzonites of the Oliverian Plutonic Series (Pl.1). The contact between the two can be located rather accurately, but small xenoliths of Ammonoosuc appear in the Oliverian (Figs. 6, 10, 11, 12, and 13) and small intrusions of the Oliverian cut the Ammonoosuc (Figs. 3, 4, 5, 14, and 15). Two great tongues of the Ammonoosuc Volcanics extend southwesterly, one through Cascade, the other through Berlin. The significance of the trace of the contact is discussed on a later page.

Three stages of deformation are recognized, D_1, D_2, and D_3. D_1, the most prominent, is characterized by the most prominent folds (F_1), foliation in the Ammonoosuc Volcanics and the Oliverian (S_1), and lineation (L_1). D_2 is recognized by folds of the foliation (F_2 and lineation (L_2) in the Oliverian Series. D_3 is not pronounced, but is indicated by northwesterly strikes related to "cross-folding."

The structural features (folds, foliation, and lineation) of the Jefferson Dome shall now be considered in greater detail, utilizing the stereographic projections in Figures 19 and 20a.

Folds are analyzed first. Many long exposures of the Ammonoosuc Volcanics in streams show relatively uniform strikes and dips, suggesting limbs of folds that are not deformed by minor folds. Even in such cases the possibility of tight isoclinal folds can not be eliminated. But in many places the bedding displays intense minor folding (Figs. 4, 16, and 17). In other places the folds are more open (Figs. 3, 13, and 15). Practically all the folds plunge northeasterly.

The stereographic projections in Figures 19 and 20a demonstrate the nature of the structure. Figure 19d is a pi-diagram of perpendiculars to the bedding in the Ammonoosuc Volcanics. The maximum indicates

that the average strike is NNE and that the average dip is 75°SE. The strike-dip symbols in Plate 1 also emphasize this fact. This maximum is due to tight or isoclinal folds, the limbs of which dip SE, one limb being overturned. A typical map pattern of folded beds is shown in Figures 4, 16, 18a. A cross section is shown in Figure 17. Open folds, such as that shown in Figure 15, are not common. Beds on the southeast limbs of synclines that dip northwest but are not overturned explain the minor maximum in the southeast sector. A few closed contours in the southwest sector represent beds striking northwest and dipping gently northeast (Fig. 3). These beds are on the crests or troughs of open folds plunging northeast. The insignificance of these minor maxima emphasizes the fact that such folds are rare. Most of the folds in the Ammonoosuc must be relatively tight; they are F_1 folds.

The pi-diagram for the perpendiculars to the schistosity in the Ammonoosuc Volcanics is shown in Figure 19e. It is very similar to the bedding diagram (Fig. 19d), except that the minor maximum in the southwest sector is more pronounced. The similarity to the bedding diagram agrees with the field observation that the schistosity is parallel to the bedding. The explanation of bedding schistosity is controversial. In isoclinal folding the axial plane schistosity is parallel to the bedding. But even if the folding is not isoclinal, stretching parallel to the limbs means shortening perpendicular to the bedding, hence conditions favorable for the formation of bedding schistosity.

Figure 19f shows that the hinges of the minor folds in the Ammonoosuc Volcanics plunge, on the average, 28°NE.

The foliation of the Oliverian Plutonic Series is due to the platy parallelism of biotite flakes and ellipsoidal grains of feldspar and quartz. It is similar to slaty cleavage, but the minerals involved are much coarser. Figure 19a shows that it strikes northeast and dips, on the average, 60°SE. Its attitude is very similar to that of the bedding and schistosity of the Ammonoosuc Volcanics (Fig. 19d and e). Like the axial planes of the folds, it formed perpendicular to the greatest principal stress axis. Prior to the deformation the rock had a hypidiomorphic granular texture, as in the Highlandcroft Plutonic Series of western New Hampshire. The similarity of Figures 19a, d, and e shows clearly we are dealing with isoclinal folds with axial plane schistosity.

The foliation of the Oliverian Plutonic Series has been deformed into F_2 folds (Fig. 21). On the average these folds plunge 32°NE (Fig. 19b). Some folds in the Ammonoosuc Volcanics belong to this generation (Figs. 3, 5b, and 15).

The lineation in the Ammonoosuc Volcanics is of several kinds. Seventy four percent is mineral lineation, resulting from elongate aggregates of biotite flakes or hornblende grains, or more strikingly, the parallelism of the c-axes of amphiboles or the long dimension of biotite flakes. Seven percent of the readings represent the parallelism of the long axes of ellipsoidal "stretched" pebbles or granules of quartz. About 9 percent of the lineation was called "ribbing" in the field; it is the intersection of a weak fracture cleavage with bedding or schistosity.

These three kinds of lineation are parallel and are also b-lineations.

The orientation of the lineation in the Ammonoosuc Volcanics is shown in Figure 20a. The plunge is northeasterly, as for the fold axes (Figs. 19b and 19f). But there is much more spread, the bearing is more northerly, and the plunges somewhat steeper. A possible explanation is given below after the consideration of the foliation in the Oliverian Plutonic Series.

The lineation in the Oliverian Plutonic Series (Fig. 19c) is made obvious by elongate aggregates of biotite, but quartz and feldspar participate in the same lineation. The lineation bearing N 45°E and plunging 30° is identical with that of the fold axes in the Ammonoosuc Volcanics. It is L_1. The lineation bearing N 20°E and plunging 12° may be related to the cross folding (F_3) to be discussed in a later section. Although the lineation bearing S 80°E, plunging 52°, may be an **a** lineation, it does not appear to differ from the other lineations. The maxima in the Ammonoosuc Volcanics (Fig. 20a) are similar and may be of the same origin.

Just northwest of Berlin the contact of the Oliverian Plutonic Series and the Ammonoosuc Volcanics strikes northwest parallel to the Dead River. Also in the northwest corner of the quadrangle the planar features of Oliverian and Ammonoosuc Formations strike northwest and dip 20° to 50°NE. The northwest strike and gentle northeast dips were initially believed to be located on the nose of the plunging Jefferson Dome. But the dominant lineation in this part of the area plunges 30° in a direction N 15°E (Figs. 19c and 20a). Since it is a **b** lineation, it appears that the northwest strikes are due to an F_3 fold (cross-fold) and that the lineation is L_3.

The body of Oliverian along the quadrangle boundary north of Mt. Jasper may be the core of an F_3 anticline, with a syncline of Ammonoosuc on the northeast side of the Dead River Valley. Future work in the Milan Quadrangle to the north, as yet unmapped in detail, must consider the possibility of F_3 folds complicating the northeast end of the Jefferson Dome.

The contact between the Ammonoosuc Volcanics and the Oliverian Plutonic Series is essentially concordant, although there are injections of Oliverian into the Ammonoosuc and xenoliths of Ammonoosuc in the Oliverian. It appears reasonable to assume that in this area the Oliverian was injected in the Ordovician as a gigantic sill some thousands of feet below the top of the Ammonoosuc Volcanics. Consequently in structural analysis this contact may be treated as if it were a stratigraphic horizon. The body of Oliverian trending northeast through Berlin occupies the core of an anticline overturned toward the northwest. The tongues of Ammonoosuc extending southwest through Cascade and Berlin are synclines overturned toward the northwest.

The synclines and anticlines shown by this contact around Cascade and further south are much more pronounced than folds shown by the Ammonoosuc-Littleton contact. This suggests that the folding of the Oliverian-Ammonoosuc contact is older than the Siluro-Devonian, that

is, Taconic in age. Such deformation would be younger than the intrusion of the Oliverian. There also may be some pre-Oliverian deformation. These deformations, hypothetical at present, could be labelled D_1 and D_2. But the contrast in the traces of the Oliverian-Ammonoosuc and Ammonoosuc-Littleton contacts is probably due to disharmonic folding.

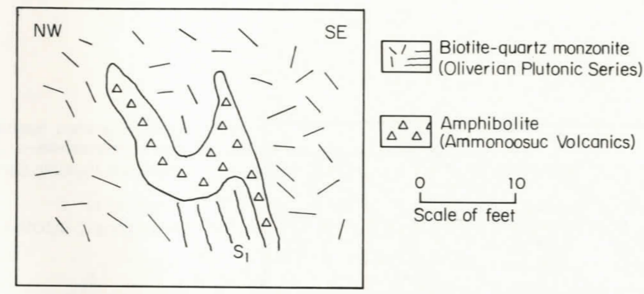

Figure 10. Xenolith of Ammonoosuc Volcanics in Oliverian Plutonic Series. F1 fold and **S1** schistosity, the latter parallel to the axial surface of the fold. Main Street, Berlin, 2300 feet northeast of City Hall.

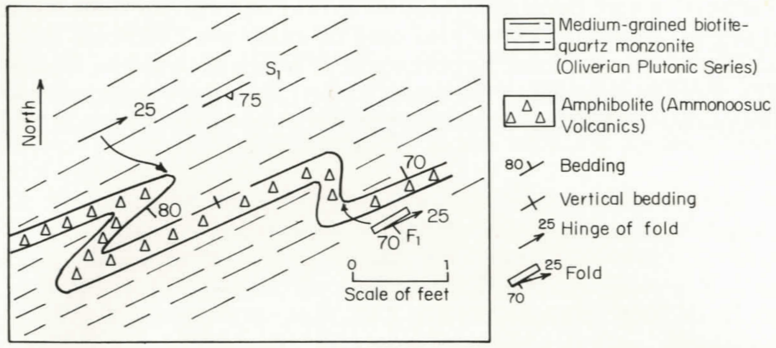

Figure 11. Xenolith of Ammonoosuc Volcanics in Oliverian Plutonic Series. F1 fold and **S1** foliation. Main Street, Berlin, 300 feet south of Catholic Church and Androscoggin Valley Hospital.

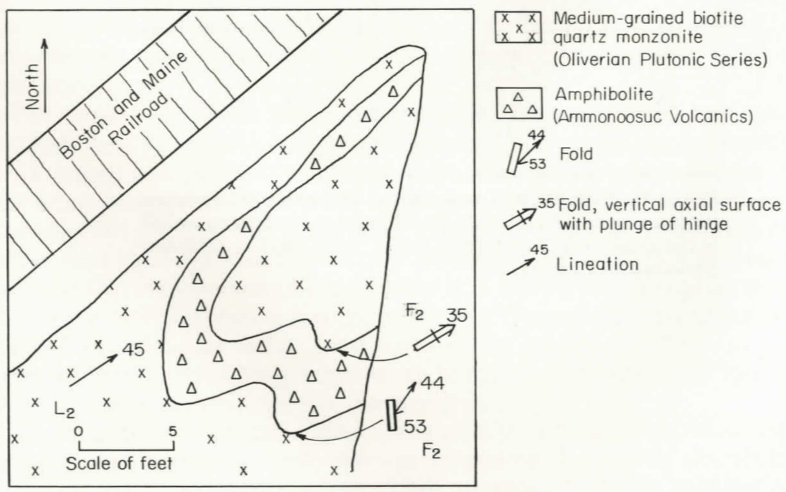

Figure 12. Ammonoosuc Volcanics and Oliverian Plutonic Series. F2 folds and **L2** lineation. Berlin, Boston and Maine R.R., 2400 feet south of City Hall.

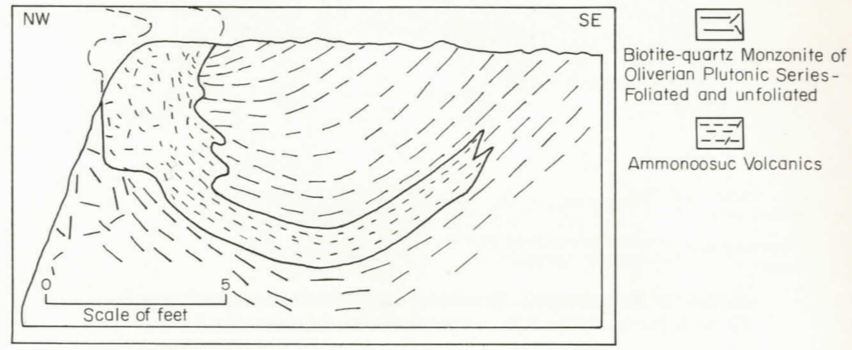

Figure 13. Ammonoosuc Volcanics and Oliverian Plutonic Series. F2 fold deforming **S1** foliation. Tinker Brook, altitude of 980 feet.

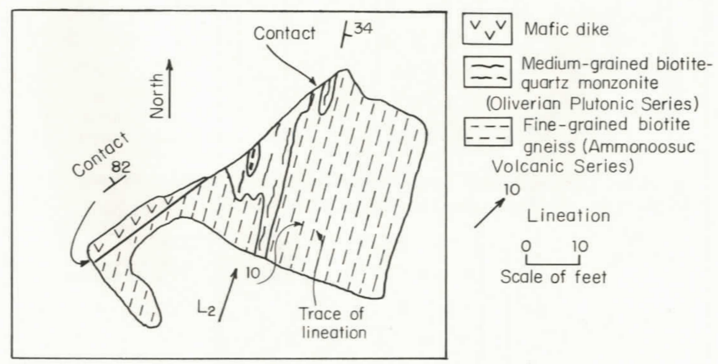

Figure 14. Ammonoosuc Volcanics and Oliverian Plutonic Series. Folded dike of Oliverian in Ammonoosuc. **L2** lineation. Jericho Brook, 200 feet west of bridge on Route 110.

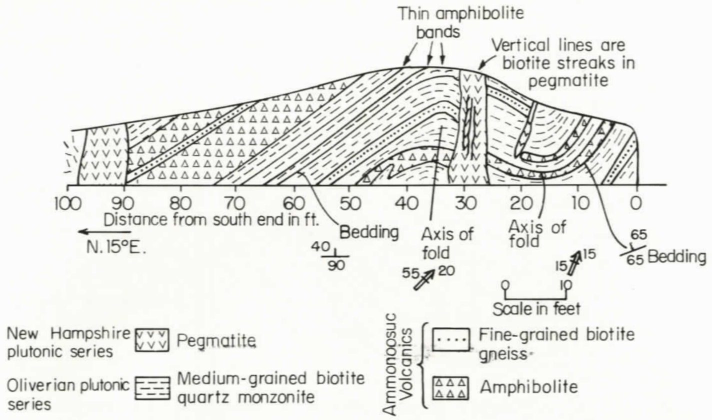

Figure 15. Ammonoosuc Volcanics and Oliverian Plutonic Series. F2 fold. Berlin Mills R.R., 4500 feet north of Cascade.

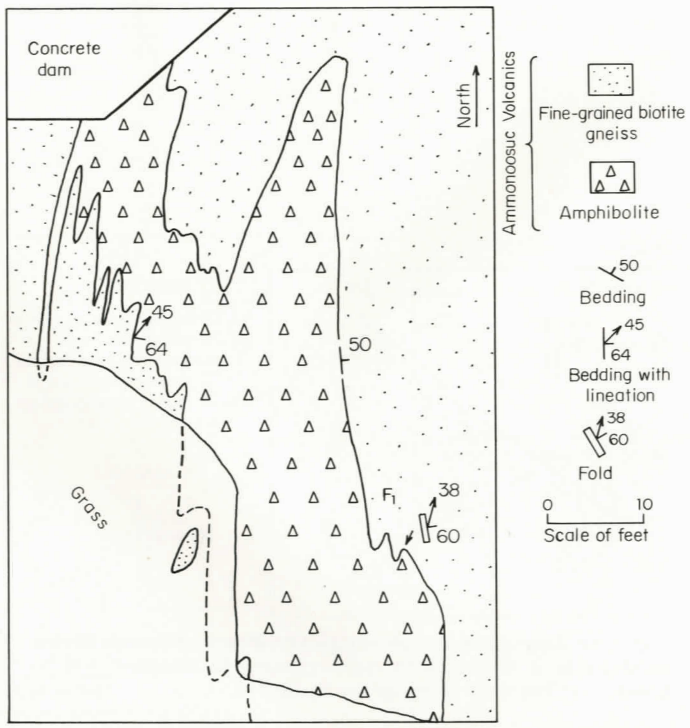

Figure 16. Ammonoosuc Volcanics. F1 fold. West end of dam on Androscoggin River, 3000 feet north of Cascade.

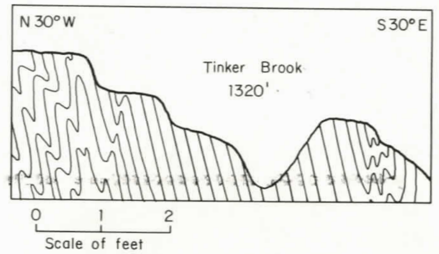

Figure 17. Typical isoclinal folding of Ammonoosuc Volcanics. Tinker Brook, altitude of 1320 feet.

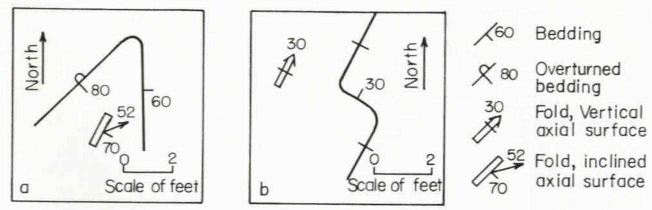

Figure 18. Minor folds in Ammonoosuc Volcanics. F1 folds. **a.** Cascade Brook, altitude of 1390 feet. **b.** Cascade Brook, altitude of 1040 feet.

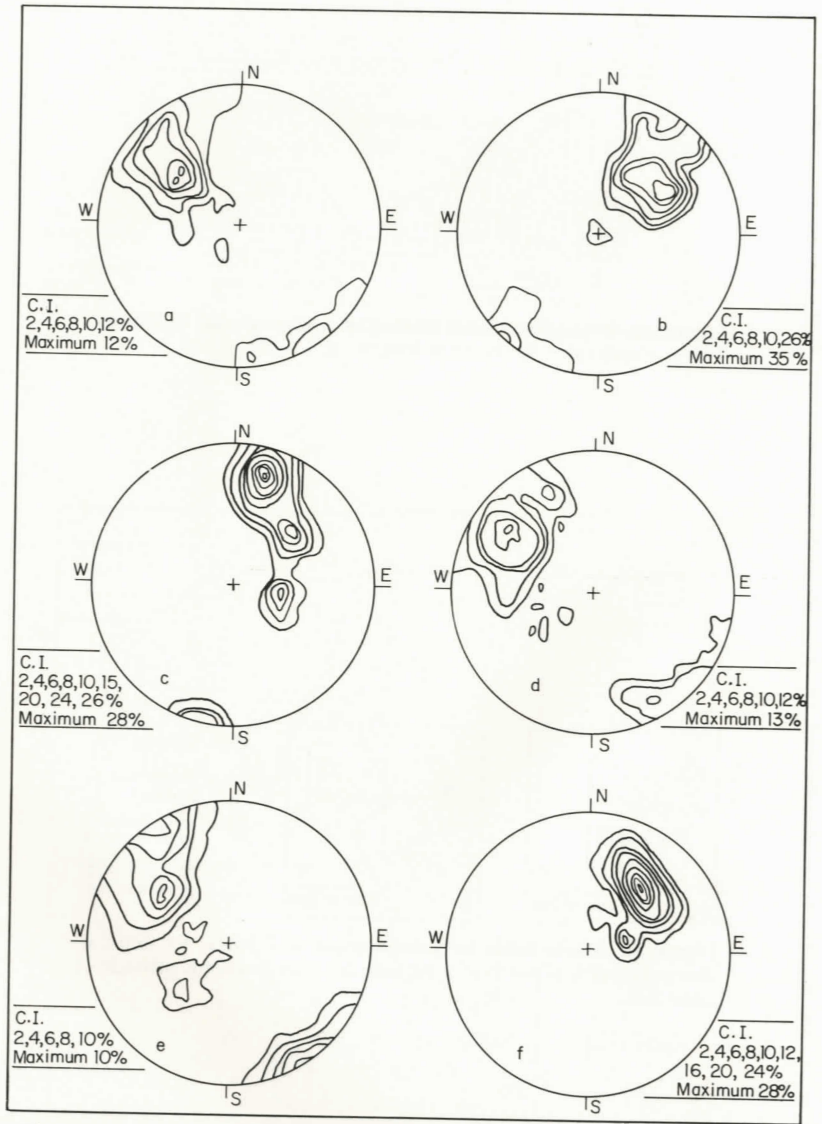

Figure 19. Stereographic Projections, Berlin District. All on lower hemisphere. **a.** Oliverian Plutonic Series, perpendiculars to foliation, 412 readings. **b.** Oliverian Plutonic Series, hinges of **F2** folds of **S1** foliation, 27 readings. **c.** Oliverian Plutonic Series, lineation, 103 readings. **d.** Ammonoosuc Volcanics, perpendiculars to bedding, 122 readings. **e.** Ammonoosuc Volcanics, perpendiculars to schistosity, probably mostly **S_1** 193 readings. **f.** Ammonoosuc Volcanics, hinges of folds, probably **F1**, 51 readings.

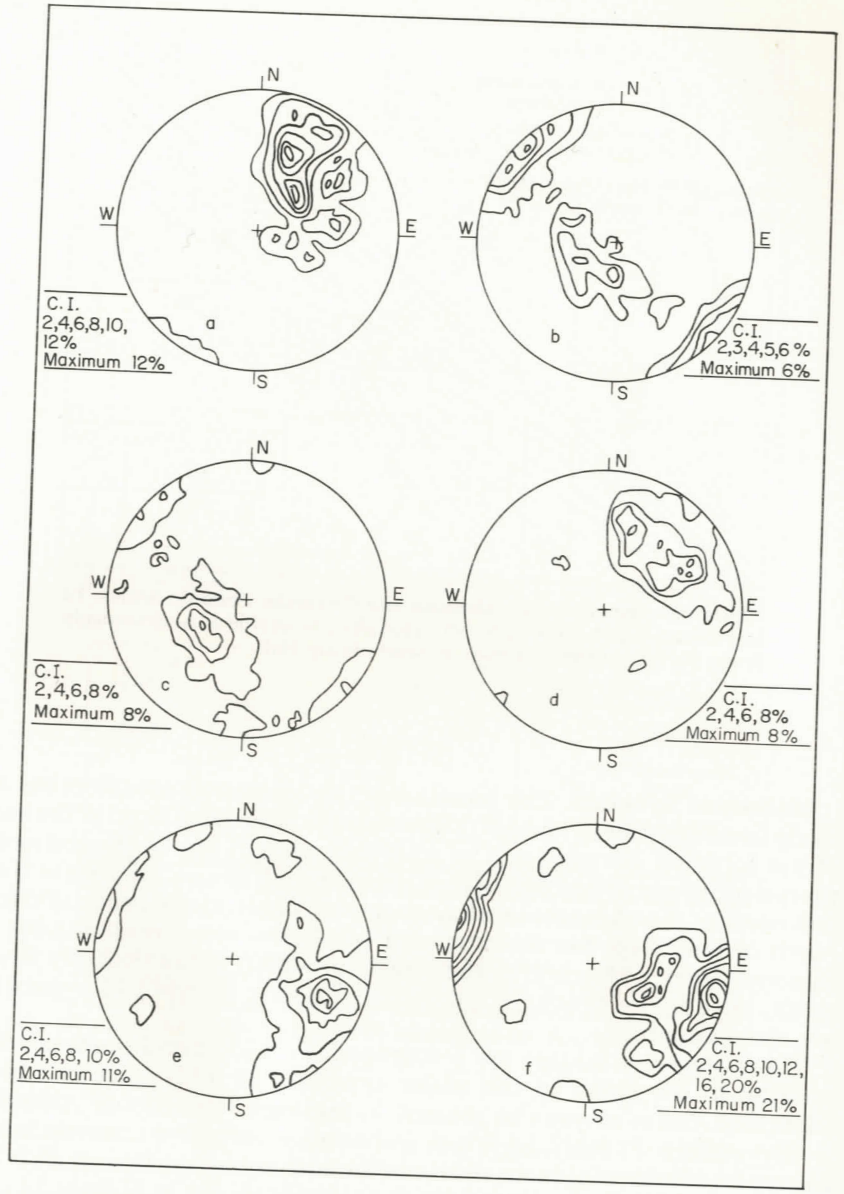

Figure 20. Stereographic Projections, Berlin, Success, and Dolly Copp Districts. All on lower hemisphere. **a.** Berlin District, Ammonoosuc Volcanics, lineation, 89 readings. **b.** Success District, Littleton Formation, perpendiculars to bedding, 966 readings. **c.** Success District, Littleton Formation, perpendiculars to gneissic layering, 382 readings. **d.** Success District, Littleton Formation, fold hinges, 279 readings. **e.** Dolly Copp District, Littleton Formation, perpendiculars to bedding, 289 readings. **f.** Dolly Copp District, Littleton Formation, perpendiculars to gneissic layering and schistosity, 69 readings.

