GEOLOGY OF THE LUNENBURG-BRUNSWICK-GUILDHALL AREA, VERMONT

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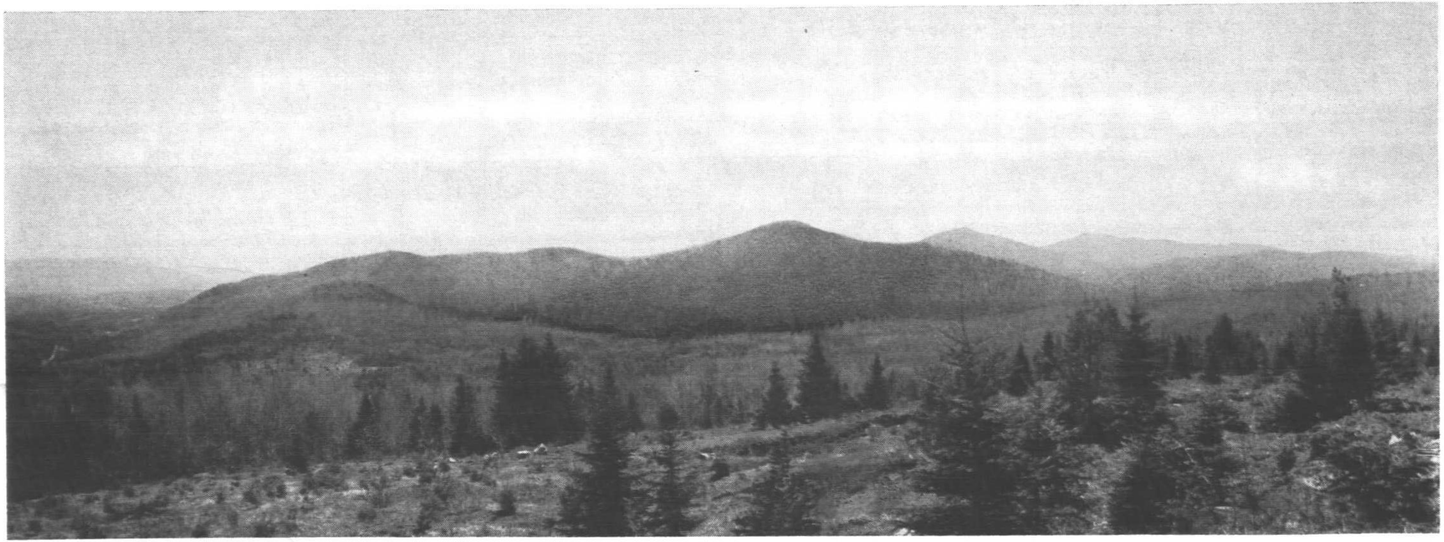

Frontispiece. View looking south from south slope of Stoneham Mountain: left foreground, Bald Mountain; center, Round Mountain; Burnside and Stone Mountains respectively to right of center. These mountains mark the approximate position of the Burnside Mountain syncline.

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ABSTRACT

The Lunenburg-Brunswick-Guildhall area is situated in the southern half of Essex County in northeastern Vermont and belongs to the western portion of the White Mountain section of the New England physiographic province.

About 70 per cent of the area's bedrock consists of various metasediments, clearly indicating increased intensity of regional metamorphism toward the northwest. Metasedimentary rock units of both the "New Hampshire sequence" and "Vermont sequence" are present. They are separated by the controversial Monroe fault which strikes northeasterly from Granby to the Connecticut River in southern Brunswick.

The "Vermont sequence" consists of the Silurian and/or Devonian Gile Mountain formation and Meetinghouse slate. The "New Hampshire sequence" includes the Ordovician Albee formation and its transitional zone which consists of a mixture of sediments of the Albee and Ammonoosuc formations, and the Ordovician Partridge formation. The bulk of the metamorphic rocks are assigned to the Albee formation. In addition, a small amount of bedrock belongs to the Silurian Clough and Fitch formations and to the Devonian Littleton formation, all of the "New Hampshire sequence." Fine-grained schists and quartzites are dominant types throughout.