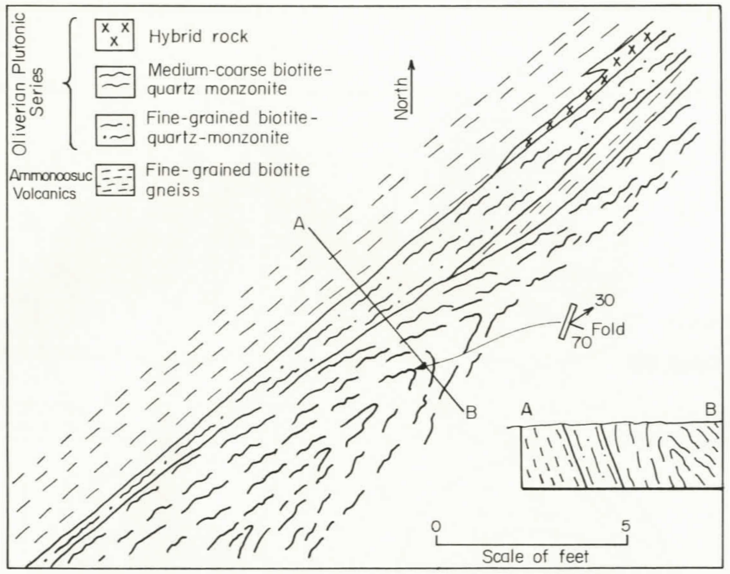

Figure 21. Ammonoosuc Volcanics and Oliverian Plutonic Series. F2 fold deforming **S1** schistosity. Mill race along west side of Androscoggin River, Berlin, 400 feet south-southwest of City Hall.

Mahoosuc Syncline. The location of the Mahoosuc syncline has already been described. The northwest margin has been placed at the base of the Littleton Formation. The southeast margin has been arbitrarily placed southeast of the crest of the Carter-Moriah Range. The axis is 1000 feet north of Pine Mountain, close to the top of Mt. Hayes, and 1000 feet north of Bald Cap, Mt. Success, and Mt. Carlo. Numerous plutons of Concord Quartz Monzonite, the largest of which is the Peabody River stock, intrude the syncline. Intrusions of quartz diorite and pegmatite are also common.

Three stages of folding are recognized. F_1 folds trend northeasterly parallel to the strike of the major syncline. F_2 folds have not been identified, but some may be present. F_3 folds are "cross-folds" trending northwesterly. F_4 folds, of minor importance, are open chevron folds. Examples of minor folds are shown in the accompanying figures. F_1 folds are illustrated by Figures 8, 22, 23. F_3 folds are shown in Figures 24 and 25. F_1 folds modified by F_3 folds are shown in Figure 26. Figure 27 illustrates F_1 folds with axial plane schistosity.

In describing the Mahoosuc Syncline the evidence offered by the map-pattern will be presented first; the significance of the stereographic projections will be considered later. The analysis of the map-pattern is based primarily on the traces of the Littleton-Ammonoosuc contact, of

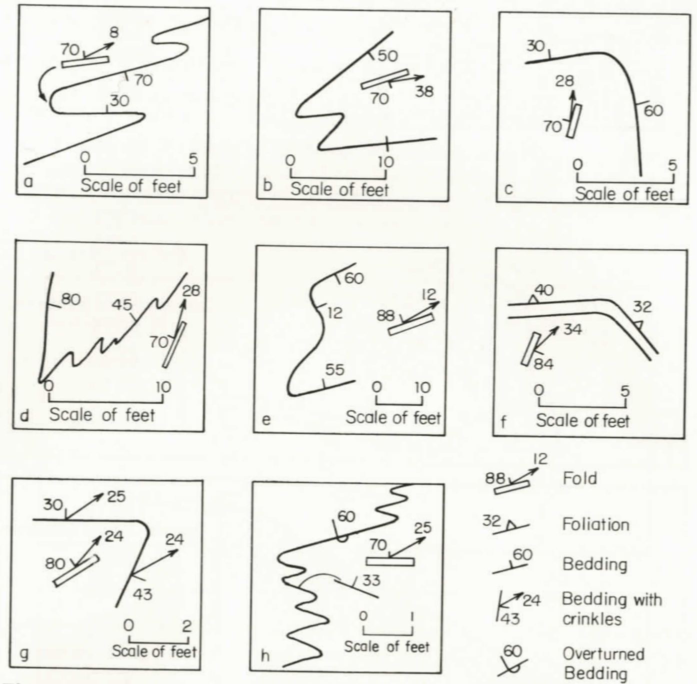

Figure 22. Minor folds in Littleton Formation. F1 folds, possibly some **F2. a.** Larry Brook, altitude of 840 feet. **b.** South Fork of Cascade Brook, altitude of 1800 feet. **c.** Brook north of Mt. Success trail, altitude of 2650 feet. **d.** Brook north of Mt. Success trail, altitude of 2350 feet. **e.** Stream north of Page Pond, altitude of 1805 feet. **f.** North Branch of Horne Brook, altitude of 1830 feet. **g.** Crinkles on limbs of plunging anticline, Pea Brook, altitude of 1340 feet. **h.** Southwest slope of the Outlook, one mile northwest of summit of Mt. Success, altitude of 2810 feet.

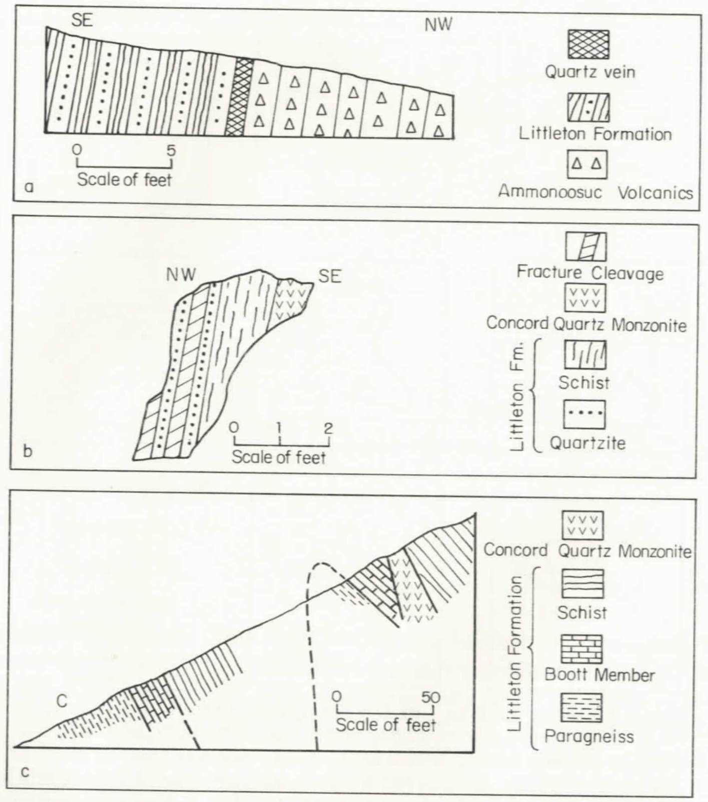

Figure 23. West Limb of Mahoosuc Syncline. a. Contact of Ammonoosuc and Littleton Formations, altitude of 1350 feet on unnamed brook 1½ miles west-southwest of summit of Cascade Mountain. **b.** Littleton Formation, altitude of 1390 feet on west slope of Pine Mtn. **c.** Boott Member at altitude of 2400 feet on Horne (Mollywocket) Brook.

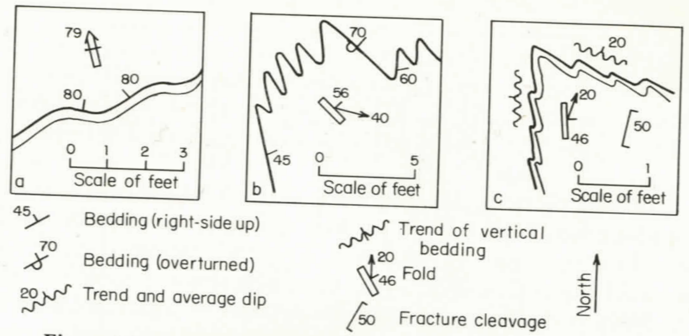

Figure 24. F3 folds in Littleton Formation. a. Altitude of 2430 feet southwest of summit of Mt. Hayes. **b.** Stream north of Mt. Success trail, altitude of 2020 feet. **c.** Altitude of 2055 feet, on North Branch of Horne (Mollywocket) Brook.

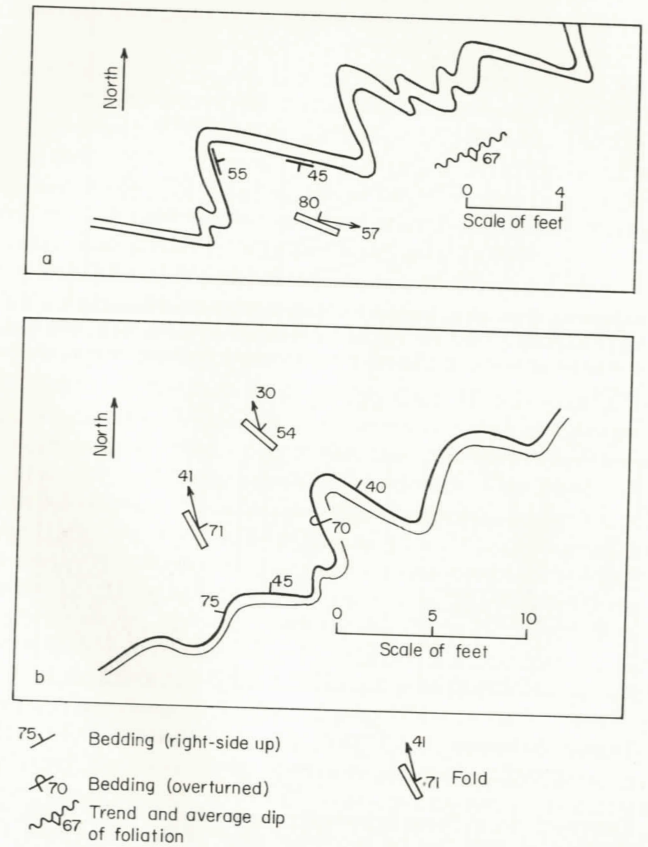

Figure 25. F3 folds in Littleton Formation. a. Brook south of Carlton Notch, altitude of 990 feet. **b.** Leadmine Brook, altitude of 730 feet.

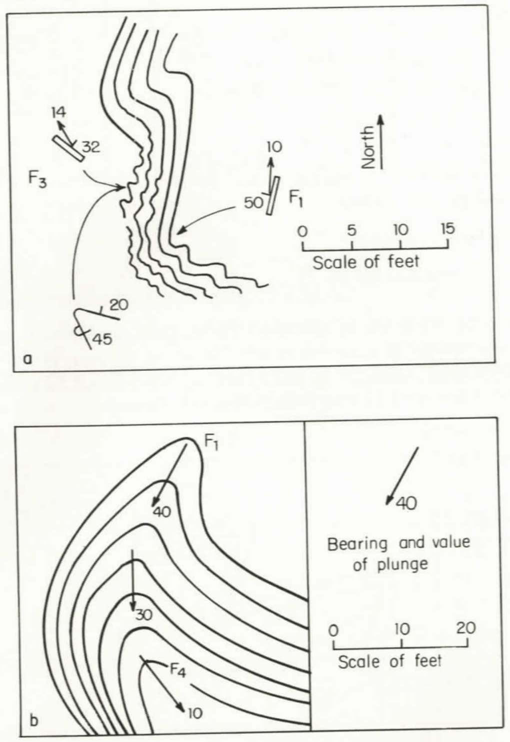

Figure 26. Coexisting F1 and F3 folds in Littleton Formation. a. F3 folds superimposed on **F1** fold deformed into **F3** fold, 500 feet northeast of bridge on North Road crossing Peabody Brook, Shelburne.

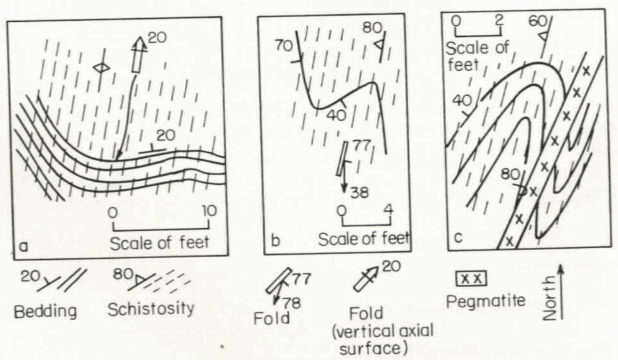

Figure 27. Axial-Plane Schistosity Associated with F1 Folds. a. Altitude of 2670 feet on southeast slope of Bald Cap Peak. **b.** Altitude of 3560 feet on ridge between Bull and Moriah Brooks. **c.** Top of 3420 foot knoll 2000 feet northeast of Imp Mtn.

the Boott Member, and of a few beds that may be traced locally. From this analysis we can deduce the geometry of larger folds, whose wave length is measured in thousands of feet or miles. This, of course, is a different type of evidence than that shown by the minor folds observed in individual outcrops.

Despite all the minor folding, the average attitude of the southeast limb of the Mahoosuc syncline can be determined reasonably well.

The western terminus of the Wildcat Ridge trail is one mile south of Pinkham Notch and is in the Crawford Notch Quadrangle. One thousand feet to the east the trail enters the North Conway Quadrangle (Fig. 1), and 1.3 miles further east enters the Gorham Quadrangle at an altitude of 4000 feet. Along that portion of the trail in the North Conway Quadrangle minor folding is unimportant and exposures are excellent. The rocks belong to unit 7 of the Littleton Formation. The bedding has a fairly uniform attitude, with an average strike of N60°E, and an average dip of 25°NW. Despite the length of the traverse, only 325 feet of strata are crossed.

The Boott Member crosses the northwest ridge of Mt. Moriah at an altitude of 3200 feet. One mile to the south-southwest the Boott Member is exposed in Stony Brook at an altitude of 1500 feet. Two miles to the north of the ridge it is exposed in Pea Brook at an altitude of 800 feet. If, despite all the minor folding the Boott Member here can be treated as a plane surface, the three-point method may be applied (Billings, 1972, pp. 559-560). The strike is N38°E, the dip is 22°NW.

On the northwest ridge of Mt. Moriah, between altitudes of 2500 and 3200 feet, the minor folds are very prominent and well exposed. Reconstruction of the fold mirror indicates a dip of 20° to 30°NW (see also Fig. 8a).

A large F_3 fold is located west of the Glen House (see also Billings, 1941, Pls. 6 and 10). Although exposures are not as complete as one might wish, the trace of the Boott Member as shown on the geological map (Pl. 1) is undoubtedly essentially correct. The Boott Member extends south-southwest from Dolly Copp Campground for $1\frac{3}{4}$ miles as far as the West Branch of the Peabody River. Here it takes a great loop to the southeast toward the Glen House, then swings back toward the west, and $\frac{1}{4}$ mile west of the quadrangle boundary is again on strike with the segment north of the West Branch of the Peabody River (Fig. 28).

The northeast limb of this large F_3 fold strikes northwest, dips 73°SW. The nose, just south of the Glen House, strikes north and dips 45°W. The south limb strikes east-northeast, dips 50°NW.

The effect of this large cross fold on the minor structural features is well displayed on Lowe's Bald Spot, altitude 2890 feet, in the Mt. Washington Quadrangle, 4 miles west-southwest of the Glen House. This is on the south limb of the fold. The bedding here strikes N 70°E, dips 50°NW. The hinges of the numerous minor folds (F_3) and the lineation (L_3), shown by sillimanite crystals $\frac{1}{2}$ inch long, plunge 20°W.

Another large F_3 fold complicates the pattern of the Boott Member around Ingalls Mountain, where the Boott Member is diverted $1\frac{1}{2}$ miles

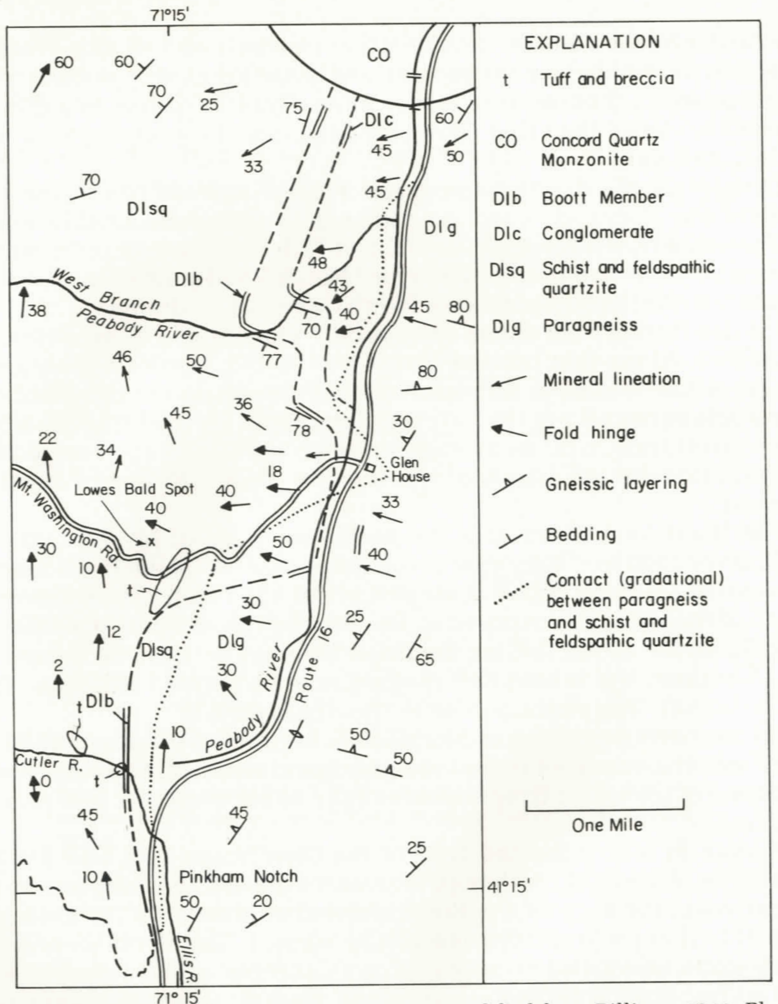

Figure 28. Large F3 Fold West of Glen House. Modified from Billings, 1941, Pl. 10.

toward the southeast. The fold is a tight syncline trending northwest. Although the attitudes of the bedding and minor folds on both limbs are highly variable, the average dip of the bedding on the southwest limb is 55°NE, whereas that on the overturned northeast limb is 65°NE.

A very striking F_3 fold is found in the extreme northeast corner of the quadrangle. At the crest of the Mahoosuc Range, at an altitude of 3200 feet, the Boott Member strikes northwest and dips 50°NE beneath the stratigraphically lower schists and paragneisses.

The structure near the axis of the Mahoosuc Syncline may be considered next. In general, the rocks are highly folded, but reconstruction of

the fold mirrors gives a clue to the location of the main axis of the syncline. The fold mirror dips to the northwest southeast of the axis and to the southeast northwest of the axis. This is shown in the structure sections.

However, on Pine Mountain the strata on the southeast side of the axis show little folding, strike north-northeast, dip 72°NW, and top to the northwest.

Turning to the northwest limb of the Mahoosuc Syncline, the strata in general are highly folded, as shown in the structure sections. But on Pine Mountain (Fig. 23b) the strata on the northwest limb have a consistent north-northeasterly strike and dips that are almost vertical. The breadth of outcrop of this limb is about one mile. The thickness thus appears to be approximately 5000 feet. This is the basis for the statement that the Siluro-Devonian strata on the northwest limb of the Merrimack synclinorium do not exceed 5000 feet in thickness.

The Boott Member is poorly exposed north of Mt. Success for two miles. Although the average strike is northeast, many irregularities may be attributed to F_3 folds.

The contact of the Littleton Formation with the underlying Ammonoosuc Volcanics (Fig. 23a) has a relatively straight northeasterly trend. The dips in the adjacent strata are steep, generally 60° or more to the southeast, locally 90°, and in places northwest, indicating overturning. Locally the contact strikes northwest, where the adjacent strata also strike northwest and dip 40° to 50°NE, due to drag folds associated with the F_1 folding.

Numerous small anticlines bring up the Boott Member within the Littleton Formation in the Mahoosuc Syncline. The two largest are on Dryad and Peabody Brooks.

One anitcline extends northeasterly from Dryad Brook to east of Gentian Pond. The southeast limb is well exposed at Dryad Falls, where the stream drops 700 feet in one-half mile. The Boott Member occurs in minor anticlines that alternate with synclines containing the overlying schists and feldspathic quartzites. The fold mirror dips 15°SE parallel to the brook bed. The northwest limb, best exposed just south of the outlet of Gentian Pond, dips gently north.

The Boott Member exposed in the complex anticline on Peabody Brook trends north-northeast for over one mile. The difference in altitude of the exposures of the Boott Member is over 1000 feet. The dips of the bedding are steep, hence the folds must be tight.

A small anticline bringing up the Boott Member is exposed at an altitude of 2300 feet on the right fork of the stream followed by the Carlo Col trail. Two other possible anticlines, bringing up what is presumed to be the Boott Member, are located at an altitude of 800 feet on a brook east of Stevens Point and at an altitude of 3400 feet on the southwest ridge of Mt. Success.

A minor syncline bringing down the Boott Member into the underlying paragneiss is exposed at an altitude of 1400 feet on that branch of

Lary Brook that flows past post No. 77 on the New Hampshire-Maine state line.

Five of the districts are important in analyzing the structure of the Mahoosuc Syncline by using the stereographic projections: Success, Dolly Copp, Pinkham, Carter, and Moriah. The following types of diagrams are involved: pi-diagrams of the perpendiculars to bedding, gneissic layering, and schistosity, and diagrams of fold hinges and lineation. The discussion is organized by districts.

In the Success District the bedding (Fig. 20b) shows a broad girdle trending northwest but somewhat concave toward the southwest. It is consistent with major folds that have steep limbs and plunge 25°NE. Some of the beds striking northwest and dipping 25°NE may represent the limbs of F_3 folds trending northwest. The diagram of gneissic layering (Fig. 20c) shows a strong concentration of layers striking northwest and dipping 40°NE. This distribution represents the limbs of northwest trending F_3 folds. This diagram differs considerably from the bedding diagram. This is because the paragneisses beneath the Boott Member are largely confined to the southeast portion of the Success area, where northwest strikes, due to F_3 folds, are dominant.

The hinges of the minor folds (Fig. 20d) plunge northeast at angles of 30°. There are two maxima, one of which represents folds plunging 30° in a direction N60°E. These are F_1 folds. They are open to tight, and the axial surfaces strike NE and are essentially vertical or dip steeply SE. A second maximum represents folds plunging 30° in a direction N14°E. These are F_3 folds. They are tight, the axial surfaces strike NW, and dip 30° to 35°NE.

In the Dolly Copp District the maximum in the bedding diagram (Fig. 20e) shows that the most prominent attitude is N20°E, 70°NW. But this is superimposed on a girdle that extends from south to north in the east part of the diagram and is convex toward the east. The girdle is partly due to a progressive swing in the strikes from northeast near Gorham to north-northeast west of Dolly Copp Campground. But it is primarily due to the large F_3 fold west of the Glen House. That part of the girdle in the northeast sector results from northwest strikes and southwest dips on the north limb of the F_3 fold. The minor maximum in the south-southeast sector results from northeast strikes and northwest dips in the south limb of the F_3 fold.

The paragneisses are found only on the extreme east side of the southern part of the Dolly Copp District. Consequently the number of readings for gneissic layering are small (Fig. 20f). The two maxima indicate attitudes of N15°E, 83°NW and N29°E, 46°NW.