Approximately 30 per cent of the area is underlain by igneous rock which crops out in two major areas. Granodiorite and diorite of the Upper Ordovician (?) Highlandcroft plutonic series is confined to the east central and southeastern portions of the region in the vicinity of the Connecticut River. Medium-grained binary granite of the Late Devonian (?) New Hampshire plutonic series extends from the western boundary to the Connecticut River in the northern third of the map-area.

The strike of the metamorphic rock averages N 20°E and dips generally

moderate to steep. Isoclinal folding is manifest in much of the "New Hampshire sequence." Flow cleavage or schistosity is distinct in the Albee formation; bedding is often obscure. The Partridge syncline and the Lunenburg anticline, both plunging to the southwest, are important large folds that dominate the structure in the southern third of the area. The overturned, doubly plunging Burnside Mountain syncline is the prevailing structure in the central part of the area; its northwest limb is truncated by the Round Mountain fault. The Monroe fault which serves to form the break between the "Vermont sequence" and the "New Hampshire sequence" has been interpreted by some geologists as a fault contact, and by others as a sedimentary contact which represents the Taconic unconformity. The problem of the exact nature of the break is not clearly resolved in this area.

Minor structural features occur in rocks of both the "New Hampshire sequence" and "Vermont sequence" and are indicative of two stages of deformation. Isoclinal folding is characteristic of early stage deformation. Chevron folding with distinct axial plane slip cleavage is evidence of the later stage of deformation.

During the earlier stage of deformation, widespread schistosity or flow cleavage resulted from the planar orientation of chlorite, sericite, and muscovite. Recrystallization and growth of various mineral porphyroblasts accompanied the later stage of deformation with the result that the metamorphic grade ranges from the chlorite zone to the sillimanite zone.

INTRODUCTION

Location

The Lunenburg-Brunswick-Guildhall area is situated in the southern portion of Essex County in northeastern Vermont. The entire townships of Guildhall and Maidstone, together with large portions of Brunswick, Ferdinand, Granby, Lunenburg, and small portions of Concord, East Haven, and Victory constitute the geographical subdivisions of this part of the county. The northern boundary is north latitude 44°45′ and the western boundary is west longitude 71°45′. The area is bounded on the east, southeast and south by the Connecticut River. The total area is equal to a little more than seven-ninths of a fifteen-minute quadrangle or approximately 170 square miles. The region comprises the western two-thirds of the Guildhall, Vermont-New Hampshire U.S. Geological Survey's Topographical Atlas Quadrangle and slightly more than one-ninth of the Whitefield, New Hampshire-Vermont U.S. Geological Survey's Topographical Quadrangle.

Guildhall village, the county seat, is located 33 miles east-northeast of St. Johnsbury, Vermont, and 6 miles north of Lancaster, New Hampshire. The southern area is traversed by U.S. Route 2 which passes via Lancaster, New Hampshire, through Lunenburg, Vermont, to St. Johnsbury. The Granby-Guildhall road is the only other highway that crosses the area from east to west. The region may be approached from either north or south by taking Route 102 along the Connecticut River.

Culture

Unlike much of lower and central Vermont, excluding the Green Mountains, the majority of the rugged hills and valleys in the map-area were never cleared for farming and a wilderness area still remains. The large tracts that were cleared for farming in northern Lunenburg, southwestern Guildhall, and at Maidstone Hill are now returned to forest land. In recent years the Soil Conservation Service has been actively co-operating with local land owners in Lunenburg reclaiming some acreage for crop land.

Most of the region is characterized by a beech-maple-birch climax forest cover in various stages of growth. Since the removal by lumbering of the extensive red and white pine stands which once clothed many of the stream valleys and lowlands, there has been a rapid succession of fir and spruce. Fir and spruce mixed with various hard woods cap several of the higher elevations. Although the last great virgin forest in this region was felled in 1914, scattered stands of the primeval forest remain today.

The principal industry is logging for pulp and lumber. The center of the pulp-paper industry is Groveton, New Hampshire, a town of 2000 population located 2 miles northeast of Guildhall. A large hardwood veneer processing plant is located in North Stratford, New Hampshire, about 12 miles north of Groveton. It is around these two forest product industries that much of the region's economy is centered.

Farming is concentrated along the fertile flood plain of the Connecticut Valley where corn, hay, oats, and potatoes are grown. A number of dairy farms are situated in the Connecticut Valley and on the gentle uplands in Lunenburg.

The mineral industry has never been of importance. A small copper mine located 3.5 miles S 65°W of Guildhall was opened about 75 years ago. The site of this unsuccessful venture is on the west slope of a hill known locally as Bolles Hill (elevation 1440′). A small granite quarry was operated about the turn of the century at a point 0.2 mile southwest of the junction of Maidstone Lake Road and Route 102. In addition minor amounts of granite were quarried at a location 0.9 mile S 60°W of Brunswick Springs, and at another location 0.6 mile S 15°E of Brunswick Springs.

River and kame terraces and eskers afford most of the sand and gravel used in the region. Both types of terraces are particularly well developed along the west side of the Connecticut River Valley in Guildhall and to the north. Several gravel pits are presently in operation in Guildhall.

The economic outlook for Essex County is bright if its forests are maintained on a sustained yield basis. The forests' potential recreational and esthetic value cannot be overlooked as good forest management can not only produce more and better timber, but it can also improve conditions for hunting, fishing, hiking, and camping. Excellent swimming and camping facilities are available at Maidstone State Forest located on Maidstone Lake.

Regional Geologic Setting

The entire region is underlain by Paleozoic rocks of which about 70 per cent are metasediments and about 30 per cent intrusive igneous rocks of two plutonic series. The stratigraphy and complex structure of the area is very much in keeping with the regional trend and pattern.

Previous Work

Geological reconnaissance work was conducted in this area on a very limited scale by several 19th century geologists. Their observations appear to have been made either along or close to existing roads. Jackson (1844) notes the presence of lenses of blue and gray limestone northwest of Lunenburg on the land of Colonel White. The country-rock nearby is described as greenish slate of the Cambrian system. Adams (1845) described the metamorphic rocks of the Lyndonville-Burke area as "Calcareo-Mica Slate." These rocks now comprise the Gile Mountain and Waits River formations. E. Hitchcock (1861) changed the name to "Calciferous Mica Schist." The metamorphic terrains of the Lunenburg-Brunswick-Guildhall area, based on observations made by S. H. Hall and C. H. Hitchcock, were mapped as mica schist and talcose schist. The northern area mapped as granite on Hitchcock's map bears some semblance to the actual disposition of the granite as shown by detailed mapping (Pl. 1). A narrow strip on the Vermont side of the Connecticut

River from Maidstone to below Lunenburg is mapped as protogine (granite). This is presently recognized as the Highlandcroft granodiorite and its fractured and injected border zone.

The study of the area made by J. H. Huntington and reported by C. H. Hitchcock (1877) is somewhat more comprehensive. This report places the metasediments as (1) belonging to the Huronian, and (2) younger than the clay slate and older than the "Calciferous Mica Schist." Those rocks belonging to the former were assigned to the Lisbon and Lyman groups and those of the latter to the Coös group. The Lisbon group is described as feldspathic chloritic schist with hornblende and epidote as accessories, and is equivalent here, in part, to Richardson's "protogine gneiss" (1906, p. 80) which is in reality mostly rock of the present-day Highlandcroft plutonic series and some of the present-day Albee formation. The gray siliceous schists of the Lyman group are equivalent in this area to much of the Albee formation. The Coös group as mapped in this area is equivalent to the present-day Gile Mountain formation. The dark gray "gneiss" of the Notch Mountains and Maidstone Lake area, together with the granite of West Mountain, are collectively mapped as rocks of the ancient Montalban group. Cambrian clay slate (Littleton formation) is noted by Huntington (op. cit.) as occurring in a syncline on Burnside Mountain. The geologic section of C. H. Hitchcock (1878) paralleling Granby Road from Guildhall to west of Granby shows some similarity to the section based on detailed mapping (Pl. 1).