The minor folds (Fig. 30a) and the lineation (Fig. 30b) are similar in showing westerly plunges ranging from 45° to vertical. The folds are small F_3 folds one to 12 inches across that are superimposed on the limbs of the large F_1 folds. A **b**-lineation, L_3, accompanies the F_3 folds. These relations are well exposed on the North Peak of Pine Mountain (Fig. 29). These F_3 folds may be explained by northeast-southwest compression acting on steeply dipping strata striking northeast. Minor F_1 folds and L_1

lineation are very subordinate in the Dolly Copp area.

A tectonic map of the area south of the Dolly Copp Road has been published elsewhere (Billings, 1941, Pl. 10).

The Pinkham District is very small, but was established as a separate area in the belief that it was on the south side of an axis depression on the F_1 folds; but it is actually an F_3 "cross-fold." Because of the relatively small number of readings available, the planar structures have been combined into one diagram (Fig. 30c, bedding, gneissic layering, and schistosity); moreover, the fold axes and lineation have been combined (Fig. 30d). The strike of the planar structures (Fig. 30c) ranges from N through N45°E to N80°E; the dips are uniformly low, 30°W, NW, and N. The area is on the southeast limb of the Mahoosuc syncline. But the large spread in strikes is because the large F_3 fold has warped the north-northeasterly strikes into east-west strikes. Figure 30d shows three maxima in the northwest quadrant. These are F_3 folds.

The data for the Carter District, which has been assigned to the southeast limb of the Mahoosuc Syncline, are shown in Figures 30e and 30f, and 31a. The bedding diagram (Fig. 30e) shows a girdle trending northwest, with practically all the concentration in the southeast quadrant, meaning northwesterly dips. The maxima indicate dips of 30° and 70°. The girdle indicates the major fold axes trend northeast with horizontal plunges. The area is on the southeast limb of the Mahoosuc Syncline and the northwestern part of the Wild River Homocline.

The gneissic layering (Fig. 30f) shows a similar pattern, but there are two maxima. An interpretation consistent with the field observations is that the layers striking N40°E, dipping 30°NW, are the gentle southeast limbs of the synclines, whereas the layering striking N55°E, dipping 80°SE, is on the steep northwest limbs. These are F_1 folds.

The axes of the minor folds in the Carter District (Fig. 31a) show several maxima, but all the larger ones are in the southwest sector; the average plunge is 23° in a direction S 50°W. These are F_1 folds.

In summary, the three diagrams (Figs. 30e, 30f, and 31a) for the Carter District indicate a general northwesterly dip, with fold axes trending northeast and plunging gently southwest.

Three projections are given for the Moriah District; these are Figures 31b, c, and d. The bedding (Fig. 31b) strikes N28°E; the dips range from 90° to 60°SE, with the maximum at 74°SE. The only interpretation consistent with the regional pattern is that the beds are thrown into isoclinal or tight folds, the axial planes dipping east-southeast. The weak girdle, convex toward the southwest suggests the major folds plunge 30°NNE. This interpretation of the structure is consistent with the structure shown by the Boott Member east of Gorham. The gneissic layering (Fig. 31c) shows a similar pattern, except the dips are steeper. Both Figures 31b and 31c, especially the latter, show a great deal of spread along the periphery, the result of F_3 folds.

Many of the minor fold axes (Fig. 31d) bear NNE, some plunging 10° in a direction S 17°W, other plunging 20° in a direction N 22°E. The northeasterly plunges are in the northern part of the district, whereas the

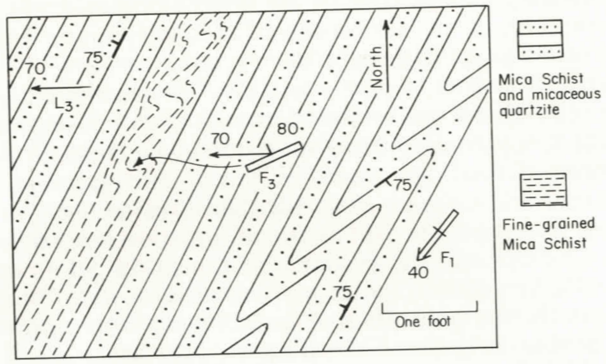

Figure 29. F1 and F3 Folds and L3 Lineation. Top of North Peak of Pine Mtn.

southwesterly plunges are in the southern part. It will be recalled that the axes of the minor folds in the Carter District to the southwest plunge southwest at an average angle of 23°.

The maximum for vertical axes is very strong. They are probably due to F_3 folds affecting vertical beds trending northeast.

Wild River Homocline

Field mapping indicates that this is a very highly folded body of strata, 15,000 feet thick, with a regional northeasterly strike and an average dip of 22°NW. Three bands of lime-silicate rocks (units 2, 4, and 6 of the Littleton Formation, Table 11) are very important in interpreting the structure. Because of all the minor folding the term homocline (Billings, 1972, p. 54) is not entirely satisfactory, but to invent a new term is even more objectionable.

It is apparent from the geological map that the lime-silicate units (2, 4, and 6) strike northeast. But the value of the dip is not clear. Two methods are available to solve this problem: (1) reconstruction of fold mirrors, or (2) the three-point method. Some pertinent data are assembled in Table 12.

For three-quarters of a mile along Dewdrop Brook, between altitudes of 1330 and 1900 feet, the stream flows over gently folded strata of lime-silicate unit No. 2 of the Littleton Formation. The top of the member drops 230 feet in 1700 feet, between altitudes of 1560 and 1330 feet. The apparent dip is thus 8°N and, assuming a strike of N45°E, the true dip is 11°NW. The drop between the base of the member at an altitude of 1900

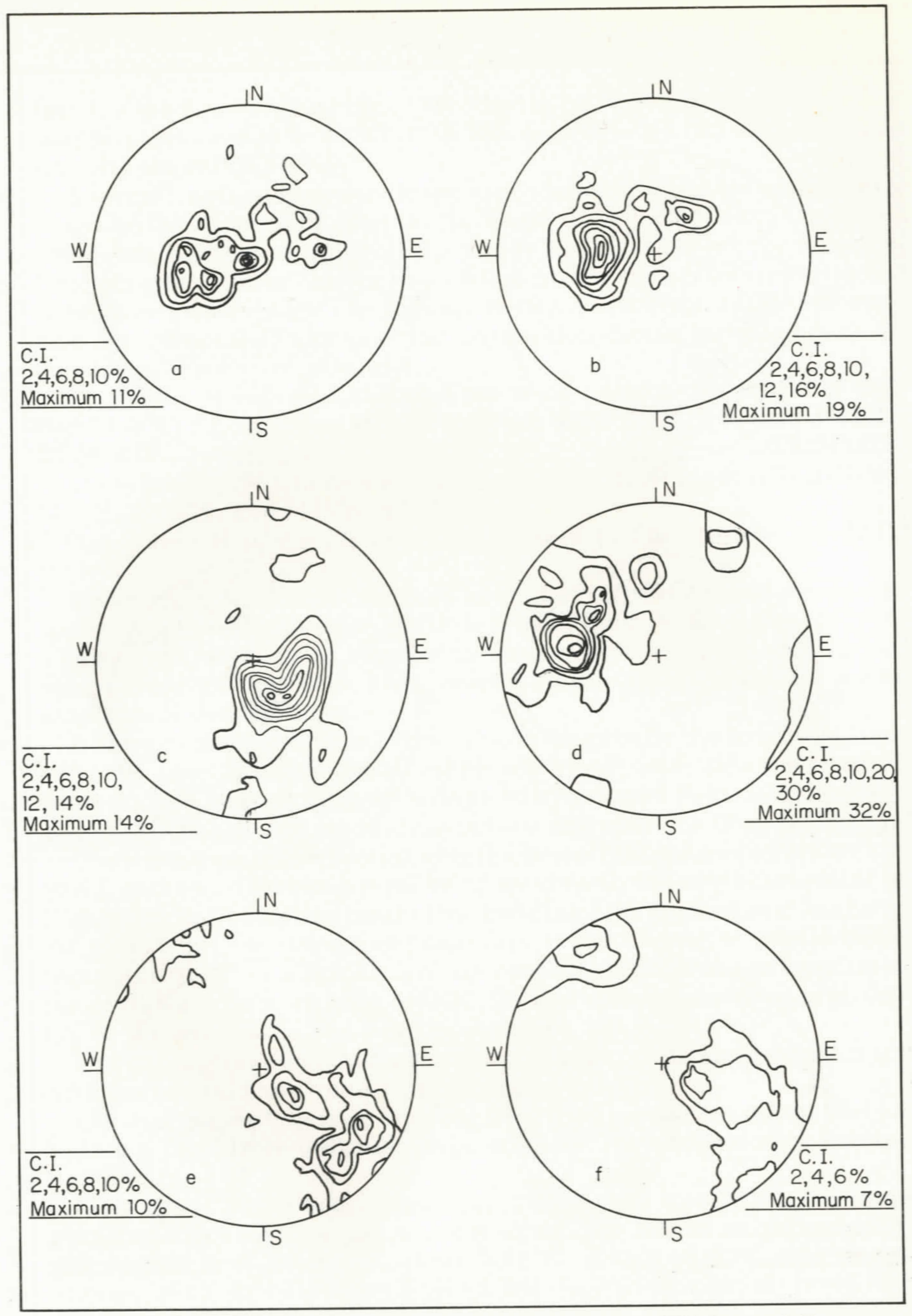

Figure 30. Stereographic Projections, Dolly Copp, Pinkham and Carter Districts. All on lower hemisphere; Littleton Formation. **a.** Dolly Copp District, fold hinges, 54 readings. **b.** Dolly Copp District, lineation, 71 readings. **c.** Pinkham District, perpendiculars to bedding and gneissic layering, 87 readings. **d.** Pinkham District, fold hinges and lineation, 37 readings. **e.** Carter District, perpendiculars to bedding, 173 readings. **f.** Carter District, perpendiculars to gneissic layering, 496 readings.

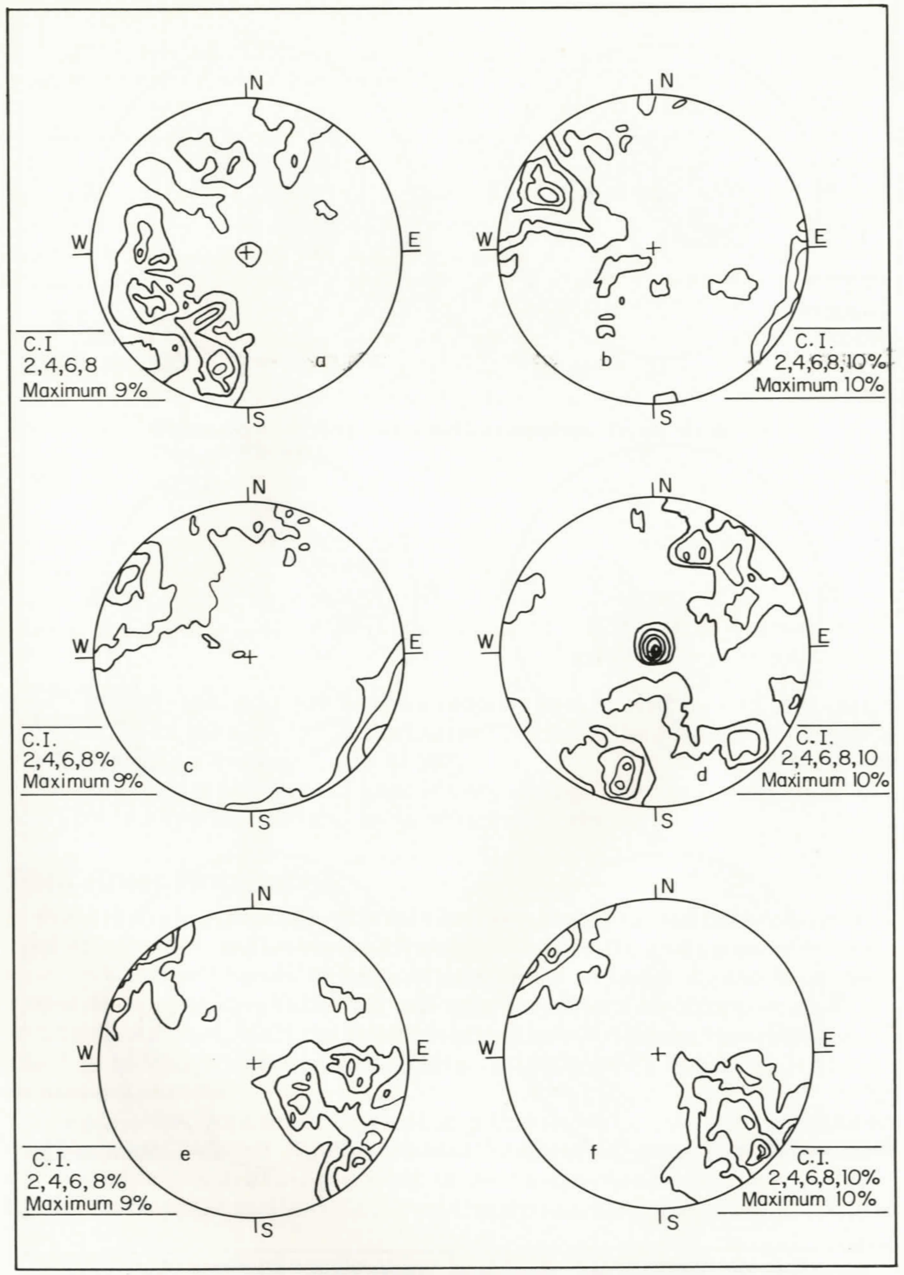

Figure 31. Stereographic Projections, Carter, Moriah and Beans Districts. All on lower hemisphere; Littleton Formation. **a.** Carter District, fold hinges, 82 readings. **b.** Moriah District, perpendiculars to bedding, 222 readings. **c.** Moriah District, perpendiculars to gneissic layering, 417 readings. **d.** Moriah District, fold hinges, 87 readings. **e.** Beans District, bedding, 139 readings. Beans District, perpendiculars to gneissic layering, 417 readings.

feet and the top at an altitude of 1330 feet is 570 feet in 3600 feet; the dip may be calculated to be 12.5°NW. If the member were 200 feet thick, the true dip would be 16°NW.

A second method to calculate the dips of the lime-silicate members is based on the three-point method (Billings, 1972, p. 502-503). The basic assumption is that, despite all the minor folding, the base (or top) of a lime-silicate member may be treated as a planar surface between exposures several miles apart. The geological map (Pl. 1) suggests this assumption may be valid. In any case, the assumption should be tested to see if consistent results are obtained.

As shown in Table 12, calculations were possible for unit 2 at two localities. The attitudes determined are N50°E, 23°NW and N32°E, 21°NW.

Three good calculations are available for unit 4, giving N42°E, 32°NW, N45°E, 26°NW, and N35°E, 8°NW.

One good calculation is available for unit 6. The attitude is N44°E, 32°NW.

In summary, the results obtained by the three-point method are suprisingly uniform. The average strike is N41°E, the average dip is 22°NW. The average for the Boott Member in the southeast limb of the Mahoosuc syncline is N45°E, 19°NW. Thus, despite all the minor folding, the major structure is very uniform.

Although the Wild River Homocline is essentially the southeast limb of a large syncline with which countless minor F_1 folds are associated, F_3 folds are also present. A good example of overturned F_3 folds is shown in Figure 32. Locally minor folding is very unimportant (Fig. 33).

The stereographic projections for the Beans District are in Figures 31e and f, and 34a. The concentration of maxima in the southeast sector in Figure 31e indicates that most of the bedding dips northwest at angles of 30° to 90°. But the average regional dip, as just shown, is considerable less. Dips of 30° to about 65°NW are probably right-side-up, topping to the northwest. Beds dipping 80°NW, 90° and steeply southeast probably top to the southeast. The net dip would be 20° to 30°NW.

The main girdle trends northwest-southeast, indicating major folds with horizontal axes trending northeast-southwest.

The diagram for gneissic layering (Fig. 31e) is very similar to that for bedding. The girdle indicates large folds with horizontal axes tending N42°E.

Most of the minor fold hinges (Fig. 34a) plunge southwest, but some plunge northeast and a few are very steep. The largest maximum indicates a plunge of 25° in a direction S 45°W. A second maximum shows plunges of 12° in a direction S 18°W. But the first maximum shows that the minor folds plunge somewhat more steeply than the larger folds.

The Royce District is represented by three diagrams, Figures 34b, c, and d. The one pronounced maximum in the bedding diagram (Fig. 34b) indicates beds striking N30°E and dipping 45°NW. But the diagram for gneissic layering and schistosity (Fig. 34c) is surprisingly different. The strike is N80°E, the dip is 40°N. However, there is a simple explanation of

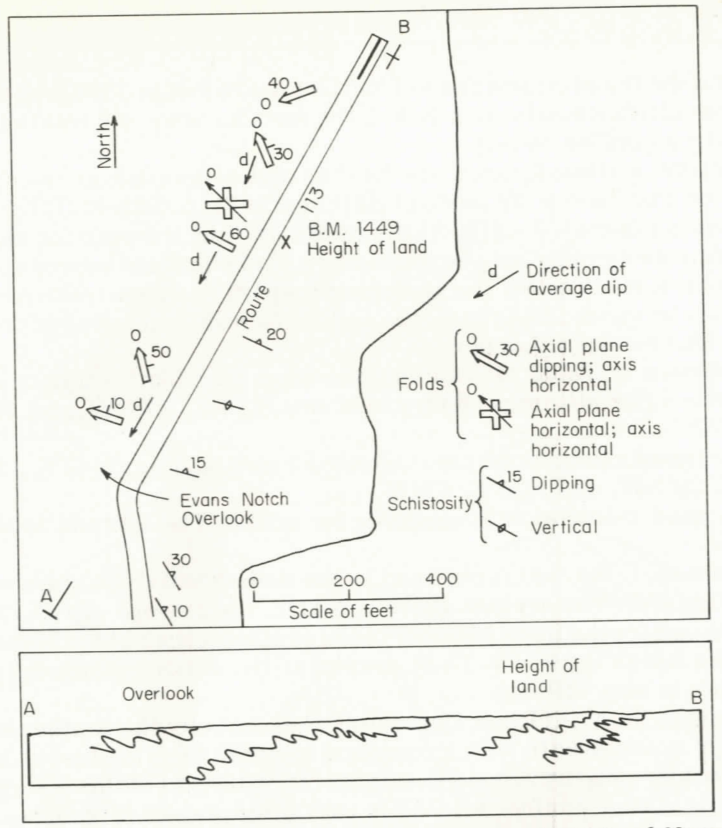

Figure 32. F3 Folds in Littleton Formation on Evans Notch Road. Near height of land, altitude of 1449 feet. Speckled Mtn. 7½ minute quadrangle.

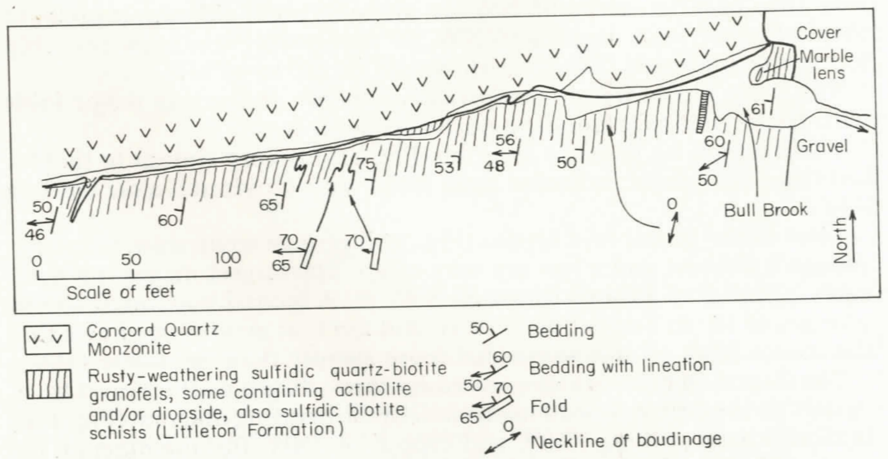

Figure 33. Sulfidic Schist with Little Minor Folding. Bull Brook, altitude of 1140 to 1160 feet.

this apparent discrepancy. Figure 34b represents the southern half of the area, where bedding is conspicuous. Figure 34c represents the northern half of the district, where the rocks are paragneiss. The strikes swing from north-northeast in the southern part of the area to east-west in the northern part. A large F_3 fold trending northwest has deformed the strata.

The fold diagram (Fig. 34d) shows a very complex pattern. Minor folds plunging gently northeast and southwest are F_1 folds. Horizontal axes trending northwest-southeast are F_3 folds. Folds plunging west and north are probably also F_3 folds.

Consideration has been given to the possibility that the three south-easterly lime-silicate units (units 2, 4, and 6) are the same stratigraphic unit repeated by large isoclinal folds, the limbs and axial planes dipping 20° to 30° NW. The obvious proof of such an hypothesis would be to find places where the lime-silicate units can be traced into one another. There is no evidence of this, but the tie could be beyond the limits of the quadrangle. Moreover, the lime-silicate units seem to be averse to crossing the state line. This is true of units 2 and 4. Unit 6 is discontinuous but has been found along the east edge of the quadrangle one-half mile north of the Androscoggin River.

Evidence of tops from sedimentary features could give a solution. At least one limb of the major hypothetical isoclinal folds should be overturned. No conclusive evidence of tops was found, but further study might be successful.

Age of the Orogeny

The deformation is younger than the Littleton Formation, the upper part of which is known to be Early Devonian. Stratigraphic evidence in Maine (Boucot **et al.**, 1964) shows that there were several phases of the Acadian Orogeny, one between the Early and Middle Devonian, a second younger than the Middle Devonian. Two determinations by the Pb-alpha method of the age of the Concord Quartz Monzonite, which is younger than the deformation, give 350 and 370 million years (Wilson, 1969). This implies that the Concord is early Late Devonian. Thus the orogeny in the Gorham Quadrangle is approximately Middle Devonian.

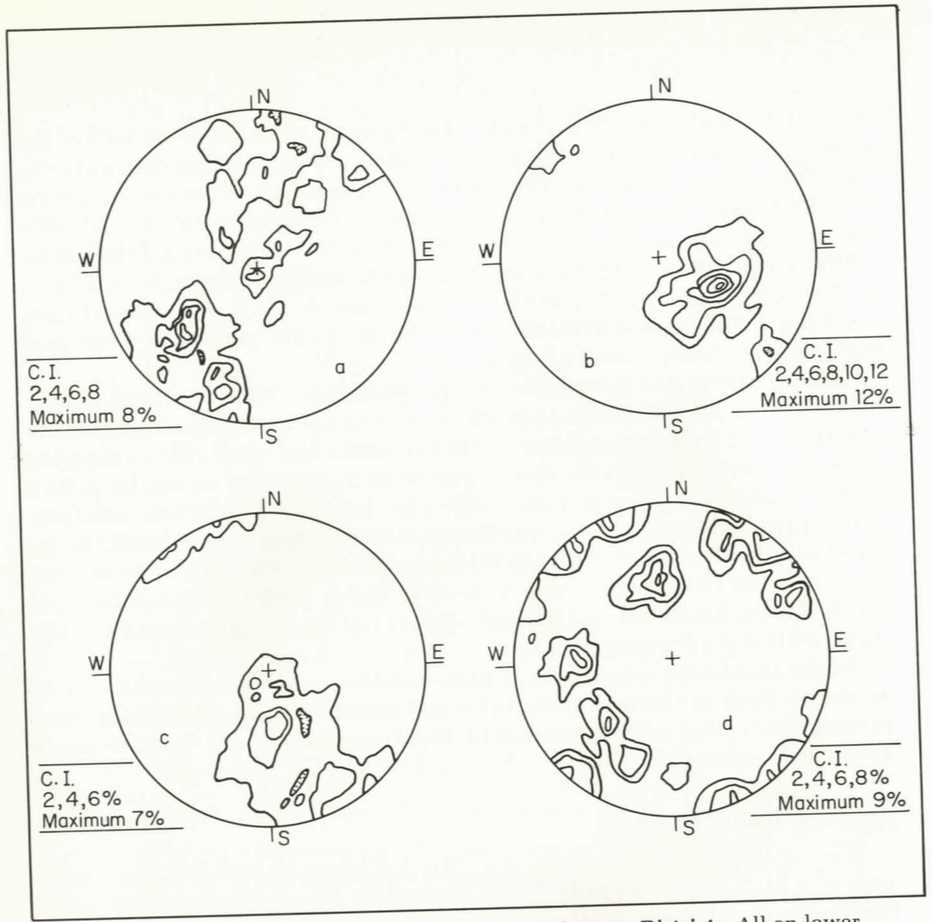

Figure 34. Stereographic Projections, Beans and Royce Districts. All on lower hemisphere; Littleton Formation. **a.** Beans District, fold hinges, 83 readings. **b.** Royce District, perpendiculars to bedding, 174 readings. **c.** Royce District, perpendiculars to gneissic layering and schistosity, 317 readings. **d.** Royce District, fold hinges, 66 readings.