Richardson (1906), in his report dealing with the geology of northeastern Vermont, calls the green schists of the Lyman group in the vicinity of Lunenburg the "Lunenburg schist." Flanking this schist to the west is a band of massive quartzite which he called "sheared quartzite." The ages of the two were considered by him as pre-Cambrian. Presently both are included as part of the Ordovician Albee formation. In addition, Richardson described a narrow belt of slate which he called the "Waterford slate" (Meetinghouse Slate of Doll, 1944) as lying on the east side of the "Bradford" or "Vershire schist" (now Gile Mountain formation, Doll, 1944) and west of the pre-Cambrian "sheared quartzite" and other metamorphics. He did not recognize the significance of the fault which he described as separating the slate from the pre-Cambrian terrain to the east. This fault is recognized now as the Monroe fault (Eric, White and Hadley, 1941), and it serves to separate the "Vermont sequence" from the "New Hampshire sequence" of rocks.

Detailed mapping by Billings (1937) in the Littleton-Moosilauke area so clarified the region's structure and stratigraphy that it has since served to guide detailed studies in much of western and northern New Hampshire and eastern-most Vermont. Billings first proposed the names of the now well established pre-Silurian Albee, Ammonoosuc, and Partridge formations, and the fossil-dated Clough (Lower or Middle Silurian) and Fitch (Middle Silurian) formations. The Lower Devonian Littleton formation was first named "Littleton argillite" by C. P. Ross (1923) for exposures on Walker Mountain southwest of Littleton, New Hampshire, and later called Littleton formation by Billings (1935).

Detailed geologic investigation in several adjacent quadrangles has been completed as follows (Fig. 1): Percy, New Hampshire quadrangle, and the Cape Horn area of the Guildhall, Vermont-New Hampshire quadrangle, R. W. Chapman (1948); Mt. Washington, New Hampshire quadrangle, M. P. Billings et al (1946); and the Littleton quadrangle (Vermont portion), Eric and Dennis (1958). Geologic mapping has been completed by R. H. Arndt in the New Hampshire portion of the Whitefield quadrangle, by B. Woodland in the Burke, Vermont quadrangle, and by B. Goodwin in the Island Pond, Vermont quadrangle. Mapping is now also completed in the Averill, Vermont-New Hampshire and Dixville, New Hampshire quadrangles.

Purpose

The geologic mapping of this area is part of a state-wide geologic mapping program instituted by the Vermont Geological Survey. The reason for undertaking this study is the mapping and interpretation of the bedrock.

Method of Study

The larger part of the summers of 1956, 1957, and 1958 was spent in field mapping. A recheck was conducted after the foliage had dropped in late October and early November, 1958. Pace and compass and altimeter were used in determining locations. A boat was used to reach the shores of some larger bodies of water.

A Vermont Geological Survey jeep, exceptionally valuable as a time and energy saver in reaching remote and rugged terrane, was made available for a total of seven weeks during the second and third field seasons. Standard U.S. Geological Survey topographical maps, enlarged to a scale of 3 inches to the mile, were used as a base in field work. Aerial photographs were of limited value. Eighty-seven thin sections