CHAPTER IV. DIKES OF BIOTITE GRANOFELS

A rather unusual type of dike-rock is described here. It is younger than the Littleton Formation but older than most or all the units of the New Hampshire Plutonic Series. Similar rocks in the Mt. Washington Quadrangle were called meta-sedimentary, and, although this is undoubtedly correct, the less genetic name seems desirable.

These dikes are thin tabular bodies that range from 0.3 to 3 feet in thickness, but average 1.3 feet. Figure 35 is a map showing their location and their attitude. Figures 36, 37, and 38 show that they cross-cut the gneissic layering of the Littleton Formation. Figure 38 indicates that some are injected along faults. Figure 39, as well as numerous observations elsewhere, show that they are older than the Concord Quartz Monzonite. Similar relations were found in the adjacent Mt. Washington Quadrangle (Fowler-Billings, 1944, p. 1268).

These rocks are dark and medium-grained; some are schistose, others are massive. Many are composed of biotite, quartz, and labradorite in about equal amounts; others contain tremolite or actinolite and/or diopside, the amphibole in some cases constituting 50% of the rock. Most of the minerals are 1 to 2 mm in diameter, but actinolite crystals are generally euhedral and 3 to 4 mm long. They were injected during the regional metamorphism, since they cross-cut the gneissic layering and foliation of the paragneiss.

Figure 35 shows that these dikes lie in two belts, the Carter-Moriah belt extending along the crest of that range as far as the Androscoggin River, the second belt lying 1 mile north of the Village of Shelburne. They have been subjected to the regional metamorphism and are older than the Concord Quartz Monzonite.

The orientation of these dikes is shown by a point diagram of the perpendiculars to the dikes in an equal area projection (Fig. 40). The six dikes dipping gently northwest are, with the exception of the one striking east-west, in the Carter-Moriah belt. The others, with the exception of the one dipping 60°SE, are in the belt NW of Shelburne village.

As in the Mt. Washington Quadrangle, these dikes are believed to have been derived from the lime-silicate rocks in the Littleton Formation. The belt northwest of Shelburne is on the trace of the Boott Member, but no outcrops of this member have been observed here in normal stratigraphic position. Apparently these rocks were sufficiently mobile to move from their normal stratigraphic position and were injected nearby as dikes. The Carter-Moriah belt probably represents a member that everywhere moved out of its proper stratigraphic position to be injected as dikes.

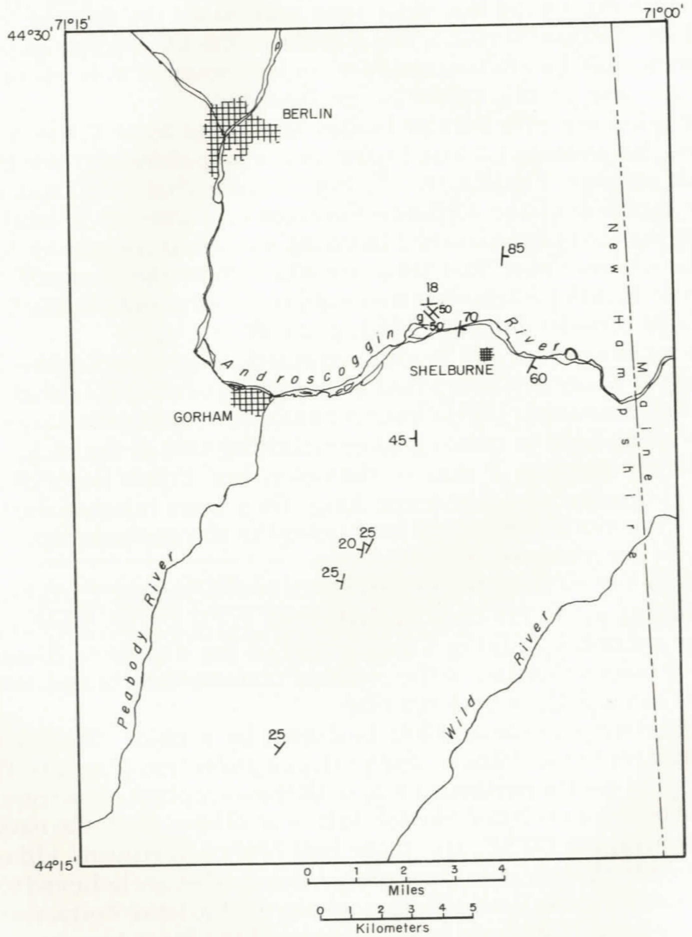

Figure 35. Map Showing Location of Dikes of Biotite Granofels.

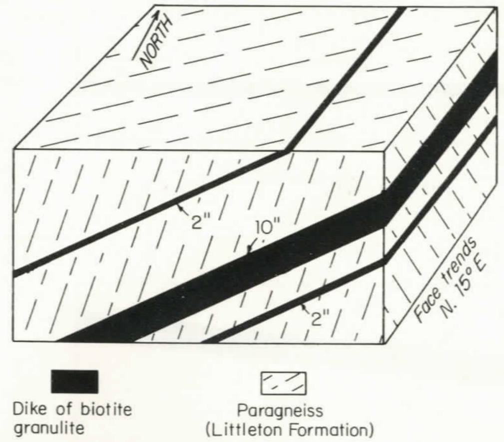

Figure 36. Dikes of Biotite Granofels on Mt. Moriah. Altitude of 3370 feet on south slope of mountain.

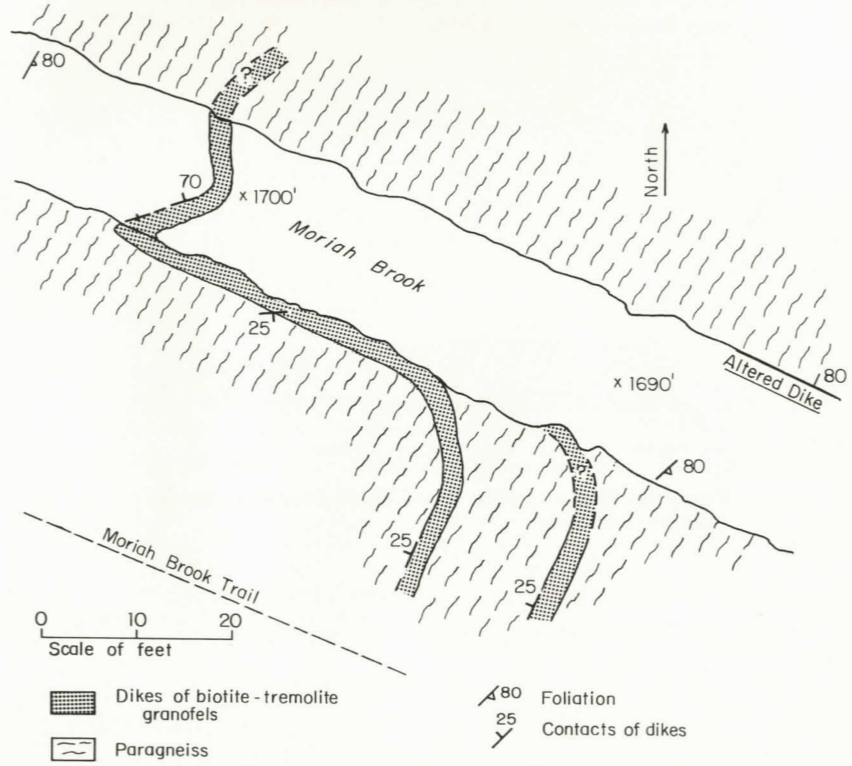

Figure 37. Dikes of Biotite Granofels on Moriah Brook. Altitude of 1700 feet.

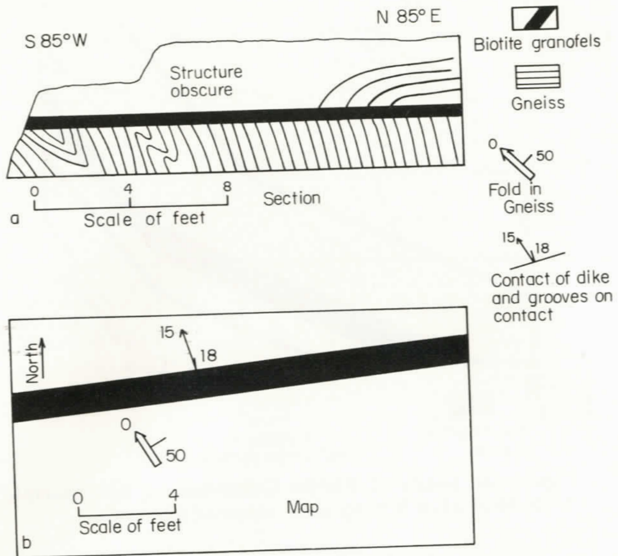

Figure 38. Dike of Biotite Granofels in Shelburne. Five hundred feet northeast of bridge on North Road over Peabody Brook. **a.** Section. **b.** Map.

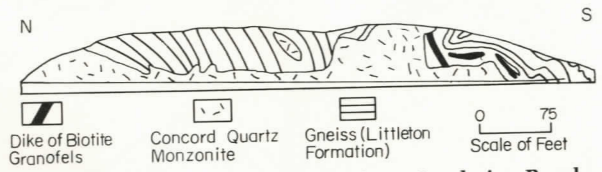

Figure 39. Dike of Biotite Granofels on Leadmine Brook. Altitude of 800 feet.

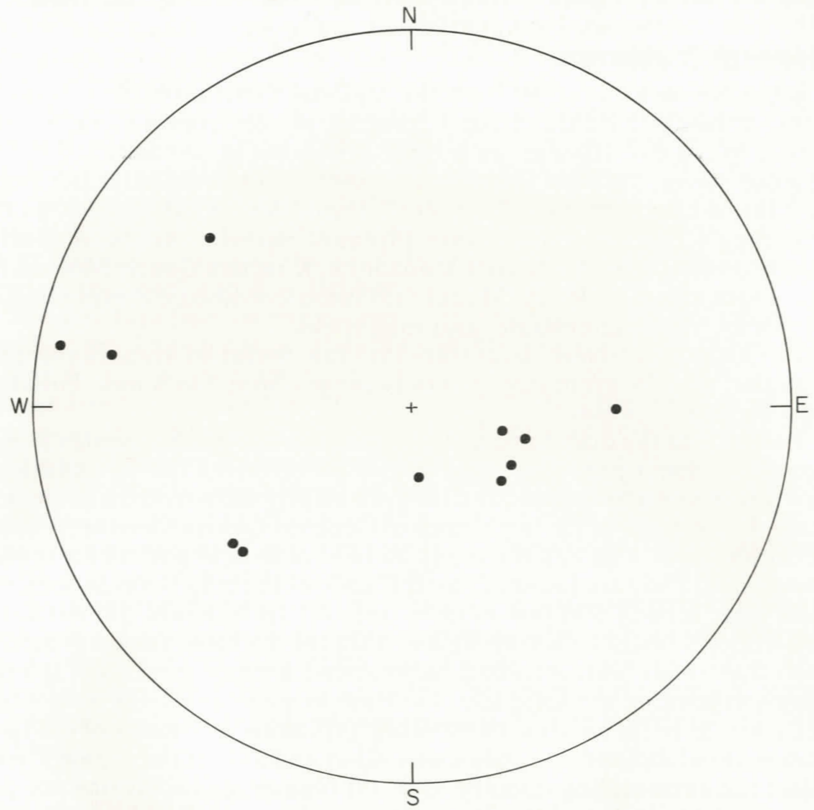

Figure 40. Equal-Area Projection of Dikes of Biotite Granofels. Lower hemisphere. Perpendiculars to 11 dikes.

CHAPTER V. NEW HAMPSHIRE PLUTONIC SERIES

General Statement

Intrusive rocks younger than the regional metamorphism are abundant in the Gorham Quadrangle, ranging in size from a stock 5 miles across to narrow dikes an inch thick. These rocks are assigned to two igneous series, the New Hampshire Plutonic Series (Middle Devonian) and the White Mountain Plutonic-Volcanic Series (Mesozoic). In this quadrangle the New Hampshire Plutonic Series consists of diorite, quartz diorite, Concord Quartz Monzonite, Kinsman Quartz Monzonite, and pegmatite. The White Mountain Plutonic-Volcanic Series consists of diorite, vent-agglomerate, and dike rocks.

The rocks of the New Hampshire Plutonic Series are hypidiomorphic granular, and the grain size generally ranges from 2 to 5 mm. Foliation may be locally present.

Portrayal of the distribution of the various units on the geological map presents a major problem. Some bodies are large, are free of inclusions, and possess sharp contacts; and they are readily shown on the geological map. An example is the large stock of Concord Quartz Monzonite south of Gorham (Pls. 1 and 2). But many bodies are hard to portray for several reasons. (1) They are too small for the scale of the map — on an inch to a mile map, a body 500 feet wide is only 0.1 inch across. (2) Although small bodies might be shown by hair-thin lines, exposures are generally such that small bodies cannot be followed for any distance. (3) Even where exposures are adequate, the time to trace and map each small body would be far too time consuming. (4) Contacts of many of the large bodies are ill defined, because many dikes and sills of the plutonic rock inject the surrounding country rock. (5) Numerous inclusions are present in places in the plutonic rock.

The large body of quartz diorite around Mt. Cabot is an example of the problem. Several inclusions of schist are present on the top of Mt. Cabot (Fig. 41a). Moreover, the southern contact is necessarily diagrammatic, as numerous dikes and sills of quartz diorite penetrate the parageneisses to the south.

Diorite

Diorite is exposed for one-half mile along Nineteen Mile Brook between altitudes of 1560 and 1780 feet. On the map it is shown as two separate bodies, due to the exposure of a small mass of two-mica gneiss at an altitude of 1710 feet.

This diorite is exceedingly heterogeneous. For descriptive purposes the following varieties are recognized: (1) gray medium-coarse; (2) gray

medium-fine; and (3) leucocratic fine-grained. The leucocratic fine-grained variety occurs as small dikes that cut the other varieties. Moreover, sharp contacts have been observed between the medium-coarse and medium-fine varieties, and between lighter-colored and darker-colored subdivisions of the medium-fine types.

All varieties are composed primarily of plagioclase, amphibole, and biotite, with such accessories as quartz, pyroxene, magnetite, and pyrite. The plagioclase ranges from An_{40} to An_{60}; in some specimens the amphibole is black, in others it is very light gray.

In the medium-coarse varieties the grain size ranges from 1 to 3 mm. The texture is hypidiomorphic granular. The average mode in column 1, Table 13, is typical of such rocks. In these particular samples, however, the dark minerals are concentrated in spherical masses 5 to 10 mm in diameter, giving a distinctly spotted appearance to the rock. In these rocks the pleochroism of the ampbibole is as follows: X = light tan, Y = light-olive green, and Z = light green.

The medium-fine variety ranges in color from gray to light-gray, depending on the percentage of dark minerals. The grain size ranges from 0.5 to 1 mm. An average mode is given in column 2, Table 13. The plagioclase forms euhedral tabular crystals 0.5 to 1 mm long, much of it occurs in aggregates composed of diversely oriented crystals. The amphibole is light-gray in hand specimens, colorless in thin sections.

The leucocratic fine-grained variety is found as narrow dikes, seldom exceeding 6 inches in thickness, that cut the other diorites. The grain-size averages about 0.5 mm. The amphibole is colorless in thin section; a mode is given in column 3, Table 13.

The diorite on Nineteen Mile Brook is cut by dikes of white aplite and pegmatite. Since such rocks are closely associated chronologically with the Concord Quartz Monzonite, this diorite is considered to be older than the Concord, and hence part of the New Hampshire Plutonic Series.

The mode of diorite from a body too small to map is given in column 4, Table 13.

Quartz Diorite

The quartz diorites are medium-grained gray hypidiomorphic granular rocks in which the grains generally range from 1 to 4 mm in diameter. Many of the bodies are too small to show on the geological map. Only four are shown, one at about 1600 feet on Lary Brook, one around Mt. Cabot, one a mile northeast of Stock Farm Mountain, and a fourth on Burnt Mill Brook. The problem of portraying the contacts of the Mt. Cabot body has already been discussed. Moreover, there is little control on the shape of the body on Lary Brook. Figure 42 is an example showing how the quartz diorite is entangled with other rocks.

The principal minerals are andesine, quartz, and biotite. Minor accessories are amphibole, muscovite, magnetite, pyrite, apatite, sphene, and epidote. Some specimens contain amphibole, some contain muscovite, but no specimens contain both. Moreover, some specimens contain neither of these minerals. Average estimated modes are given in Table 13; column 5 and 6 for those containing amphibole; column 7 for those with neither amphibole nor muscovite; and column 8 for those containing muscovite. Column 9, from a small body at 810 feet on Austin Brook, contains considerable microcline and hence is quartz monzonite.

The quartz diorites intrude the Littleton Formation (Figs. 41 and 42) but are cut by Concord Quartz Monzonite and pegmatites, and hence belong to the New Hampshire Plutonic Series. They are very similar to the Winnipesaukee and Spaulding Quartz Diorites found elsewhere in New Hampshire (Billings, 1956, p. 54).

Structurally the quartz diorites are very irregular bodies, with countless dikes and sills extending into the country rock. The method of emplacement was very similar to that of the Concord Quartz Monzonite, as discussed below.

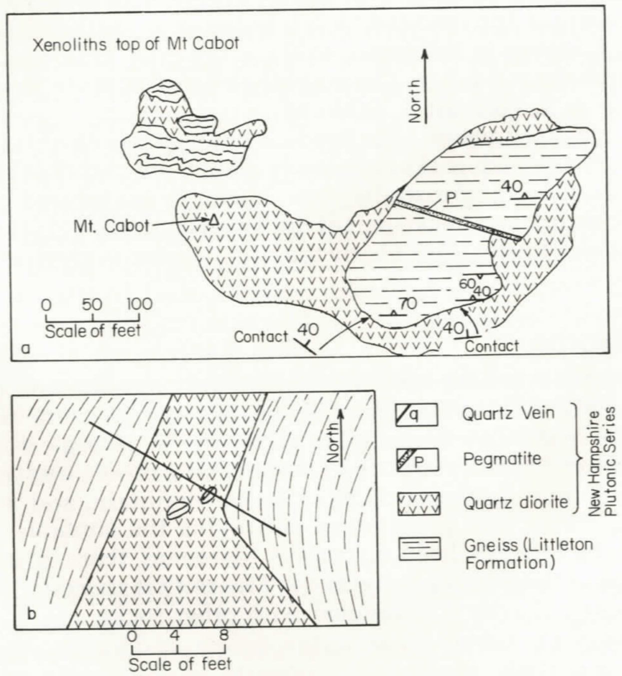

Figure 41. Quartz Diorite Intruding Littleton Formation. a. Top of Mt. Cabot. **b.** Dike at altitude of 880 feet on south slope of Hark Hill.

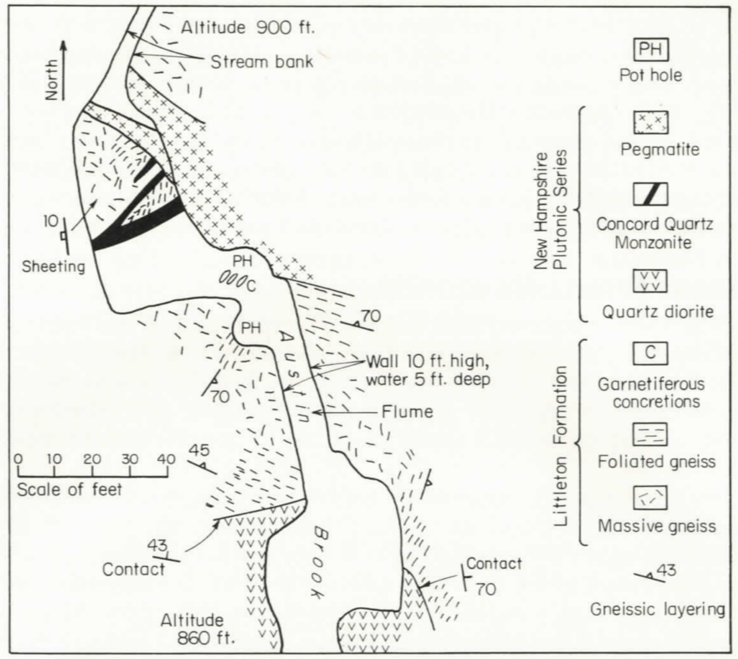

Figure 42. Quartz Diorite, Paragneiss of Littleton Formation, and Pegmatite. Pitchers and Bowls, Austin Brook, altitude of 860 feet.

Kinsman Quartz Monzonite

The northern part of a large body of porphyritic quartz monzonite is exposed along the southern border of the quadrangle. In the North Conway Quadrangle this was called the Meredith Granite (Billings, 1928), but on the geological map of New Hampshire (Billings, 1956) it was shown as the Kinsman Quartz Monzonite. These two names represent varieties of the same lithologic type. Although the feldspar phenocrysts are considerably smaller than in the typical Kinsman, the similarity is sufficiently close to justify using the same name.

About 10% of the Kinsman Quartz Monzonite in this area consists of tabular phenocrysts of microcline that are 10 to 20 mm long, 5 to 10 mm deep, and 3 to 5 mm wide, set in a medium-grained groundmass. The contacts of the phenocrysts with the groundmass are usually highly irregular. The groundmass, in grains 1 to 3 mm in diameter, consists primarily of quartz, microcline, and oligoclase, with significant amounts of biotite and muscovite and such minor accessories as apatite and pyrite. A mode is given in column 10, Table 13. Locally the phenocrysts are aligned to produce a planar structure.

The relation of the trace of the contact to topography indicates that it must be steep. In any one outcrop the feldspar phenocrysts are generally aligned to produce a planar structure. The dips are vertical or nearly so. On Baldface Brook and Bicknell Ridge (in the North Conway Quadrangle south of Eagle Crag) the strikes range from N40°E through N90°E to N25°W. In the interior of the pluton in the North Conway Quadrangle the phenocrysts are diversely oriented (Billings, 1928, p. 83-84). The limited data in the Gorham Quadrangle indicate that the Kinsman Quartz Monzonite was forcefully injected as a large domical mass analagous to a salt dome, developing steep planar structures along its contacts.

Concord Quartz Monzonite

This is a very common rock in New Hampshire, but has been mapped under several different names, such as Concord Granite, Bickford Granite, and binary granite (Billings, 1956, p. 61-63). In accordance with petrographic terminology, since potash feldspar and plagioclase are present in approximately equal amounts, the term quartz monzonite should be used.

The Concord Quartz Monzonite forms many mappable bodies, as well as countless small dikes and sills (Figs. 43, 44, 45, 46, and 47). The largest stock is in the Peabody River Valley south of Gorham (Pls. 1 and 2 in pocket of back cover). Oval in plan, it extends 5 miles in a northeasterly direction, and 3 miles in a northwesterly direction. Many smaller bodies are shown on the geological map. For reasons already discussed, the shape of these bodies in many cases is difficult to ascertain.

The Concord Quartz Monzonite is typically a white medium-grained hypidiomorphic granular rock composed primarily of oligoclase, potash feldspar, and quartz, with lesser amounts of biotite and muscovite, and such accessories as magnetite and apatite. An average mode, based on 20 specimens, is given in column 11, Table 13. Typically the average grain ranges in diameter from 2 to 4 mm, but some varieties are coarser, others are finer.

Pegmatites are closely associated with the Concord Quartz Monzonite spatially and chronologically. They are coarse white rocks composed primarily of perthite, oligoclase, quartz, biotite, and muscovite; some contain garnet. The individual minerals range in size from 1 to 12 inches. The pegmatites occur as dikes, sills, and irregular bodies ranging in thickness from a few inches to many scores of feet. Only one, that on top of Artists Rock, was large enough to show on Plate 1. But literally thousands of them occur throughout the Concord Quartz Monzonite and other formations. No special study was made of the pegmatites.

The Peabody River stock, south of the village of Gorham, covers about 12 square miles. The topographic relief is about 1200 feet.

The contact of the Concord Quartz Monzonite with the Littleton Formation is superbly exposed on the south slopes of Pine Mountain for a length of over 2000 feet (Pl. 2). Neither the topographic map nor the aerial photographs were on a sufficiently large scale to show the amount of detail that could be obtained. The area is much too rugged for mapping

by plane table. Consequently, a base on a scale of one inch to one hundred feet was prepared from the topographic map, supplemented by pace and compass traverses. It was soon realized that it would be inadvisable to transfer the topographic contours to this map. Therefore, only some representative altitudes are shown on the map. The map is not intended to be a complete outcrop map of the area except near the contact of the Concord and Littleton units.

Plate 2 shows that the contact, despite its very irregular trace, maintains a rather uniform altitude between 1900 and 2150 feet. The contact is everywhere knife-sharp. Its attitude was recorded at six localities. The strike differs greatly. In two instances the dip of the contact is vertical, in the other four cases it has an average dip of 60° under the metamorphic rocks. The bend in the strike of the metamorphic rocks near the contact is impressive. Both north and south of the summit the bedding strikes north-northeast and dips, on the average, 70°NW. On the large open ledge 575 feet southwest of the summit graded bedding shows tops to the northwest. Approaching the contact these beds swing southeasterly and become overturned, dipping northeasterly.

An exposure of the northwest contact of the Peabody River stock (Fig. 45)shows that the Concord is locally foliated in a zone a few feet wide. Similar foliation is also shown at the contacts of some small bodies (Fig. 46).

The other stocks of Concord Quartz Monzonite appear to have steep contacts, judging from the way they cut across the topographic contours.

It is clear that the Concord is younger than the folding of the Littleton (Figs. 43, 44b). It even intrudes the fracture cleavage (Fig. 47).

The best evidence bearing on the mechanics of emplacement of the Concord Quartz Monzonite is given by the Peabody River Stock. There is no evidence of metasomatism. The replaced rocks have been pushed upward or sideways or have been stoped downward. The outward dip of the contact is hard to reconcile with upward shoving; although the bedding bends toward the contact, the amount is quite insignificant compared with the bending necessary for lateral pushing. Upward shoving or downward stoping seems the only plausible mechanism.

In general the bodies of Concord Quartz Monzonite, as well as those of quartz diorite, were probably injected as large horizontal sheets at some distance below the present surface. The magma rose because of its lower specific gravity, shattering the brittle country rock so that the mobile magma was injected as dikes and sills. Some large roof blocks were pushed up, others were stoped downward.

Relative Ages of Rocks of the New Hampshire Plutonic Series

The diorite is considered to be the oldest member of this series; it is cut by aplites and pegmatites that are related to the Concord Quartz Monzonite. The quartz diorite is cut by the Concord. On Bicknell Ridge the Concord intrudes the Kinsman Quartz Monzonite. Pegmatites cut the

Concord. The Concord is younger than the fracture cleavage in the Littleton Formation (Fig. 47).

Age of New Hampshire Plutonic Series

As indicated on a previous page, the Concord Quartz Monzonite, on the basis of Pb-alpha ages, is early Late Devonian. A general discussion of radiometric ages in the northern Appalachians is in Lyons and Faul (1968).

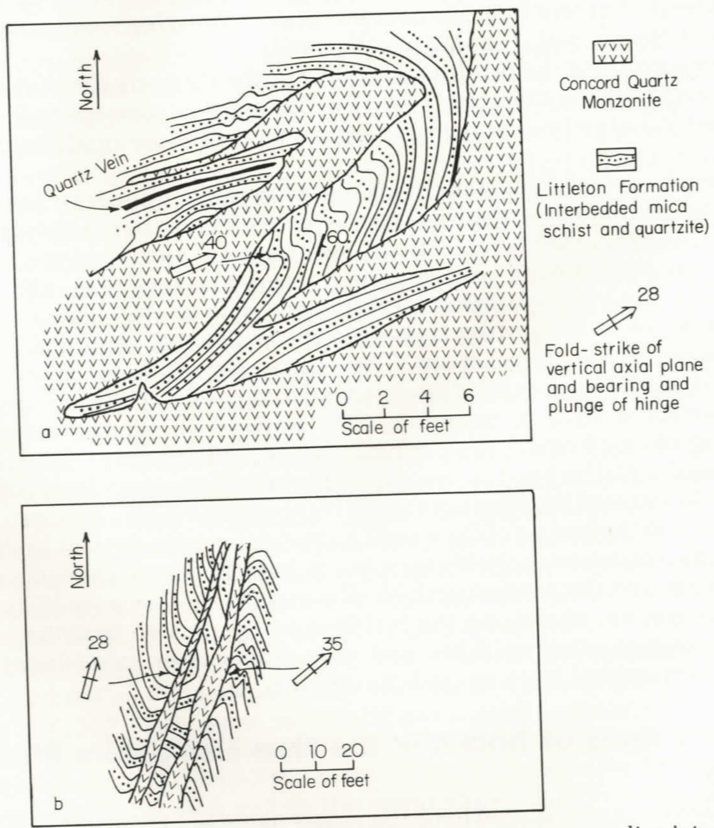

Figure 43. Concord Quartz Monzonite. Irregular bodies intruding interbedded mica schist and feldspathic quartzite of Littleton Formation. **a.** Foot of cliff on east slope of North Bald Cap. **b.** Pine Mtn., altitude of 2270 feet southeast of summit.

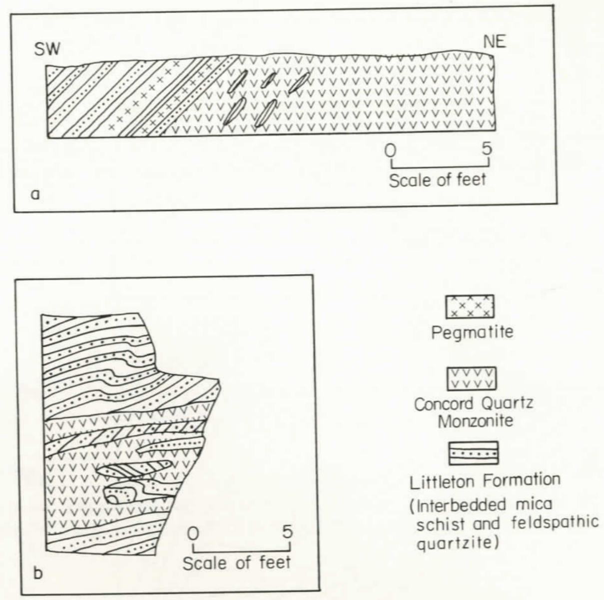

Figure 44. Concord Quartz Monzonite. Intruding interbedded mica schist and feldspathic quartzite of Littleton Formation. **a.** West contact of Pt. Lookout stock, east of Mascot Pond. **b.** Five hundred feet northeast of bridge on North Road over Peabody Brook; outcrop at altitude of 900 feet.

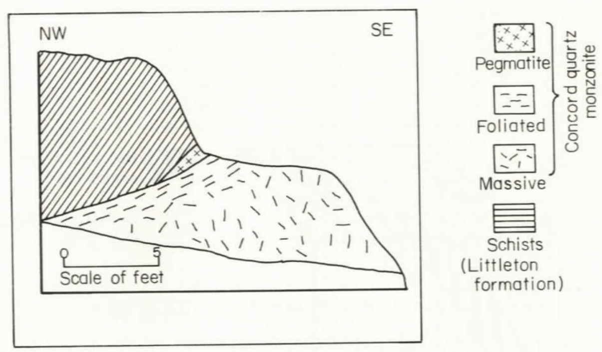

Figure 45. Northwest Contact of Peabody River Stock. Two thousand feet west of Mt. Hayes Cemetery in Gorham.

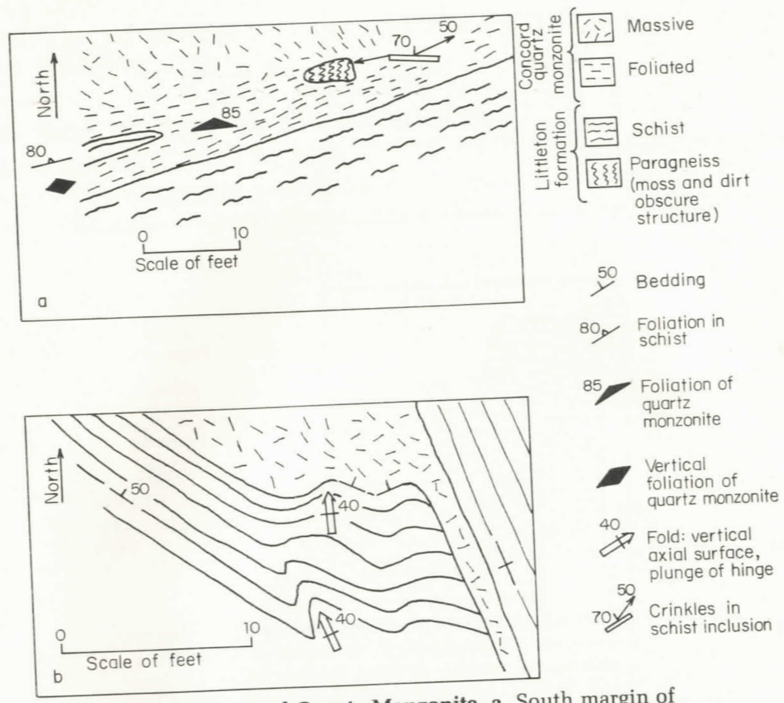

Figure 46. Concord Quartz Monzonite. a. South margin of sill 25 feet wide, brook north of Mt. Success trail, altitude of 2195 feet. **b.** Summit of Mt. Hayes.

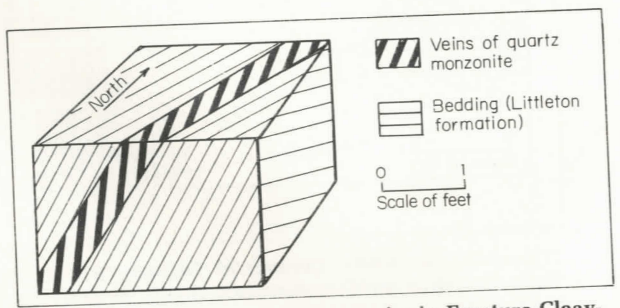

Figure 47. Concord Quartz Monzonite in Fracture Cleavage. South of trail at an altitude of 2270 feet on southwest slope of Mt. Hayes.

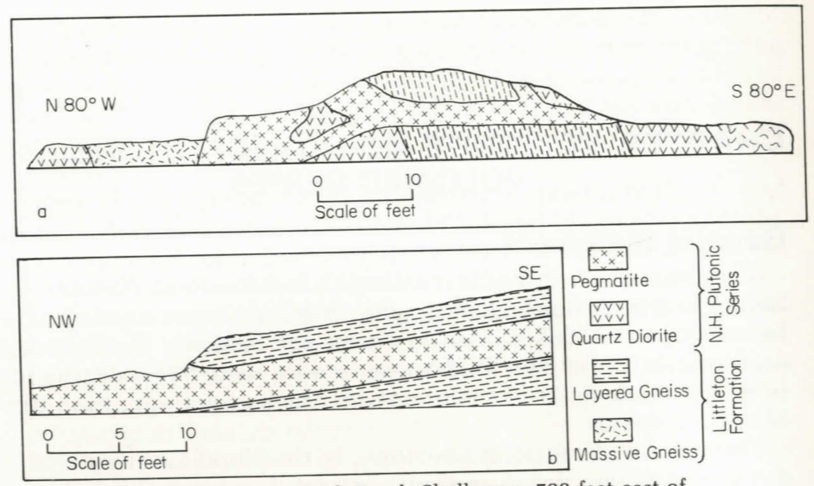

Figure 48. Pegmatite. a. North Road, Shelburne, 700 feet east of Austin Brook. **b.** South Branch of Stony Brook, altitude of 1880 feet.

CHAPTER VI. WHITE MOUNTAIN PLUTONIC-VOLCANIC SERIES

General Statement

There are no large bodies of the White Mountain Plutonic-Volcanic Series in the Gorham Quadrangle. However, some small bodies have been assigned to this series: (1) diorite (on Peabody River) and (2) vent agglomerate. Moreover, the post-metamorphism dike rocks are included here, although some of them may be older or younger than the White Mountain Series.

The Conway Granite at Redstone, in the North Conway Quadrangle, has been reliably dated as about 185 million years (Early Jurassic) by various investigators and methods (Wilson, 1969). Although Foland **et al.** (1970) have suggested from studies utilizing the K/Ar and Rb/Sr methods that the various members of the White Mountain Series may differ in age by as much as 100 million years, Zartman and Marvin (1970) have indicated that these methods may not be reliable.

Diorite

One-half mile south of Gorham, diorite is exposed for 150 feet along the Peabody River. It is bounded both to the north and south by Concord Quartz Monzonite (Fig. 49).

The diorite is medium-fine-grained, averaging about 1.0 mm. Both the north and south margins are finer grained. Moreover, small apophyses cut the Concord Quartz Monzonite along the northern contact. The principal minerals in this diorite are andesine, amphibole, and biotite, with minor amounts of magnetite, sphene, and carbonate. Representative modes are given in Table 14, columns 1 and 2.

This diorite is younger than the Concord Quartz Monzonite, and is considered to belong to the White Mountain Plutonic-Volcanic Series.

Vent Agglomerate

Two small volcanic vents have been mapped. One is on Leadmine Brook at an altitude of 760 feet. The other is on the Mt. Washington Auto Road at an altitude of 2300 feet at the extreme west edge of the quadrangle.

The vent on Leadmine Brook is 100 feet long and 50 feet wide. The southern contact, which is well exposed, strikes N75°W and dips 75°NE. Sub-angular clasts, 3 to 12 inches across, are set in a white granular matrix. The clasts comprise 90% of the rock. Near the margins some of the clasts are schist and Concord Quartz Monzonite. But most of the

clasts are fine-grained porphyritic andesite containing 12% of lath-shaped andesine-labradorite phenocrysts 0.5 to 2.0 mm long. The groundmass of these clasts consists primarily of plagioclse, amphibole, and biotite, with small amounts of magnetite. The grain size of the groundmass is 0.03 to 0.15 mm. A mode of an andesite clast is given in column 3, Table 14.

The matrix of the agglomerate is composed of quartz, feldspar, and mica, apparently representing pulverized Concord Quartz Monzonite. An irregular network of veins, which are 5 to 30 mm thick and are composed of the same material as the matrix, cut the adjacent rocks.

"The northern end of the vent along the Auto Road is a volcanic breccia with dark, rounded fragments of metadiabase up to 6 inches across in a light-gray matrix rich in micaceous minerals. The southern end of this body has fragments of fine-grained metadiabase, porphyritic basalt, and quartz in a matrix of metadiabase. (Fowler-Billings, 1944, p. 1267)." The light-colored matrix is tuff resulting from the explosive fragmentation of country rock. The matrix composed of metadiabase has consolidated from magma.

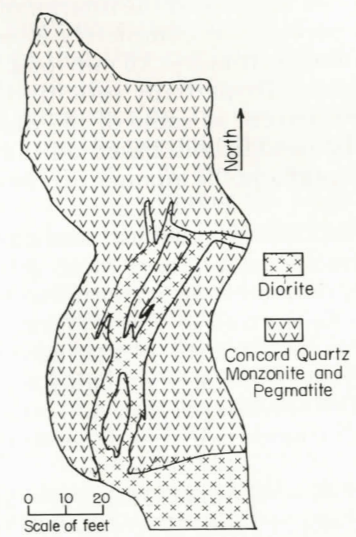

Figure 49. Diorite of White Mountain Plutonic-Volcanic Series. Intrudes Concord Quartz Monzonite. Peabody River, altitude of 830 feet.

Post-Metamorphism Dikes

Introduction. This section of the paper is concerned with the dike rocks younger than the regional metamorphism, excluding granite, aplite, and pegmatite dikes derived from the New Hampshire Plutonic Series. Many of the dikes described here, and perhaps all of them, are related to the White Mountain Plutonic-Volcanic Series.

Plate 3 shows the location and strike of the dikes. The thicknesses range from a few inches to 20 feet; the average is 3.5 feet. Seventy-three percent dip 80° or more, 19% dip between 60° and 80°, and eight percent dip less than 60°. The numbers on Plate 3, by reference to Table 15, give the lithology of each dike.

Table 16 shows the relative abundance of the various kinds of dike rocks. Of the 241 dikes recorded, 69 were identified by thin section (column 2). Forty-four more were identified from hand sepcimens or in the field (column 3). In the thin section a distinction was made between diabases and metadiabases, but this was not possible in hand specimens. In column 3 they are called trap for lack of a better designation. One hundred twenty-eight of the dikes are composed of fine-grained dark rocks for which no specimen was collected and which were recorded as "mafic rock" in the field notes and are so listed in Tables 15 and 16.

Petrography. Average estimated modes are given in Table 17, as well as modes calculated from chemical analyses. Chemical analyses of five of the dike rocks are given in Table 18.

Seventy-five percent of the dikes are diabase, many of them altered to metadiabase. An ophitic texture is characteristic of all of them; the labradorite laths are generally 0.2 to 0.3 mm long but may be less near contacts of the dikes and larger near the interior of the thicker dikes. The interstitial augite is partially or completely altered to other minerals. Phenocrysts of labradorite, from 3 to 10 mm long, are present in some of the diabase but are generally partially sericitized. Augite phenocrysts, about 2 mm long, are present in some of the diabase.

Four groups may be established, based on the percentage of plagioclase phenocrysts present and the amount of alteration of the interstitial material.

Seven of the thin sections are diabase **sensu restrictu** as defined for this paper; that is, unaltered augite is more abundant than alteration minerals presumably derived from it (hornblende, chlorite, and carbonate). An average mode is given in Table 17, column 1a. Augite shows the pink pleochroism characteristic of titaniferous augite. Some of the opaque mineral is pyrite, the rest is probably magnetite or ilmenite. A few thin apatite needles are also present. A chemical analysis is given in Table 18, column 1. The mode calculated therefrom is given in Table 17, column 1b.

Only three thin sections, all from dike 2, were classified as porphyritic diabase. A mode is given in Table 17, column 2. The labradorite phenocrysts are 2 to 8 mm long, whereas the augite phenocrysts are 2 mm long. The groundmass consists of labradorite laths 0.2 mm long, in a ophitic

arrangement. Where least altered the interstitial material is augite and opaque. More commonly, however, the augite is partially altered so that the rocks contain small amounts of carbonate, chlorite, and uralitic hornblende.

Thirty-five of the thin sections are classed as metadiabase. They are texturally similar to the diabases **sensu restrictu**, but the augite is much more altered. An average mode is given in Table 17, column 3a. The occasional phenocrysts of labradorite range in length from 1 to 5 mm. The groundmass labradorite, which shows an ophitic texture, is generally 0.2 to 0.4 mm long, but in a few specimens is larger or smaller. Unaltered augite averages 2% of these rocks but original augite is mostly altered to carbonate, chlorite, opaques, and uralitic hornblende. Some of the carbonate forms spheres 1 mm in diameter, but much of it is a gray cloudy fine-grained material constituting 15% of the rock. The carbonate does not effervesce in cold dilute hydrochloric acid; hence it is dolomite rather than calcite; moreover some of the carbonate has been replaced by limonite, suggesting that it is ankeritic. Some of the opaque mineral is pyrite, the rest is probably magnetite, ilmenite, or ulvospinel. An opaque mineral that forms arborescent or trellised patterns is probably secondary. Rice et al. (1971) identified a similar mineral found in a dike in Lincoln, New Hampshire as pseudobrookite and considered it to be primary. Uralitic hornblende is in aggregates of small acicular grains. Limonite, sericite, and biotite are present in traces. The chemical analysis, Table 18, column 2, shows much more CO_2 and H_2O+ than the unaltered diabase. A mode calculated from this analysis is given in Table 3, column 3b.

Nine of the thin sections were classified as porphyritic metadiabase (Table 17, column 4). They are mineralogically and texturally similar to the metadiabase, except that they contain 10% or more of labradorite phenocrysts 1 to 10 mm long. The feldspar is partially sericitized.

There is only one thin section of the porphyritic hypersthene metadiabase. It differs from the porphyritic metadiabases in having 7% of hypersthene as phenocrysts 0.5 to 0.7 mm long. The labradorite phenocrysts are 1 to 4 mm long, whereas the plagioclase in the groundmass occurs as laths 0.2 mm long. The rest of the matrix consists of augite, opaques, and carbonates.

Seven of the thin sections were classified as camptonite, primarily on the basis of the presence of barkevikite which is pleochroic brown in thin section. The camptonites are fine-grained black rocks in which the minerals are generally 0.1 to 0.2 mm long. An average mode is given in Table 17, column 6. The plagioclase is labradorite. Augite, in subhedral crystals 0.1 to 0.3 mm across, is interstitial to the plagioclase and is characterized by pink pleochroism. Barkevikite, in needle-like crystals 0.1 to 0.3 mm long, is a distinctive feature of these rocks. Three chemical analyses, made by Mr. Peter Lyttle using the electron probe, are given in Table 19, columns 1, 2, and 3. An old analysis of barkevikite from the type camptonite at Campton Falls (Livermore Falls), New Hampshire, is given in column 4. The barkevikite from the Gorham Quadrangle is richer in MgO, but poorer in iron and alkalis. Carbonate and chlorite are abundant in these camptonites, as they are in most camptonites from New Hampshire. A chemical analysis of one of the camptonites from the Gorham Quadrangle is given in Table 18, column 3. Like all camptonites in New Hampshire (Billings and Wilson, 1964, p. 66), the rock is very low in silica but relatively rich in CO_2. A mode calculated from this analysis is given in Table 17, column 6b.

Three thin sections are diorite. The dikes from which they come are noteworthy for two reasons. They strike north or northwest, contrary to the majority of the dikes. Moreover, they obviously control the location of streams. They are black, fine-grained rocks in which the individual grains are 0.1 to 1 mm in diameter. An estimated average mode is given in Table 17, column 7. The plagioclase laths, which are andesine, are much broader relative to their length than the plagioclase in the diabases. Much of the hornblende forms interstitial grains 0.1 to 0.5 mm across; it is pleochroic in shades of yellow and green. But some of the hornblende occurs as acicular grains. A chemical analysis of diorite is given in Table 18, column 4. A mode calculated therefrom is given in Table 17, column 7b.

There are two thin sections from the same dike of augite lamprophyre. This is a fine-grained black rock rich in augite, some of which occurs as phenocrysts 0.5 to 1.0 mm long (Table 17, column 8). Much of the plagioclase is sericitized or kaolimized.

The thin section of dike 93, 12 feet thick and on the east side of the Androscoggin River 0.4 miles northeast of Cascade, has been classified as a metagabbro. It is not unlike dike 45 at an altitude of 1415 feet on Tinker Brook. However, the dike on Tinker Brook has an ophitic texture, whereas dike 93 has a hypidiomorphic granular texture. An estimated mode is given in Table 17, column 9. The minerals range in size from 0.5 to 1.0 mm. Plagioclase is badly clouded, and is andesine or labradorite. One percent of barkevikite indicates a relationship with the camptonites. Other minerals are opaques, zoisite, and biotite.

Dike 26, exposed on the south fork of Cascade Brook at 1780 feet, is fine-grained hornblende syenite. In hand specimen it is a fine-grained rock with feldspar phenocrysts, 3 to 5 mm long, comprising one percent. Casual inspection suggests that the groundmass is gray. But closer study shows that it consists of pink feldspar and black hornblende, both minerals 0.3 to 1 mm across. The mode is given in Table 17, column 10. The feldspars show a trachytic texture. The thin section shows that the phenocrysts are highly sericitized, but albite twinning is present, and the extinction angle suggests albite-oligoclase. Despite the high degree of alteration, the albite twinning of the groundmass feldspar also indicates albite-oligoclase. The hornblende, 19%, is pleochroic light- to dark-green and consists of aggregates of acicular grains. Interstitial quartz is present; other minerals are opaques and carbonate.