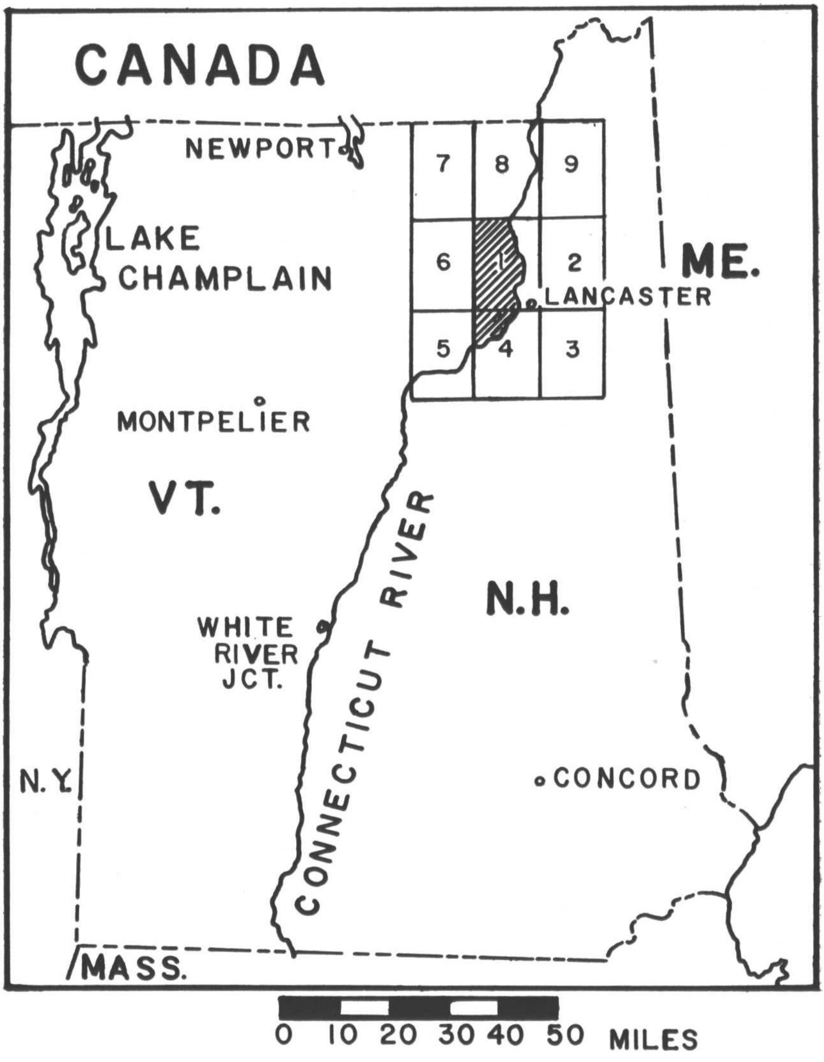

Figure 1. Index map showing the Lunenburg-Brunswick-Guildhall area represented by diagonal lines. Surrounding quadrangles include: (2) Percy, (3) Mt. Washington, (4) Whitefield, (5) Littleton, (6) Burke, (7) Island Pond, (8) Averill, and (9) Dixville.

were studied. From the fall of 1958 to the fall of 1959 time was devoted to study of the geological data and preparation of the manuscript and maps. In addition, suites of Paleozoic rocks from surrounding areas which are included in the geological collection at Harvard University were examined carefully.

Acknowledgments

The area was mapped while the author was in the employ of the Vermont Geological Survey and under the direction of Charles G. Doll, State Geologist. The writer wishes to thank Dr. Doll for his constant interest and helpful suggestions as the work progressed, and for making possible the use of a jeep during the course of some of the field work.

Especial acknowledgment is made here to Dr. James B. Thompson, Jr., of Harvard University who visited the writer in the field for three days. Dr. Thompson's extensive knowledge of the regional stratigraphy and structure together with stimulating discussions of the same proved helpful in clarifying a number of problems. In addition the writer is grateful to Dr. Marland P. Billings and Dr. Thompson for permission to examine suites of northern New England rocks in the Harvard University collection.

Ten days were spent in the field with Professor Bertram Woodland and his assistant mapping the common boundary area of the Burke and Guildhall quadrangles where mutual problems of interest existed. On other occasions visits in the field and discussion of the regional geology with Dr. and Mrs. Woodland (Dr. Mary Vogt), Dr. Bruce Goodwin (Island Pond quadrangle), and Dr. Paul Myers (Averill quadrangle) proved helpful.

The writer and his family are more than grateful for the many courtesies received from permanent and summer residents of the area. Cooperation and kindness made the writer's stay in the field a memorable one.

Thanks are also due to Andre Tetreault and Christos P. Alex who ably assisted in the field in the summers of 1957 and 1958, respectively.

The photomicrographs used in this bulletin were made by William Perkins; the hand specimens were photographed by Arthur Latham and Arthur N. Johnson, while Allen E. Andersen, Jr., capably assisted as draftsman.

A University of Massachusetts Teachers Research Grant aided appreciably in defraying the cost of preparation of the manuscript and maps.

PLATE 3. River or possible kame terrace west of North Road, Guildhall.

Physiography

The area described in this report lies in the western portion of the White Mountain section of the New England physiographic province (Fenneman, 1938). The Caledonia Range, the western range of the White Mountain section, lies to the west and the Pilot Range and Stratford Mountain of the White Mountains lie to the east beyond the Connecticut River. Maturely dissected topography characterizes the region. The higher summits range between 2,000 feet and 2,700 feet, and the highest peak, Stone Mountain, attains an elevation of 2,753 feet. Remnants of an ancient erosional surface occur at elevations of 1,200 feet to 1,400 feet.