Four of the thin sections are rhyolite. Confined to the northwest corner of the quadrangle, they are dense tan rocks, which in many instances possess a flow layering that is poor to excellent. The layers, which are

parallel to the walls of the dikes, range from 0.05 to 5 mm in thickness but in most cases are 1 to 3 mm. One specimen contains vugs with quartz and feldspar crystals, suggesting a relatively shallow intrusion. The rocks are so fine-grained that identification of the minerals in the thin sections is impossible but the presence of spherulites suggests devitrification and relatively shallow intrusion. One of the specimens has slickedsided surfaces parallel to the flow banding, suggesting that flowage continued after intrusion. A chemical analysis, Table 18, column 5, indicates a rhyolite. The mode in Table 17, column 11, was calculated from this analysis. On Mt. Jasper a 20-foot tunnel is in a rhyolite dike.

Structure. Most of the post-metamorphism dikes are seen at only one locality: in natural exposures, in railroad or highway cuts, or along streams. Some, however, as will be shown below, can be traced for long distances along streams. The contacts are everywhere sharp. Most of the dikes are simple, consisting of a single body. Some more complicated relations are shown in Figures 50 and 51. Two or more parallel dikes of the same rock may occur in close proximity to one another, as shown in Figure 50a, b, and c. In computing the average thickness of all the dikes in the quadrangle, the thickness of such parallel dikes was calculated to be the sum of the thickness of the individual dikes. In the preparation of Figure 53 such dikes are treated as one, because along strike they may become a single multiple dike. For example, along strike the dike shown in Figure 50c becomes a multiple anastomosing dike (Fig. 50d). One dike is composite (Fig. 50e); it was treated as one in Figure 53. Some dikes change strike (Figs. 50f and 51a); the data from the longest section was used in preparing Figure 53. Small branches diverge from some dikes (Fig. 51b and c); the data for the main segment were used in preparing Figure 53. The dip of some dikes is not constant (Fig. 51d); an average value was used in preparing Figure 53. Some dikes cross one another (Figs. 51e and 52); both dikes are plotted in Figure 53. Some dikes have complicated patterns (Fig. 51b); the most prominent reading is entered in Figure 53. Three intersecting dikes are shown in Figure 52.

The perpendiculars to 235 of the 241 dikes listed in Tables 15 and 16 and shown on Plate 3 are plotted in the stereographic projection in Figure 53; the attitude of six of the dikes was not measured in the field. It is apparent that most of the dikes dip steeply. Also, although the strikes "box the compass," the great majority strike northeasterly.

The dikes range in thickness from a few inches to 20 feet, the average being 3.5 feet. Fourteen of the dikes are followed by streams, and consequently can be traced for long distances, a mile in one case (Table 20). Moreover, since the gradient of these streams is considerable, the highest exposure may be hundreds of feet above the lowest (vertical range in Table 20), 880 feet in one case.

Tectonic significance. The tectonic significance of the dikes presents interesting problems. The dikes that are exposed are only a fraction of the total number of dikes in the area. A discussion of all the factors that should be considered in an attempt to calculate the actual number of dikes would consume many pages.

A method analogous to the Rosival method may be applied. Along streams where outcrops are good, three dikes per mile are observed on the average. Since the outcrops constitute only one-third the total length of such streams, the number of dikes per mile is nine. Imaginary northwest-southeast traverse lines placed a mile apart over the whole quadrangle total 222 miles in length. The total number of dikes is 222 x 9 = 1998. Any dike over a mile long is counted more than once; in fact, it is counted as many times as its length in miles.

Another method is based on area. Reference to Plate 3 shows that in places the number of **known** dikes averages 9 per square mile. Obviously there are undoubtedly unexposed dikes; conversely, some of the dikes may be counted twice if exposed in adjacent areas. The total number of dikes is approximately 18 per square mile. But in other areas where there are large exposures, the number is much less. The average for the quadrangle appears to be of the order of 10 per square mile or 216 x 10 = 2160.

An average of the two calculations is about 2000, but even this is very crude.

If the dikes are dilatational the amount of stretching can be calculated. The following assumptions are made: (a) all the dikes strike northeast and are vertical; (b) there are nine dikes per mile along northwest-southeast traverses; (c) average width is 3.5 feet. The amount of stretching is 22.5 feet per mile or 405 feet where the quadrangle has its greatest northwest-southeast extent, which is 18 miles. Differential vertical movements could account for this amount of stretching. Although these figures are not precise, their magnitude shows that extensive stretching of the continent did not accompany the intrusion of the post-metamorphism dikes.

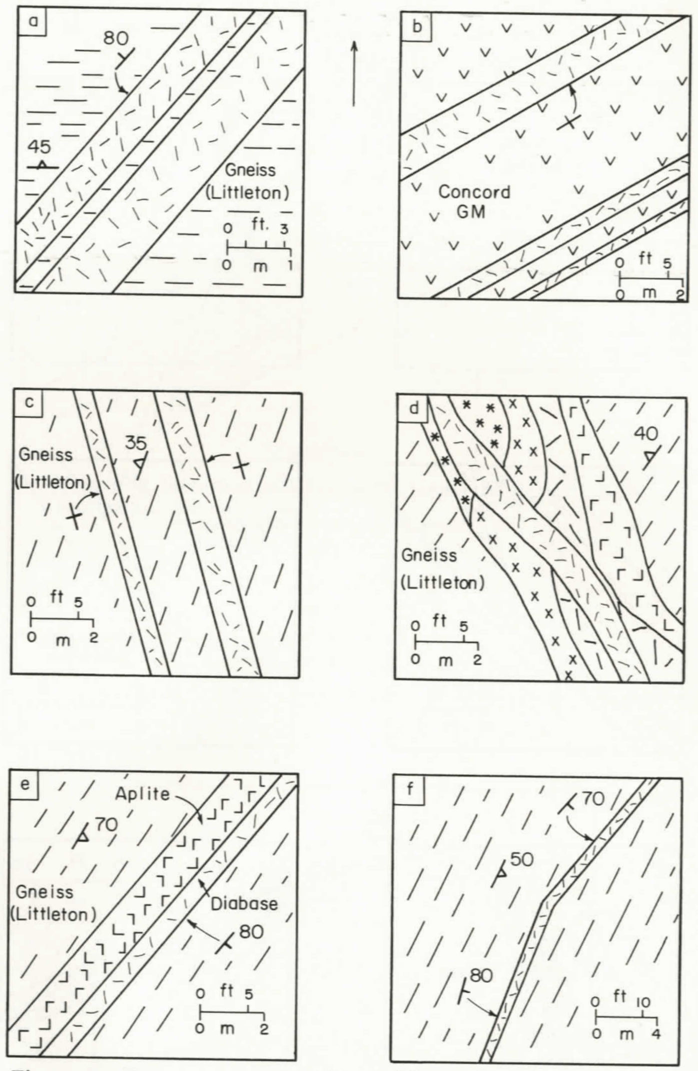

Figure 50. Patterns of Post-Metamorphism Dikes. a. Two parallel dikes; "mafic rock"; trail, 3000 feet north of Cold River Campground. **b.** Three parallel dikes; "mafic rock"; Leadmine Brook, altitude of 780 feet. **c.** Two parallel dikes; eastern is porphyritic diabase, western is porphyritic metadiabase; south fork of Stony Brook, altitude of 2100 feet. **d.** Multiple dikes, same dikes as those in map **c**; south fork of Stony Brook, altitude of 2120 feet. **e.** Composite dike; Bull Brook, altitude of 1560 feet. **f.** Change in strike; "mafic rock"; altitude of 1610 feet on tributary entering Bull Brook at altitude of 1580 feet.

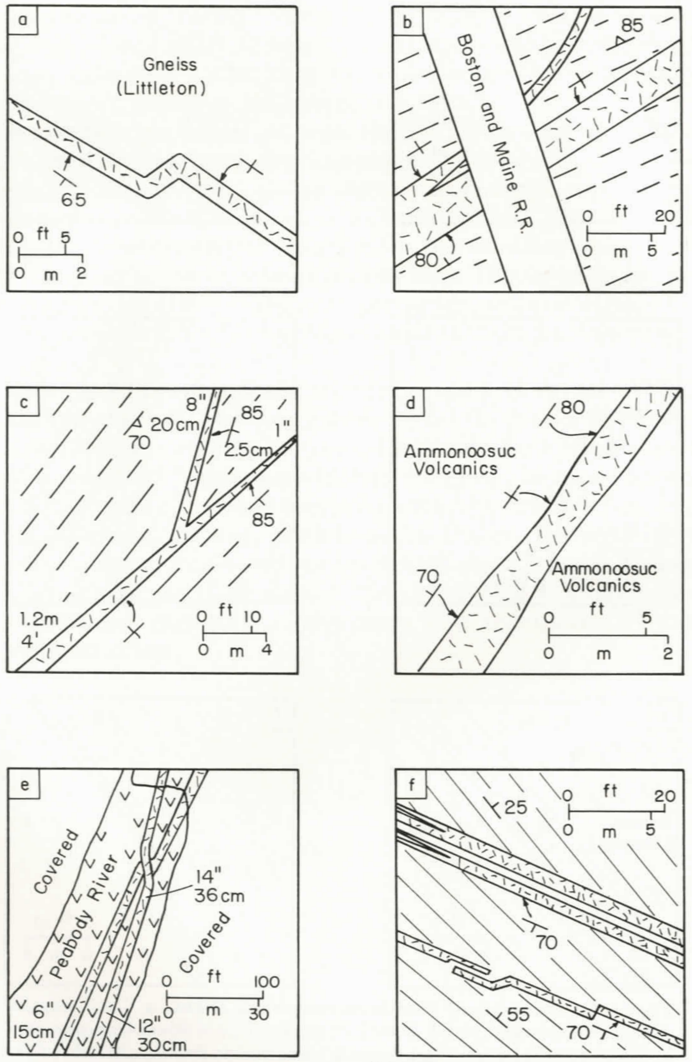

Figure 51. Patterns of Post-Metamorphism Dikes. a. Sharp changes in strike; "mafic rock"; Martins Brook, altitude of 1540 feet. **b.** Branching dike; metagabbro; Boston and Maine R.R., ½ mile north of Cascade. **c.** Branching dike; "mafic rock"; altitude of 1390 feet on tributary that enters Blue Brook at altitude of 1170 feet. **d.** Change in dip; "mafic rock"; Tinker Brook, altitude of 1040 feet. **e.** Intersecting dikes; width of dikes exaggerated for clarity; 14" dike is metadiabase, 6" dike is "mafic rock," Peabody River, altitude of 910 feet. **f.** Splitting dikes; camptonite; Middle Branch of Mad River, altitude of 1170 feet.

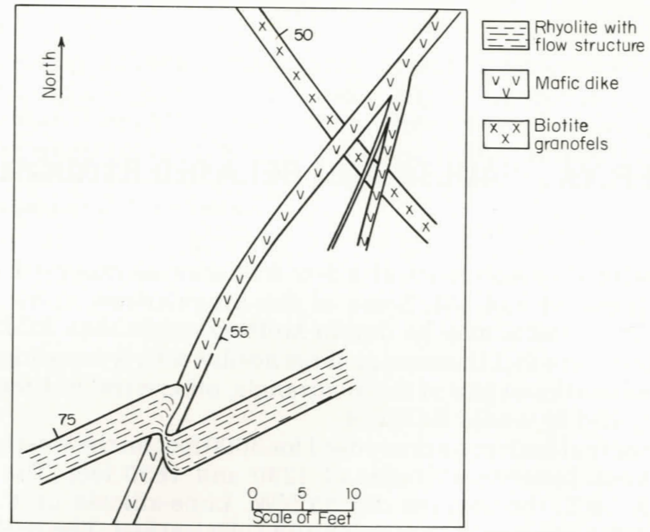

Figure 52. Intersecting Dikes on Mt. Jasper. Altitude of 1525 feet on southwest slope.

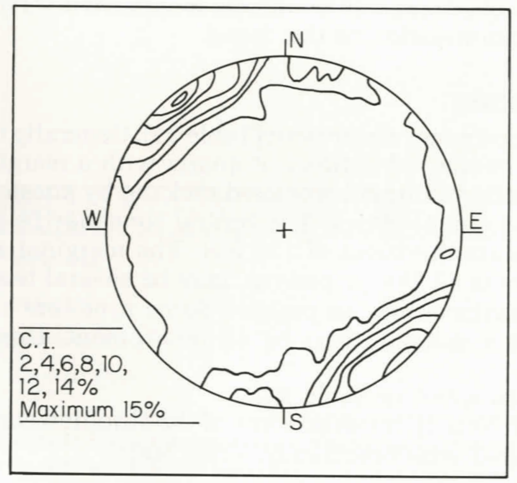

Figure 53. Stereographic Projection of Post-Metamorphism Dikes. Lower hemisphere. Perpendiculars to 237 dikes.

CHAPTER VII. FAULTS AND RELATED STRUCTURES

Faults

Faults with displacements of a few feet may be observed in some outcrops (Figs. 54 and 55). Some of the irregularities in the trace of sedimentary contacts may be due to faulting rather than folding. It is reasonably certain that there are no large northwesterly trending traverse faults in the southeast part of the quadrangle, otherwise the lime-silicate units (2, 4, and 6) would be offset.

A longitudinal fault zone is exposed for 3000 feet on the west branch of Connor Brook between altitudes of 1230 and 1630 feet. The average strike is N 50°E, the average dip 55°NW. Lime-silicate unit No. 6 is exposed in the hanging wall at an altitude of 1300 feet. The fault zone is characterized by brecciation, gouge zones a foot thick, slickensided surfaces, fractures, and silicified zones up to 2 feet wide. The fault zone erodes more readily than the adjacent rock, and is followed by the stream, which in places is in a gorge 50 feet deep. In these battered rocks stratigraphic relations are not obvious, but it is probably a normal fault. The presence of silicification substantiates the assumption that the silicified zones described below are along faults.

The only topographic feature suggesting erosion along a fault is the valley of Nineteen Mile Brook flowing N 15°W, over a thousand feet deep, and separating Wildcat Mountain from Carter Dome. But in the North Conway quadrangle lime-silicate member 6 does not appear to be offset on the continuation of this trend.

Silicified Zones

A few silicified zones are present (Table 21). Generally these consist of a central area composed entirely of quartz with a marginal zone composed of partially silicified brecciated rock cut by anastomosing quartz veins one or two inches thick. The central zone may be absent, but can reach a maximum thickness of 130 feet. The marginal zone, which in some instances is all that is present, may be several tens of feet thick. Slickensided surfaces may be present. Some zones are expressed topographically by a valley, others by an escarpment. Dips are probably steep.

Basic data are listed in Table 21.

Elsewhere in New Hampshire some of the silicified zones are demonstrably associated with brecciation along faults.

Joints

In general, no effort was made to record and analyze systematically the joints. A proper study would have been very time consuming and unless done properly might be misleading. But a few of more spectacular examples were recorded. Near Imp Shelter, in the Carter-Moriah Range, joints striking northeast and dipping 25°NW have a strong control on minor topographic features.

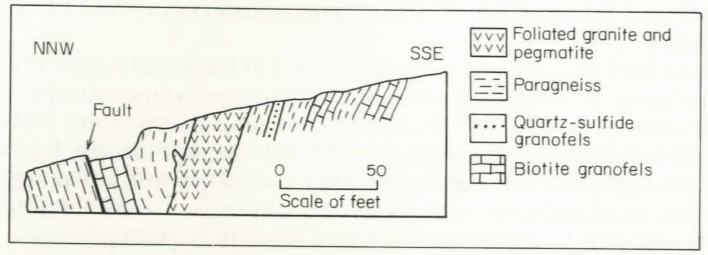

Figure 54. Minor Fault and Minor Lime-Silicate Unit. Cowboy Brook, altitude of 3090 to 3130 feet.

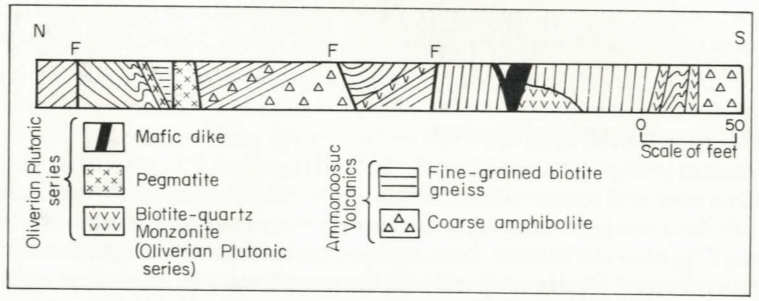

Figure 55. Faults in Folded Ammonoosuc Volcanics. Boston and Maine R.R., ½ mile northeast of Cascade.

CHAPTER VIII. REGIONAL METAMORPHISM

Introduction

In recent years a great deal has been written on regional metamorphism in New England (Thompson and Norton, 1968; Albee, 1968; Billings, 1956). The publications contain much factual information as well as discussions of theoretical aspects of the problems. Emphasis has been on metamorphic zonation, equilibrium relations, partitioning of elements among the various minerals, and temperature and pressure during metamorphism. Textural features and their bearing on metamorphic history have been largely neglected. Theoretical aspects of metamorphism will be discussed only to the extent that the Gorham Quadrangle offers pertinent information. The metamorphism is believed to be Middle Devonian.

Most, and perhaps all but a small portion of the quadrangle is in the sillimanite zone. A small area west of Dolly Copp Campground is in the staurolite zone (Fig. 56). On the geological map of the state (Billings, 1956) the Ammonoosuc Volcanics and the Oliverian Plutonic Series are shown in the staurolite zone, but neither staurolite nor sillimanite are found there, as aluminous sediments are lacking.

The subject will be discussed chronologically by formations.

Ammonoosuc Volcanics

Rocks of this formation have been described on an earlier page. The minerals were identified by optical methods and by microprobe. It is expected that Mr. Richard Sanford will consider the significance of the analyses in relation to regional metamorphism. A very detailed study of similar rocks in southwestern New Hampshire and northern Massachusetts has been made by Robinson and Jaffee (1969) and Robinson **et al.** (1968).

Oliverian Plutonic Series

Granting that the rocks of the Oliverian Plutonic Series are metamorphosed rocks of the Ordovician Highlandcraft Plutonic series, the original texture was hypidiomorphic granular. In the subsequent metamorphism the texture became granoblastic, and foliation and lineation developed. There was no significant change in chemical composition.

Littleton Formation

The metamorphism of the Littleton Formation will be treated under

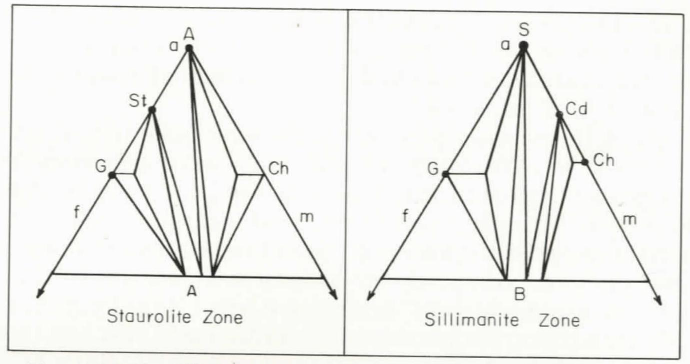

Figure 56. Equilibrium Diagrams for Staurolite and Sillimanite Zones. G-garnet, B-biotite, S-sillimanite, Cd-cordierite, Ch-chlorite, a-Al_2O_3 corner of triangle; f points to iron corner, m points to magnesium corner. After Albee (1968).

three categories: (1) metamorphic mineral zonation; (2) metamorphic textural zonation and metamorphic history; and (3) origin of paragneisses (migmatites).

A map showing the distribution of metamorphic zones in the Mt. Washington Quadrangle (Billings, 1941, Fig. 3) includes the western part of the Gorham Quadrangle south of the Dolly Copp Road and west of the Peabody River (Route 16). This map was based on both mineralogy and texture, and hence is not entirely satisfactory for those two features individually. In the present paper a distinction will be made, as it has a bearing on the metamorphic history.

An area west of Dolly Copp Campground, covering 1½ square miles, half in the Gorham Quadrangle and half in the Mt. Washington Quadrangle, lies in the staurolite zone. Presumed mineral assemblages in this part of the staurolite zone are shown in Figure 56a (Albee, 1968). Some of the specimens, such as that shown in Table 6, column 8, contain garnet as well as staurolite. They represent rocks with a chemical composition near the left side of the diagram. Others contain andalusite rather than garnet; they represent rocks with a chemical composition just left of center. The temperature during metamorphism was about 600°C., the pressure about 2.5 kilobars, equivalent to a load of 9.5 km or 6 miles.

In the rest of the quadrangle the Littleton Formation is in the sillimanite zone as shown in Figure 56b (Albee, 1968). Columns 4, 6, and 7 of Table 6 are representative of these zones. The presence of garnet indicates the original sediments had a chemical composition similar to the left-hand part of the diagram. Chlorite in these rocks is retrograded from biotite. The temperature at the time of metamorphism was probably

700°C., and the pressure about the same as in the staurolite zone.

The minerals in the lime-silicate rocks were identified by optical methods. No study was made to determine the partitioning of elements among the various minerals.

Differences in metamorphic histories have resulted in contrasting textures. In the Mt. Washington quadrangle, although some fresh andalusite is present, most of it has been altered to "pseudo-andalusite," a mixture of sillimanite, muscovite, and quartz. In the coarser and intermediate varieties the knots of "pseudo-andalusite" range in length from 1 to 5 cm, less commonly are as long as 20 cm. In the fine-grained rocks the "pseudo-andalusite" knots are 0.5 to 1.0 cm long. As shown in Figure 57, with rising temperature the pelitic rocks reached the andalusite zone (point a). Eventually, as the temperature continued to rise, the rocks passed into the sillimanite zone (point b).

In the Gorham Quadrangle rocks containing "pseudo-andalusite" are rare and wherever found the "pseudo-andalusite" is small. Large and intermediate size andalusite crystals never formed. There may be several reasons for this: (1) the original sediments may not have had the right chemical composition; (2) temperatures may have risen so rapidly that the andalusite stage was bypassed and the rocks moved directly into the sillimanite stage; and (3) the influx of potash and silica may have occurred somewhat earlier than in the Mt. Washington area so that excess Al_2O_3 was promptly made into muscovite before andalusite could form.

Within the large F_3 fold west of the Glen House the mineral lineation is parallel to the hinges of the minor F_3 folds. It is L_3. Such relations may be observed on Lowes Bald Spot, which is ¼ mile west of the quadrangle boundary and ¼ mile north of the Mt. Washington Auto Road. But most of the mineral lineation elsewhere in the quadrangle is parallel to the F_1 folds; it is L_1. All the recrystallization with which the lineation is associated appears to be contemporaneous throughout the quadrangle. Thus, although the F_1 folds and L_1 lineation were initiated during the D_1 deformation, the final folding and development of lineation took place during the D_3 deformation.

The paragneiss (migmatite) of the Littleton Formation typically consists of two parts, a biotite-rich darker portion and a lighter white "granite part" composed of quartz and plagioclase. Metamorphic differentiation of an original siltstone has produced these two parts.

An analysis of the origin of the paragneisses involves two problems: how important was metasomatism and did the genesis of the paragneiss involve partial melting?

The subject of metasomatism has been discussed on an earlier page. It has been shown (Table 9) that the chemical composition of the paragneiss is very similar to that of the slates in the low-grade zone, implying little or no metasomatism.

The paragneiss may be the result of partial melting. One possible consequence of a rise in temperature is illustrated in Fig. 57 (A.B. Thompson, 1974). For example, if the pressure were 3.5 kilobars in rocks of appropriate composition, they would eventually become hot enough

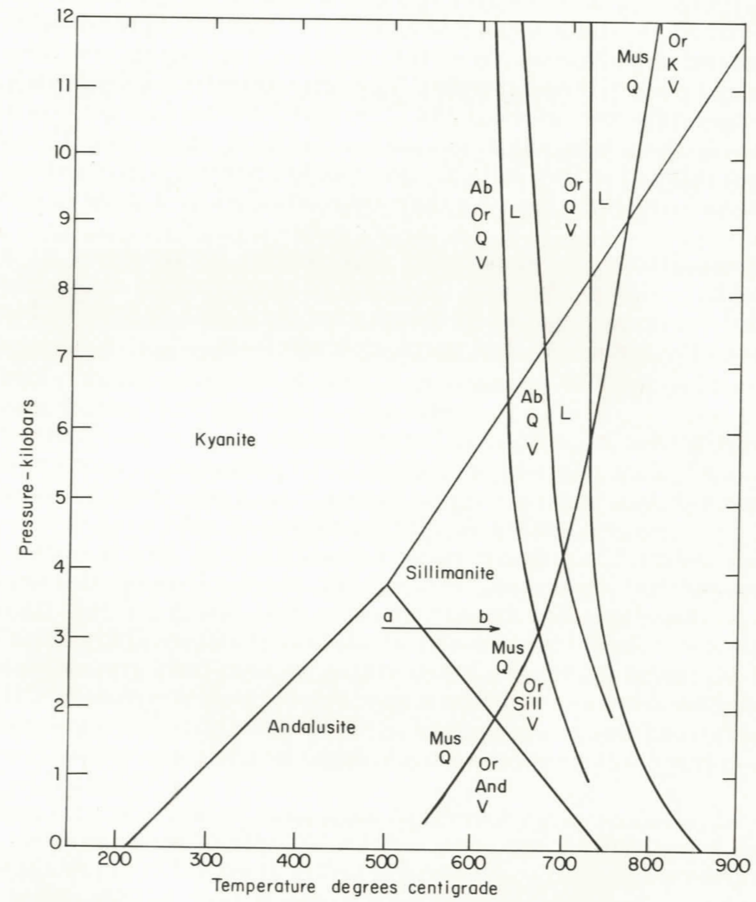

Figure 57. Petrogenetic Grid for Pelitic Rocks. After A.B. Thompson (1974). Shows temperatures-pressures at which kyanite, andalusite, and sillimanite are stable aluminum silicate. Curve labeled Mus-Q shows temperatures-pressures at which muscovite (plus quartz) breaks down to orthoclase, aluminum silicate (andalusite, sillimanite, or kyanite) and vapor. Three other curves are melting curves for granitic rocks in which feldspar is orthoclase and albite, or albite, or orthoclase.

for sillimanite to form. At about 700°C. the "granite melting" curve would be reached. If quartz, potash feldspar, and oligoclase were present in the rocks they would start to go into mutual solution. Because of an excess of Al_2O_3, these rocks had muscovite instead of potash feldspar. Quartz and oligoclase would go into solution, and segregate to form the layers and pods in the migmatites. The muscovite would not participate. As temperature rose, at about 750°C. muscovite would become unstable and break down into potash feldspar, sillimanite, and water. This stage was not reached in the Gorham area. The temperatures given above are only approximations because they are controlled by a number of variables.

Nielson (1973) has concluded that similar paragneisses in west-central New Hampshire were the result of metamorphic differentiation that did not involve partial melting; rather their genesis involved segregation in the same way that porphyroblasts form.

CHAPTER IX. GEOLOGICAL HISTORY

The geological history of New Hampshire has been discussed in many publications and only a brief review is necessary, with special emphasis on those features pertinent to the Gorham Quadrangle.

In this area the history began with the accumulation of the Ammonoosuc Volcanics in the Middle Ordovician. The volcanics show a great range in composition, from basalts to rhyolites. Pyroclastic rocks are more abundant than flows. Similar rocks, 2000 to 5000 feet thick accumulated over much of New England at the same time. There were probably many eruptive centers, but because of later folding and metamorphism they are hard to identify.

The Oliverian Plutonic Series injected in Middle Ordovician time as a medium- to coarse-grained hypidiomorphic granular rock. There is no evidence of the Ordovician Taconic orogeny in this area, but the evidence may have been obliterated by the Acadian Orogeny.

A period of erosion was followed by an invasion of Silurian seas. No rocks of this age are known in the Gorham Quadrangle, but they may be present; they are found both to the northwest and southeast.

In the Early Devonian tens of thousands of feet of sand, shale, and silt were deposited. The Somerset geanticline (Cady, 1968), where the Bronson Hill anticline is now located, was a positive area, with deep basins developing to the northwest (eastern Vermont) and southeast (Maine). The sediments were derived largely from a land mass in what is now the Gulf of Maine.

The rocks were folded during the Acadian orogeny in the Middle and Late Devonian about 390 to 360 million years ago. At that time the rocks were at a depth of 9.5 km (6 miles) beneath the surface of the earth (A.B. Thompson, 1974). Four stages of folding have been recognized in the Gorham Quadrangle, but all were probably merely phases of a continuous deformation; the earlier folds trend northeasterly. The folds of the third stage trend northwesterly. The fourth stage is represented by minor open chevron folds and was not studied.

The rocks were metamorphosed during the Acadian orogeny, mostly in the sillimanite zone, but a small area was in the staurolite zone. The rocks of the Ammonoosuc Volcanics were converted to amphibolites, fine-grained biotite gneisses, and related rocks. The rocks of the Oliverian Plutonic Series were changed into foliated and lineated granoblastic gneisses. The arenaceous and argillaceous carbonate rocks of the Littleton Formation became lime-silicate granofelses and related rocks. The shales and sandstones of the Littleton Formation became schists, feldspathic quartzites, and paragneisses. Although small andalusite crystals formed in some of the more aluminous rocks, the andalusite was converted into sillimanite, muscovite, and quartz. The paragneisses (migmatites) were siltstones that became progressively metamorphosed to higher grades and eventually segregated in a dark biotite-rick portion and a light-colored quartz-feldspar portion. This differentiation probably did not involve melting.

The dikes of biotite granofels, although few in number, are of considerable theoretical interest. They are lime-silicate rocks that were derived from the lime-silicate members of the Littleton Formation and injected prior to the intrusion of the New Hampshire Plutonic Series.

Two members of the New Hampshire Plutonic Series were emplaced near the end of the orogeny. The Kinsman Quartz Monzonite at the south end of the quadrangle has a marginal platy structure. The Concord Quartz Monzonite and the associated pegmatites are ubiquitous throughout the Littleton Formation. The Concord forms several large stocks and countless small dikes and sills. Large pockets of magma formed at depth. Rising because of its lower density, it shattered and intruded the overlying rocks. Larger bodies worked their way upward in part by stoping.

The Early Jurassic White Mountain Plutonic-Volcanic Series (185 million years old) is of minor importance in this area. Diorite, a few volcanic vents and many dikes belong to this series. This series consolidated at a depth of 6.5 km (3.9 miles) beneath the surface of that time (Wilson, 1969, p. 83).

Since the Jurassic the area has been undergoing stream erosion. The present topographic features began to develop a few million years ago. The details of the topography were profoundly modified during the Pleistocene by glacial erosion and deposition.

CHAPTER X. CONCLUSIONS ON METHODS OF STRUCTURAL ANALYSIS

One of the main objectives of the present investigation was to evaluate the comparative effectiveness of the various methods of structural analysis. It should be made clear, however, that the conclusions are applicable only to metamorphic terrains similar to those in the Gorham Quadrangle.

The most important document in a structural field study is the geological map, showing the distribution of the lithologic and stratigraphic units, as well as symbols for bedding, foliation, and other elements. In areas of simple structure, such as the Valley and Ridge Province of the Appalachian Highlands, this type of map is sufficient to deduce the structure. In areas of complex structure such maps may by themselves not be adequate, and must be supplemented by other methods.

A tectonic map, as the term has been used in New England, is essentially a geological map with many different structural symbols concentrated as close as the scale will permit (Billings, 1941, Pl. 10). By scanning such maps the experienced structural geologist can readily visualize the structure in three dimensions.

Where structural features are small, maps on a scale of 1/62,500 or 1/24,000 (common scales for topographic maps issued by the Untied States Geological Survey) may not be adequate. Large scale maps, on a scale of 1" = 100', 1" = 200', or 1" = 400', as in the present study, may be essential to show the concentrated data.

In recent years a great deal of emphasis has been placed on the use of the equal-area and stereographic projections for structrual analysis (Bucher, 1944; Billings, 1972). Such projections have been used in the present study (Figs. 19, 20, 30, 31, 34, 40, and 53). They purport to be a statistical study of the areas they cover. But they have several deficiencies. The exposure of basic data is usually haphazard because of the terrain, thus tending to invalidate a statistical analysis. Moreover, these projections fail to show the geographic relations of the numerous points entering the diagram.

In structural petrology the emphasis has been on microscopic studies. But such investigations are of little use in deducing the geologic structure. On the other hand, they are of inestimable value in studying the internal strains and mechanics of deformation (Billings, 1972, p. 428-431). Such methods were not employed in the Gorham Quadrangle because suitable rocks were not available, the studies would be time consuming, and the interpretation of the data is often inconclusive.

Geophysical methods have been of great aid in investigating the larger geological structures of New Hampshire (Billings, 1972; pp. 456, 463-468, 491). But most of the published geophysical maps are on too small a scale for analyzing minor features.

An aeromagnetic map of the Berlin area, scale 1/62,500 was published (Bromery, **et al.**, 1957) after our field work was completed. Strong positive anomalies are associated with the Ammonoosuc Volcanics, and there is excellent correlation between the geological and aeromagnetic maps (Billings, 1972, p. 462-465).

Gravity surveys (Joyner, 1963; Kane, **et al.**, 1972) are on too small a scale to be of use in the Gorham Quadrangle.

In summary, geological and tectonic maps, especially those on large scales, have been the most useful documents in unravelling the structure. The map pattern, especially that shown by marker beds or members, is the single most important information in areas such as the Gorham Quadrangle. Stereographic projections have been of supplementary help. Geophysical methods have not been employed, chiefly because their greatest value is in analyzing large structures.

CHAPTER XI. MINERAL RESOURCES

Introduction

The value of any mineral deposit depends not only on the quality and quantity, but also, in many cases, on the proximity of the consumer. Resources that are of potential value in the Gorham Quadrangle are metals (lead and zinc), pegmatites, silicified rock, and sand and gravel.

Metals

Two lead mines have been worked in the Gorham Quadrangle in the past, the Mascot and Shelburne. Both have been described by Cox (1970) and the latter by Hitchcock (1878, part V, p. 64-65).

The Mascot Mine lies a mile north of Gorham, on the slopes north of Mascot Pond. According to Cox (1970) the vein strikes N.35°E., dips 70°NW, is 10 to 20 feet wide, and extends through a vertical range of at least 200 feet. The vein, which cuts the Concord Quartz Monzonite, is a breccia composed of angular fragments of altered quartz monzonite set in a matrix of quartz and manganosiderite. The principal ore minerals are galena and sphalerite, with minor quantities of chalcopyrite. The galena contains small amounts of silver and tin. The gangue minerals are quartz, pyrite, and manganosiderite.

The vein is along a fault. The associated rocks are sheared and slickensided. Moreover, Cox (1970) says that a vertical "aphanitic" dike 2 feet thick, striking N.80°W., has been offset 10 feet along the vein, and an additional 14 feet along two adjacent faults 2 and 6 feet northwest of the vein. Cox considers the mineralization to be related to the White Mountain Plutonic-Volcanic Series, that is, of early Jurassic age.

The vein was mined from 1881 to 1885 and again in 1906. Three levels extend about 150 feet northeast along the vein.

The Shelburne Mine is located on the West Branch of Leadmine Brook at an altitude of 960 feet. The vein, exposed in the brook bed for 300 feet, is a silicified zone, 10 to 15 feet wide, that strikes N.75°E. and dips 65°NW. The ore body is a breccia composed of altered and silicified country rock cut by small quartz veins. The principal ore minerals are galena (0.5% silver), sphalerite, and minor chalcopyrite. Gangue minerals are quartz, arsenopyrite, and manganosiderite. The vein was mined intermittently between the 1830's and 1880.

The Stevens prospect is at an altitude of 1240 feet on Stevens Brook. A small prospect hole has been opened on a vein 2 feet wide. It strikes N. 35°E. and dips 70°NW.

The area where these mines and this prospect are located was investigated in 1948-49 by the U.S. Bureau of Mines, in 1962 for the Brown

Company by Lawrence Wing, now with Lawrence Wing and Associates, Bangor, Maine, and in the 1960's by the U.S. Geological Survey (Cox, 1970).

Pegmatites

Granite pegmatites are common throughout the Gorham Quadrangle, but little prospecting or quarrying has been done. The pegmatites occur as dikes and sills that range in thickness from a few inches to many tens of feet, and as irregular bodies. The principal minerals are quartz, feldspar, and mica, locally with small amounts of garnet, tourmaline, and beryl.

The Fisher prospect is on the west slopes of Artist Rock at an altitude of 1050 feet. A detailed description is given in Cameron (1954, p. 136).

The Chandler quarry was studied in 1953 during this investigation. The body is at least 50 feet across and the west wall is 35 feet high. The pegmatite is very coarse grained; crystals of feldspar (perthite) as much as 5 feet in diameter are present and masses of interstitial quartz are as much as 10 feet long. It is SW of Cold River Forest camp.

Muscovite (white mica) is used in electrical appliances, vacuum tubes, capacitors and other products (Brobst and Pratt, 1973, p. 415-423). Sheet mica should be flat, free from defects, and large enough to be cut into pieces one square inch. Scrap mica consists of smaller pieces. Most sheet mica is imported because of labor costs in the United States.

Fifty-five percent of the feldspar sold in the United States is used in glass, 31 percent in pottery, 4 percent in enamel, and 10 percent in other products (Brobst and Pratt, 1973, p. 217-222). Distance from markets is one deterrent to mining feldspar in New England.

Beryl is one source of beryllium (Brobst and Pratt, 1973, p. 85-93), a metal of low specific gravity used in aircraft, spacecraft, and generation of nuclear power. Unfortunately beryl is very erratically distributed in pegmatites, and generally in small quantities.

Gemstones (Probst and Pratt, 1973, p. 247-250) have been found in pegmatites in western Maine (Morrill, 1963) and there is always the chance of finding some in pegmatites in the Gorham Quadrangle.

Excellent specimens of quartz, feldspar, topaz, phenacite and other minerals have been found in the adjacent North Conway quadrangle (Billings, 1927; Gillson, 1927; Morrill, undated), but they are associated with the Conway Granite, which is absent from the Gorham quadrangle.

Silicified Rock

The rock from a silicified zone in Lyndeborough in southern New Hampshire (Greene, 1970) has been quarried and crushed to fine particles to mix with concrete to give it sparkle and luster. The only silicified zone of sufficient size in the Gorham Quadrangle to be utilized in this way is the zone at the north edge of the quadrangle 0.8 mile east of the Androscoggin River. Those portions of the zone containing pyrite can not be used, because this mineral would soon rust, giving the concrete a

brown color. Transportation costs to market are a deterrent to such utilization at the present time.

Sand and Gravel

At present the United States produces enough sand and gravel to meet its needs, but within 25 years the available resources may not be adequate (Brobst and Pratt, 1973, p. 561-565). Ninety-six percent of the consumption is in the construction industry: concrete aggregate, bituminous mixes, and fill.

Most of the sand and gravel deposits in the Gorham Quadrangle are glacial deposits, laid down in temporary lakes when the ice was melting or by streams flowing away from the ice. The sand and gravel in the bed of modern streams is reworked glacial material.

Several large sand pits are present in the quadrangle: (1) at an altitude of 1700 feet along the Mt. Washington Auto Road; (2) at an altitude of 1500 feet along the Dolly Copp Road; and (3) east of Moose River, one mile west-southwest of its mouth.

No special survey was made of these resources in the present study, as it was felt they were adequately described by Goldthwait et al. (1951). Most of the deposits are along the Androscoggin, Dead, and Moose Rivers. A few north of the Success Pond Road are not shown on their map. Now that new topographic maps are available on a scale two and a half times as large as that used in this study, a resurvey of the sand and gravel resources is highly desirable.

TABLES 1-21

Table 1. Ammonoosuc Volcanics, Representative Chemical Analyses of Amphiboles, Pyroxenes, and Biotites (WGT %)

	Anthophyllite		Gedrite	Cummingtonite		Hornblende			Clinopyroxene		Biotite			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	49.93	53.76	47.11	53.84	55.16	42.27	44.28	43.05	51.55	51.80	38.24	37.12	34.94	39.37
TiO_2	.02	.03	.44	.00	.00	.15	.58	.69	.20	.05	1.39	1.40	1.15	.93
Al_2O_3	7.24	.00	11.90	1.80	.76	15.78	11.55	12.53	1.90	1.09	17.02	17.23	16.15	17.14
FeO‡	21.66	25.63	17.99	22.46	22.18	17.16	15.08	18.81	8.36	10.69	14.00	15.95	23.79	11.05
MgO	18.42	18.61	16.60	18.92	20.12	10.30	11.48	11.31	13.04	13.78	16.17	16.32	15.50	17.32
MnO	1.20	.54	.82	1.14	1.07	.40	.29	.33	.35	.37	0.13	.24	.14	.05
CaO	.20	.19	.33	.17	.40	11.86	12.31	12.88#	24.66	25.02#	0.00	.27	.28	.03
K_2O	.04	.03	.05	.04	.08	.37	.51	.70	.00	.07	8.60	6.34	3.98	8.02
Na_2O	.29	.12	1.43	.16	.00	1.65	1.74	1.89	.53	.84	0.46	.19	.32	.55
Total	99.00	98.91	96.67	98.54	99.77	99.94	97.81	102.19	100.61	103.70	96.02	95.08	96.24	94.45
Total No. of Analyses*	4	8	2	6	24	14	11	4	6	5	2	4	5	6

Columns	Specimen No.	Rock	Locality
1, 4, and 11	G108A	Anthophyllite-cummingtonite amphibolite	Bean Brook, altitude 1310'
2 and 13	G189A	Fine-grained light-gray anthophyllite gneiss	Sixth Avenue, Berlin
3 and 14	G291	Coarse biotite-gedrite gneiss	Boston and Maine Railroad, 0.6 mile north of Cascade
5, 6, and 12	G112A	Hornblende-cummingtonite amphibolite	Bean Brook, altitude 1330'
7 and 9	G136	Hornblende-augite amphibolite	Cascade Brook, altitude 1120'
8 and 10	G137	Hornblende-augite amphibolite	Cascade Brook, altitude 1170'

‡ Total iron calculated as FeO. # CaO is anomalously high in G137. * Each column is one analysis; this line is the total number of analyses made.

Table 2. Ammonoosuc Volcanics, Representative Chemical Analyses of Chlorite, Epidote, Garnet, Magnetite, Ilmenite, and Plagioclase.

	Chlorite		Epidote		Garnet	Magnetite		Ilmenite	Plagioclase					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	25.31	26.69	37.87	38.19	38.24	0.95	.37	.08	63.10	59.12	58.29	57.50	63.15	62.85
TiO_2	.06	.36	.13	.06	.00	0.07	.09	47.05	.00	.01	.00	.00	.00	.23
Al_2O_3	20.94	22.92	25.66	25.03	19.61	4.82	.98	.14	23.29	26.59	26.76	27.05	22.67	24.20
FeO ‡	20.76	12.64	9.65	13.25	35.47	93.33	85.94	47.55	.35	.00	.16	.18	.16	.38
MgO	20.07	23.39	.08	.06	4.00	0.10	.07	.31	.04	.00	.04	.03	.00	.04
MnO	.12	.08	.09	.17	3.03	0.13	.21	1.02	.00	.11	.03	.04	.01	.00
CaO	.08	.00	23.81	23.49#	1.81	0.14	.13	.04	5.01	8.84	7.01	9.14#	5.31	5.24
K_2O	.03	.00	.02	.07	.03	0.10	.13	.11	.04	.12	.07	.07	.05	.07
Na_2O	.04	.01	.08	.05	.01	0.06	.00	.07	8.19	7.04	7.27	7.22	8.65	6.25
Total	87.42	86.09	97.39	100.37	102.21	99.70	87.91	96.36	100.02	101.83	99.62	101.22	100.00	99.25
Total No. of Analyses*	2	3	1	7	12	2	1	1	5	8	3	6	2	1

Columns	Specimen No.	Rock	Locality
1, 5, and 13	G189A	Fine-grained light-gray anthophyllite gneiss	Sixth Avenue, Berlin
2, 8, and 14	G291	Coarse biotite-gedrite gneiss	Boston and Maine Railroad, 0.6 mile north of Cascade
3 and 11	G136	Hornblende-augite amphibolite	Cascade Brook, altitude 1120'
4 and 12	G137	Hornblende-augite amphibolite	Cascade Brook, altitude 1170'
6 and 9	G108A	Anthophyllite-cummingtonite amphibolite	Bean Brook, altitude 1310'
7 and 10	G112A	Hornblende-cummingtonite amphibolite	Bean Brook, altitude 1330'

‡ Total iron calculated as FeO. # CaO is anomalously high in G137. * Each column is one analysis; this line is the total number of analyses made.

Gorham Quad.

Table 3. Average Estimated Modes for the Ammonoosuc Volcanics

Column	1	2	3#	4	5	6	7#	8	9#	10	11	12#	13#
Number in Average	5	1	2	1	1	2	3	2	1	1	4	3	2
Quartz	30	30				20				25	5		
K-feldspar		25											
Plagioclase*	55_{25}	32_{20}	42_{32}	69_{35}	54_{40}	63_{20}	76_{25}	55_{35}	66_{26}	68_{20}	55_{40}	54_{39}	30_{40}
Biotite	12	18	16	8	20	3	4	1	1	2	1	1	
Hornblende					20						37	26	43
Anthophyllite						12		40	25	3			
Gedrite			35				16						
Cummingtonite				15					5			17	
Augite													26
Magnetite	1		3	8	6	2	2	4	3	2	1	1	
Pyrite		5	2								1	1	
Garnet	2						2						
Apatite	tr		tr				tr	tr			tr	tr	
Sphene	tr										tr		
Carbonate					tr								
Chlorite			2									tr	
Epidote												tr	1
Zircon	tr												

#In at least one specimen the minerals were analyzed by microprobe.

*Subscript is percentage of anorthite; based on electron probe for columns 3, 7, 9, 12, and 13, otherwise on maximum extinction perpendicular to zone of (010).

1. Fine-grained biotite gneiss (only feldspar is plagioclase)
2. Fine-grained biotite gneiss (contains both plagioclase and orthoclase)
3. Coarse biotite-gedrite gneiss
4. Biotite-cummingtonite schist
5. Biotite-hornblende schist
6. Anthophyllite gneiss
7. **Fine-grained light-gray anthophyllite gneiss**
8. **Anthophyllite amphibolite**
9. **Anthophyllite-cummingtonite amphibolite**
10. White fine-grained anthophyllite gneiss
11. Hornblende-amphibolite
12. Hornblende-cummingtonite amphibolite
13. Hornblende-augite amphibolite

Table 4. Average Estimated and Calculated Modes of Oliverian Plutonic Series.

	1	2	3	4
No. thin sections in average	10		4	
Quartz	33	36	27	28
K-feldspar	32	32	23	27
Plagioclase	29_{17}	27_{17}	35_{22}	33_{20}
Biotite	4	3	11	7
Muscovite	1	2	2	3
Apatite	tr	tr	tr	tr
Magnetite)	)	tr	)	1
Ilmenite)	) 1	tr	) 2	1
Pyrite)	)	tr	)	tr
Allanite	tr		tr	
Zircon	tr	tr	tr	tr

1. Pink biotite-quartz monzonite, Mt. Washington quadrangle, Billings and Rabbitt, 1947, p. 575.
2. Pink biotite-quartz monzonite, Mt. Washington quadrangle, calculated from chemical analysis, Billings and Rabbitt, 1947, p. 584.
3. Gray biotite-quartz monzonite, Mt. Washington quadrangle, Billings and Rabbitt, 1947, p. 575.
4. Gray biotite-quartz monzonite, Mt. Washington quadrangle, calculated from chemical analysis, Billings and Rabbitt, 1947, p. 584.

Table 5. Lithology of the Littleton Formation

Rock	Percentage of Formation
Metaconglomerate	tr
Quartzite	tr
Feldspathic quartzite	3
Spangled mica schist	9
Interbedded feldspathic quartzite and spangled mica schist	20
Shiny fine-grained mica schist	2
Sillimanite schist	tr
Sillimanite granofels	1
Staurolite schist	2
Paragneiss (migmatite)	60
Lime-silicate and related rocks	3

Table 6. Average Estimated Modes of the Littleton Formation Exclusive of the Paragneiss and Lime-Silicate Rocks.

	1	2	3	4	5	6	7	8	9
Number in average	1	2	4	8	3	6	3	3	1
Quartz	93	80	63	55	55	45	39	57	35
Microcline						tr			
Plagioclase		15_{15}	20_{25}	10_{25}	tr	2_{22}	3_{18}		32_{60}
Diopside									15
Biotite	5	2	14	20	4	15	9	24	3
Chlorite				tr	13	3			
Muscovite	2	2	4	15	23	25	15	12	
Sericite						6	16		
Sillimanite				tr		2	2		
Staurolite						tr		5	
Garnet			tr	tr	1	1	2	2	15
Magnetite					tr	tr	1		
Ilmenite			tr						
Pyrite		1	1	tr	3	1	tr		
Apatite					tr		tr	tr	
Tourmaline					1	tr	tr	tr	
Carbon?								1	

1. Quartzite
2. Feldspathic quartzite, lighter type
3. Feldspathic quartzite, darker type
4. Spangled mica schist
5. Shiny fine-grained mica schists (Column 9, Table 6, Billings, 1941)
6. Sillimanite schist (Column 5, Table 6, Billings, 1941)
7. Sillimanite granofels (Column 7, Table 6, Billings, 1941)
8. Staurolite schist (Column 6, Table 6, Billings, 1941)
9. Metamorphosed concretion

Table 7. Average Estimated and Calculated Modes of the Paragneiss of the Littleton Formation.

	1	2	3	4	5	6	7	8
Number of specimens averaged	5	5	10	*	*	*	*	*
Field Number	-	-	-	W/215	G/300	G/350	G/357	G/358
Quartz	33	40	34	36	34	37	39	41
Plagioclase	17	47	23	17	17	14	10	14
Biotite	27	5	23	29	27	24	23	17
Chlorite	tr	tr	tr				6	3
Muscovite	19	7	17	12	20	20	21	23
Garnet	3	tr	2	1				
Sillimanite	1	1	1	5	tr	4		
Apatite	tr	tr	tr	tr	tr	tr	tr	tr
Magnetite	tr	tr	tr					
Ilmenite						1		
Pyrite				tr	1	1	tr	1
Zircon	tr?		tr?					
Tourmaline		tr	tr					
Carbonate					tr	tr	tr	1
Percent anorthite in plagioclase	22	20	22	19	18	19	21	19

*Calculated from analysis in Table 8.

1. Paragneiss, dark portion (Billings, 1941, p. 880)
2. Paragneiss, light portion (Billings, 1941, p. 880)
3. Paragneiss, weighted average of No. 1 and 2, 80% No. 1, 20% No. 2
4. Paragneiss, Greens Grant Peabody River, altitude of 1340 feet (Billings, 1941, Table 2, column 1a)
5. Paragneiss, Greens Grant, highway cut, Route 16, just above crossing of Nineteen Mile Brook
6. Paragneiss, Shelburne, Portland-Montreal pipeline, 1500 feet west of Evans Island
7. Paragneiss, well-layered type, Pinkhams Grant, Crawford Notch quadrangle, big road cut, 1/4 mile south of Glen Ellis Falls
8. Paragneiss, massive type, Pinkham Grant, Crawford Notch quadrangle, big road cut, 1/4 mile south of Glen Ellis Falls.

Table 8. Chemical Analyses of the Littleton Formation

SiO_2

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	62.87	63.73	65.14	63.76	66.73	58.92	64.33	62.93	67.25	61.38	65.03	59.01
TiO_2	0.92	0.79	0.79	0.99	0.66	0.93	1.06	0.99	0.97	0.60	0.80	1.00
Al_2O_3	17.43	16.45	17.95	15.96	15.76	18.55	17.98	18.95	16.42	16.81	16.52	18.93
Fe_2O_3	0.55	0.95	0.70	0.69	0.65	0.94	1.41	1.80	1.76	2.95	1.69	1.27
FeO	6.67	5.96	4.96	6.80	5.03	6.63	4.80	4.34	4.29	5.36	4.36	6.03
MgO	2.71	2.26	1.99	2.72	1.88	3.24	1.19	1.32	1.65	2.73	2.45	3.08
MnO	0.73	0.10	0.08	0.19	0.09	0.08	0.03	0.02	0.62	0.07	0.02	0.06
CaO	0.59	0.76	0.69	0.58	0.83	0.48	0.03	0.15	0.05	0.20	0.10	0.24
Na_2O	1.71	1.90	1.56	1.31	1.72	1.49	0.54	0.68	0.79	1.60	0.16	0.77
K_2O	4.08	4.16	3.94	3.88	3.55	3.74	3.49	3.44	2.81	3.47	4.26	4.42
H_2O+	2.10	1.88	1.61	2.36	1.44	3.90	3.90	3.90	3.68	4.00	3.71	4.26
H_2O-	0.08	0.16	0.06	0.08	0.07	0.11	0.39	0.25	0.21	0.13	0.17	0.17
P_2O_5	0.11	0.19	0.10	0.10	0.19	0.14	0.11	0.12	0.07	0.18	0.09	0.14
S	0.04	0.66	0.46	0.08	0.44	0.17	0.03	0.03	0.03	0.03	0.03	0.02
CO_2	0.02	0.04	0.05	0.14	0.45	0.25	0.04	0.02	0.03	0.03	0.03	0.05
BaO	n.d.	0.03	0.04	n.d.	0.04	n.d.	0.05	0.04	0.03	0.03	0.03	0.05
F	n.d.	0.09	0.08	0.10	0.08	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
C	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.44	0.76	0.58	0.31	0.32	0.31
Total	100.11	100.13	100.22	99.76	100.13	99.57	99.82	99.74	100.04	99.88	99.79	99.81
Less	0.02	0.29	0.21	0.07	0.20	0.06						
	100.09	99.84	100.01	99.69	99.93	99.51						

1. Paragneiss, Greens Grant, Peabody River, altitude of 1340 feet, Billings, 1941, column 10, Table 10.
2. Paragneiss, Greens Grant, highway cut, Route 16, just above crossing of Nineteen Mile Brook. Analyst D. Thaemlitz, Rock Anal. Lab., Dept. Geology, University of Minnesota.
3. Paragneiss, Shelburne, on Portland-Montreal pipeline 1500 feet west of Evans Island. Analyst D. Thaemlitz, Rock Anal. Lab., Dept. Geology, University of Minnesota.
4. Paragneiss, layered type, Pinkhams Grant, Crawford Notch Quadrangle road cut, ¼ mile south of Glen Ellis Falls. Analyst D. Thaemlitz, Rock Anal. Lab., Dept. Geology, University of Minnesota.
5. Paragneiss, massive type, same locality as 4. Analyst D. Thaemlitz, Rock Anal. Lab., Dept. Geology, University of Minnesota.
6. Slate, Slate Ledge quarry, Littleton quadrangle, Billings, 1941.
7. Black slate, 5/8 mile west of Walker Mountain, Littleton quadrangle, Shaw, 1956.
8. Black slate, Mormon Hill, Lisbon township, Littleton quadrangle, Shaw, 1956.
9. Slate, 2 miles N.15°W. of Lisbon village, Moosilauke quadrangle, Shaw, 1956.
10. Slate, one mile NE of Moulton Hill, Lyman township, Moosilauke quadrangle, Shaw, 1956.
11. Black gray shale, 2 miles west of village of Littleton, Littleton quadrangle, Shaw, 1956.
12. Gray shale, ¼ mile east of Ogontz Lake, Lyman township, Littleton quadrangle, Shaw, 1956.

Table 9. Average Chemical Composition of Paragneiss and Slate of the Littleton Formation.

	1	2
SiO_2	64.41	62.70
TiO_2	0.83	0.91
Al_2O_3	16.71	17.74
Fe_2O_3	0.71	1.69
FeO	5.88	5.16
MgO	2.31	2.24
MnO	0.24	0.13
CaO	0.69	0.18
Na_2O	1.64	0.86
K_2O	3.92	3.66
H_2O+	1.88	3.91
H_2O-	0.09	0.20
P_2O_5	0.14	0.12
S	0.34	0.05
CO_2	0.14	0.07
BaO	0.02	0.04
F	0.07	nd
C	nd	0.38
Total	100.02	100.04

1. Average of 5 paragneisses from Gorham Quadrangle.

2. Average of 7 slates and shales from Littleton Formation from the chlorite zone in the Littleton-Moosilauke area.

Table 10. Average Estimated Modes of the Lime-Silicate Rocks of the Littleton Formation.

No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Averaged	13	7	4	3	3	7	3	5	10	1	1	2	1
Quartz	33	20	29	46	33	35	33	28	40	35	15	28	10
Plagioclase	41_{65}	46_{75}	40_{70}	31_{50}	36_{50}	34_{65}	42_{80}	29_{70}	27_{75}	30_{70}		20_{60}	tr_{60}
Diopside			1	6	10		19	22	19	5			80
Hornblende	tr		11	1					11	20			
Actinolite		14			9	28	5				33		
Biotite	22	17	18	14	10	tr			tr	10	10	22	
Garnet	tr	tr		1	1	1	tr		1				
Sphene	tr	tr	tr			1	tr	1	1		tr		
Apatite			tr										
Pyrite	2	1	1		1	1	1		1		2		
K-feld											40	30	10
Misc.	2	2		1									

Name	Relative Abundance in percent
1. Biotite granofels	35
2. Biotite-actinolite granofels	15
3. Biotite-hornblende granofels	6
4. Biotite-diopside granofels	2
5. Biotite-diopside-actinolite granofels	2
6. Actinolite granofels	13
7. Diopside-actinolite granofels	3
8. Diopside granofels	10
9. Diopside-hornblende granofels	10
10. Diopside-hornblende-biotite granofels	1
11. Biotite-actinolite-K-feld granofels	1
12. Biotite-K-feld granofels	1
13. Diopside-K-feld granofels	1

Table 11. Stratigraphy of the Littleton Formation

Unit	Description	Thickness (feet)
9	Interbedded feldspathic quartzite and spangled mica schist; some paragneiss near Pinkham Notch	4000
8	Boott Member - lime-silicate granulite and related rocks	10-200
7	Paragneiss; because of change in sedimentary facies is feldspathic quartzite and mica schist in places	7000
6	Lime-silicate granulite and related rocks (crosses Moriah Brook between altitudes of 1700 and 1800 feet)	0-400
5	Paragneiss; some feldspathic quartzite and mica schist	2900
4	Lime-silicate granulite and related rocks; also much paragneiss (crosses Moriah Brook between 1400 and 1500 feet)	0-500
3	Paragneiss; some feldspathic quartzite and mica schist	4500
2	Lime-silicate granulite and related rocks (crosses Baldface Brook at altitude of 1900 feet)	5-325
1	Paragneiss; some feldspathic quartzite and mica schist	7000
	Total	25,415-26,825

Table 12. Attitude of Lime-Silicate Units in Wild River-Homocline.

I. By Three Point Method

Unit	Location of Three Points	Altitude	Strike	Dip
2	a. Brook entering Wild River at 1755'	2160'	N 50°E	23°NW
	b. Baldface Brook	1940'		
	c. Cedar Brook	2000'		
2	a. Blue Brook	1660'	N 32°E	21°NW
	b. Tributary to Blue Brook rising on West Royce	1440'		
	c. Tributary to Blue Brook rising on West Royce	2100'		
4	a. Moriah Brook	1500'	N 42°E	32°NW
	b. Ridge south of Bull Brook	1750'		
	c. Tributary entering Bull Brook at 1110'	1250'		
4	a. Ridge south of Bull Brook	1750'	N 45°E	26°NW
	b. Tributary entering Bull Brook at 1110'	1250'		
	c. Martins Brook	1440'		
4	a. Tributary entering Bull Brook at 1110'	1250'	N 35°E	8°NW
	b. Martins Brook	1440'		
	c. Brook north of Martins Brook	1670'		
6	a. Moriah Brook	1780'	N 44°E	32°NW
	b. Tributary entering Bull Brook at 1550'	1780'		
	c. Tributary entering Bull Brook at 1110'	2300'		

II. By Apparent Dip in Stream
Unit 2 on Dewdrop Brook. Streams flows north. See text. Assuming strike is N.45°E, true dip is 11° to 16°NW.

Table 13. Average Estimated Modes of the New Hampshire Plutonic Series

	1	2	3	4	5	6	7	8	9	10	11
Number in average	2	2	1	1	2	4	5	7	1	1	20
Quartz	7	1			27	7	18	28	20	30	30
K-feldspar									35	30	35
Plagioclase	61	60	86	53	58	76	67	56	44	31	27
Pyroxene					1						
Amphibole	8	32	7	39	2	4			1		
Biotite	22	3	4	5	15	13	15	14		7	5
Chlorite											
Muscovite								2		2	2
Magnetite	1	5	3	2		tr		tr			tr
Pyrite	1	tr		1	tr	tr	tr	tr			
Apatite				tr	tr	tr	tr	tr			
Sphene					tr	tr	tr				
Epidote					tr			tr			
Anorthite in plagioclase	45	55	40	40	40	38	40	30	40	20	27
Range in grain size	2.0-5.0	0.2-1.0	0.5-1.0	1.0-2.0	1.0-5.0	1.0-4.0	1.0-4.0	1.0-4.0			0.5-4.0

1. Diorite, gray medium-coarse, Nineteen Mile Brook body
2. Diorite, gray medium-fine, Nineteen Mile Brook body, light gray
3. Diorite in leucocratic fine-grained, 6" dike in Nineteen Mile Brook body
4. Diorite, medium-grained, small body, 2420 foot altitude on tributary of Lary Brook, 0.6 mile N. 80°E., summit Mt. Success.
5. Quartz diorite with amphibole, quartz-rich
6. Quartz diorite with amphibole, quartz-poor
7. Quartz diorite, with neither amphibole nor muscovite
8. Quartz diorite with muscovite
9. Quartz monzonite with amphibole; facies of quartz diorite
10. Kinsman Quartz Monzonite, 1/3 of K-feldspar occurs as phenocrysts 5 to 20 mm long
11. Concord Quartz Monzonite

Table 14. <u>Average Estimated Modes, Diorite and Vent Agglomerate, White Mountain Plutonic-Volcanic Series.</u>

	1	2	3
Number in average	1	1	1
Quartz		5	
Plagioclase	58	40	63
Amphibole	30	32	25
Biotite	10	18	10
Magnetite	2	1	2
Sphene		1	
Carbonate		3	
Anorthite in plagioclase	45	40	50

1. Diorite, fine-grained marginal phase, ½ mile south of Gorham, Peabody River, apophysis cutting Concord Quartz Monzonite.
2. Diorite, ½ mile south of Gorham on Peabody River.
3. Andesite from clast in vent agglomerate, 760 feet altitude on Leadmine Brook.

Table 15. <u>Lithology of Post-Metamorphism Dikes</u>
(Numbers as shown on Plate 3)

Diabase	13, 71, 135, 171, 188, 213, 216
Metadiabase	5, 7, 11, 14, 31, 35, 37, 45, 68, 72, 89, 90, 92, 96, 98, 99, 136, 143, 150, 151, 152, 153, 154, 156, 177, 183, 184, 197, 201, 210, 217, 220, 229, 237, 240
Porphyritic diabase	2
Porphyritic metadiabase	53, 57, 121, 155, 195, 196, 198, 202
Hypersthene diabase	103
Camptonite	3, 36, 56, 104, 105*, 174, 180*, 219, 232
Diorite	1*, 22, 141, 178, 181*
Augite lamprophyre	23
Metagabbro	93
Fine-grained syenite	26
Rhyolite	29, 32, 33*, 48*, 158*, 161*, 172, 175
Trap*	9, 30, 49, 85, 91, 106, 109, 113, 137, 138, 139, 140, 142, 144, 148, 160, 162, 165, 176, 189, 191, 192, 193, 194, 208, 211, 215
Porphyritic trap*	54, 55, 73, 75, 100, 102, 107, 114, 122
Mafic rock#	4, 6, 8, 10, 12, 15, 16, 17, 18, 19, 20, 21, 24, 25, 27, 28, 34, 38, 39, 40, 41, 42, 43, 44, 46, 47, 50, 51, 52, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 69, 70, 74, 76, 77, 78, 79, 80, 81, 82, 83, 84, 86, 87, 88, 94, 95, 97, 101, 108, 110, 111, 112, 115, 116, 117, 118, 119, 120, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 145, 146, 147, 149, 157, 159, 163, 164, 166, 167, 168, 169, 170, 173, 179, 182, 185, 186, 187, 190, 199, 200, 203, 204, 205, 206, 207, 209, 212, 214, 218, 221, 222, 223, 224, 225, 226, 227, 228, 230, 231, 233, 234, 235, 236, 238, 239, 141

*No thin section. Hand specimen or field identification.

#Field name for mafic rock for which neither hand specimen nor thin section is available.

Table 16. <u>Relative Abundance of Post-Metamorphism Dikes</u>

1 Name	2 Thin section only		3 Hand specimen only		4 Field only	5 Total
	No.	%	No.	%	No.	
Diabase	7	11	27*	61		
Metadiabase	35	51				
Porphyritic diabase	1	1	9#	20		
Porphyritic meta-diabase	8	12				
Hypersthene diabase	1	1			128+	
Camptonite	7	11	2	5		
Diorite	3	4	2	5		
Augite lamprophyre	1	1				
Metagabbro	1	1				
Fine-grained syenite	1	1				
Rhyolite	4	6	4	9		
Totals	69	100	44	100	128	241

*Called trap in Table 15

#Called porphyritic trap in Table 15

+Called mafic rock in Table 15

Table 17. <u>Estimated and Calculated Modes of Post-Metamorphism Dikes.</u>

	1		2	3		4	5	6		7		8	9	10	11
	a	b		a	b			a	b	a	b				
Phenocrysts															
K-feldspar														2	
Plagioclase			14			12	10								
Augite			1			1						4			
Hypersthene							7								
Groundmass															
Quartz		5			5				1					5	25
K-feldspar		5						10?	9					67	65
Plagioclase	63	55	47	58	51	48	45	33?	24	53	44	35	53	1	
Augite	18	12	30	2			15	13	21			50	15		
Hornblende	1		3	4	12	tr		1		40	50			19	
Barkevikite								19	26				1		
Biotite	3			2		3		1		2	2				9
Apatite	tr	tr	tr	tr	1				tr		tr				tr
Magnetite		3			2				2		1				1
Ilmenite	7	6	5	7	4	8	tr	4	1	5	3	5	8	3	tr
Pyrite		tr	tr		tr				tr		tr				tr
Chlorite	2	14	1	7	8	10		7	3			4			
Carbonate	6	tr	tr	20	9	18	23	12	11		tr	2	20	2	tr
Sericite					8										
Zoisite													3		
Kaolinite									2						
Percent An in plag															
In Phenocrysts			50			55	50								
In Groundmass	45	40	50	55	40	45	40	50	50	42	40	?	54		

1. Diabase
   a. Estimated, 7 thin sections
   b. Calculated from chemical analysis Table 18
2. Porphyritic diabase, estimated, 3 thin sections
3. Metadiabase
   a. Estimated, 35 thin sections
   b. Calculated from chemical analysis Table 18
4. Porphyritic metadiabase, estimated 9 thin sections
5. Hypersthene metadiabase, estimated, 1 thin section
6. Camptonite
   a. Estimated, 7 thin sections
   b. Calculated from chemical analysis Table 18
7. Diorite
   a. Estimated, 7 thin sections
   b. Calculated from chemical analysis Table 18
8. Augite lamprophyre, estimated 2 thin sections
9. Metagabbro, estimated, 1 thin section
10. Fine-grained syenite, estimated, 1 thin section
11. Rhyolite, calculated from chemical analysis Table 18

Table 18. Chemical Analyses of Post-Metamorphism Dike Rocks

	1	2	3	4	5
SiO_2	51.64	45.86	41.22	47.78	71.45
TiO_2	3.44	2.65	2.52	1.71	0.12
Al_2O_3	15.81	15.82	14.19	14.65	13.35
Fe_2O_3	2.10	2.65	2.64	0.31	0.50
FeO	10.00	7.58	7.39	13.86	2.67
MnO	0.14	0.17	0.18	0.20	0.07
MgO	4.89	4.84	8.85	7.77	0.13
CaO	6.90	7.20	11.63	8.52	0.52
Na_2O	3.78	2.98	1.95	2.85	3.43
K_2O	0.80	2.30	1.67	0.60	6.67
H_2O-	0.00	0.05	0.85	0.00	0.00
H_2O+	0.31	3.03	1.34	1.36	0.79
P_2O_5	0.19	0.64	0.29	0.12	trace
S	0.034	0.03_2	0.20	0.06_4	0.02_4
CO_2	0.06	4.20	5.04	0.04	0.05
BaO	0.02	0.09	0.09	0.05	0.03
	100.11_4	100.09_2	100.05	99.88_4	99.80_4

1. Diabase. Dike No. 227, Wildcat Ridge Trail, altitude of 3100 feet, North Conway quadrangle (specimen No. G-J9).
2. Metadiabase. Dike No. 95, Moriah Brook, altitude of 2270 feet (specimen No. G-250).
3. Camptonite. Dike No. 110, Middle Branch of Mad River, altitude of 2410 feet (specimen No. G-330).
4. Diorite. Dike No. 26, South Branch of Horne (Mollywocket) Brook, altitude of 1890 feet (4600 feet S 80°W of summit of North Bald Cap)(specimen No. G-126).
5. Rhyolite. Dike No. 173, Mt. Jasper, 150 feet S 80°W of summit (specimen No. G-149).

Analyses by Hiroshi Haramura

Table 19. Chemical Composition of Barkevikite from Camptonites

	1	2	3	4
SiO_2	40.3	39.7	41.1	37.80
TiO_2	6.2	4.7	5.0	4.54
Al_2O_3	13.8	13.4	13.8	12.89
Fe_2O_3	-	-	-	6.14
FeO	11.8*	12.5*	13.2*	12.55
MnO	0.2	0.2	0.1	n.d.
MgO	11.7	12.8	12.1	4.10
CaO	12.0	11.5	10.5	13.64
Na_2O	2.1	2.2	2.2	5.26
K_2O	1.4	1.1	1.3	3.24
	99.5	98.1	99.3	100.16

*Total iron as FeO

1. Camptonite, altitude of 1160 feet, Middle Branch Mad River
2. Camptonite, altitude of 1310 feet, Middle Branch Mad River
3. Camptonite, altitude of 1360 feet, brook two-thirds of a mile northwest of Mt. Forest
4. Camptonite from Livermore Falls, Campton township, type locality of camptonite (Lord, 1898, p. 343).

Analyses 1, 2, and 3 are by Peter Lyttle on electron probe; each oxide is an average of several determinations.

Table 20. Length of Some of the Longer Post-Metamorphism Dikes.

Number	Known Length (feet)	Vertical Range (feet)
2	3900	880
10	750	40
23	500	150
141	5000	350
162	300	50
165	1000	240
168	1600	520
177	700	30
178	2500	225
183	600	40
192	1000	200
198	3500	445
216	1400	140
220	500	90

Table 21. Silicified Zones

Location	Notes	Strike	Dip	Known length	Width
2000' NW of Mt. Jasper	Country rock: amphibolite of Ammonoosuc Volcanics. Network of 1/8" quartz veins on southeast side	N35°E?	?	100'	35'+
1145-1500' altitude on brook 3400' north of Mt. Forest	Country rock: quartz monzonite of Oliverian Plutonic Series, much splintered. Solid quartz veins as much as 10' and 3' thick; in places causes stream valley	N34°E	?	1800'	50'+
One mile east of Androscoggon River north edge of quadrangle	Country rock: quartz monzonite of Oliverian Plutonic Series. Resistent, causing 15' escampment in places. Part in Bean Brook may be en echelon relative to main part to north	N17°E ± 7°	?	6000'	5'-130'
Altitude of 1645' in brook 4000' S10°E of Mt. Carberry	Country rock: Littleton Formation	N90°E	90°	-	5'
Altitude of 895 in Moose Brook	Contact of Oliverian and Ammonoosuc. An "incipient" silicified zone, quartz veins 1" to 6" thick	N55°E	65°SE	-	10'
Brook south of Carlton Notch, altitude 1520'	Country rock: paragneiss of Littleton Formation	N70°E?	?		5'
Brook south of Carlton Notch, altitude 1740 to 1825'	Country rock: paragneiss of Littleton Formation. Controls course of stream	N82°E	62°SE	-	4'
Connor Brook between altitudes of 1230 and 1630 feet	Discontinuous silicified zones up to 2 feet wide along a normal (?) fault, 3000 feet long, along which lime-silicate unit No. 6 is in contact with paragneiss unit No. 5.	N50°E	55°NW	-	0-2'
West Branch of Leadmine Brook, altitude of 970 feet	Exposed in stream bed. Site of Shelburne Mine	N65°E	75°W	300'	2-15'

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