The linear plan of the ridge of prominent hills and mountains extending from Baldwin Hill in the southwest to Bear Mountain in the northeast is evident on the maps. These hills and mountains, composed of resistant metamorphic rock, depict the northeasterly regional trend nicely and are akin to the underlying structure. West and Bull Mountains in the north, and Duren Mountain and Flynn Hill southwest of Guildhall have been developed on coarsely crystalline intrusives. There is excellent topographic expression of the body of granite upholding West Mountain. Notch Pond Mountain, Lake Mountain, and Stoneham

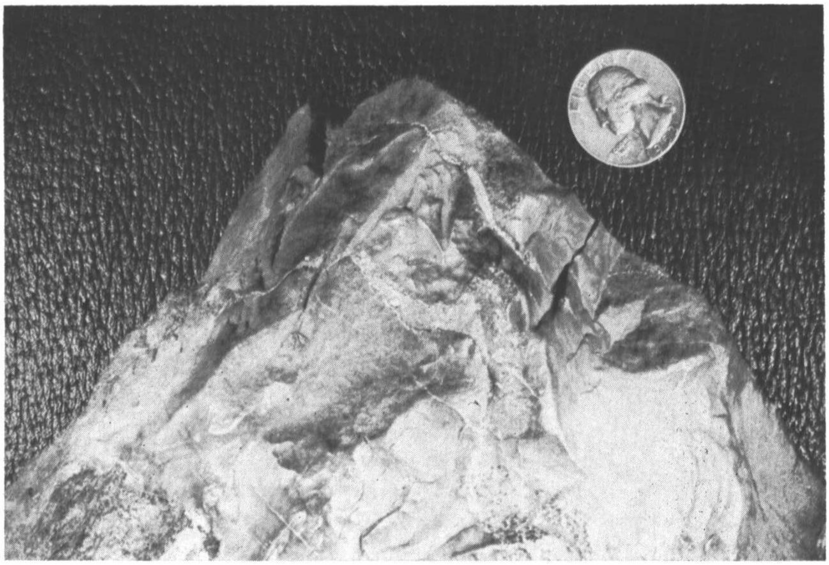

PLATE 4. Ventifact clearly illustrating facets, pits, ridges, and typical high gloss. From a location 1.5 miles south-southeast of Stratford, New Hampshire.

Mountain are domical features lying adjacent to the large igneous bodies.

All of the area lies in the Connecticut Valley drainage basin. The Connecticut River meanders repeatedly across a broad flood plain for much of its course from Bloomfield to South Lunenburg. Numerous ox-bow ponds and swamps occupy abandoned meanders. Well-developed river terraces may be seen at a number of points from southern Guildhall to Bloomfield (Pl. 3).

The river sands have been reworked by the wind into small dunes at a number of locations on both sides of the Connecticut River at elevations ranging from 880 feet to 920 feet, especially in Guildhall, Maidstone, Northumberland, and Stratford. A few examples of ventifacts were found 1.5 miles south-southeast of Stratford, New Hampshire, on the east side of U.S. Route 3 (Pl. 4).

The majority of the streams are small and flow in a northeasterly, easterly, or southeasterly direction. A few, small, westerly flowing streams in southern Granby and eastern Victory enter into the Moose River to the west. Excluding the Connecticut River, Paul Stream, over 13 miles long, is the largest stream in the area. Its drainage basin involves about one-fourth of the total region mapped. Granby Stream enters Paul Stream about 2.4 miles south of Ferdinand Bog, and at this point Paul Stream swings abruptly to the northeast. Granby Stream and its tributary, Wilke Brook, together with Paul Stream (for much of its northeasterly course) are adjusted to the strike of the Monroe fault. The southeasterly trending brooks in Guildhall are good examples of streams that cut the strike of the underlying metamorphic rocks.

Of the 18 ponds and lakes that beautify the area, only 2 are of appreciable size. Neal Pond in Lunenburg is about 1 mile long and 0.3 mile wide, and Maidstone Lake to the north is approximately 2.4 miles long and roughly 0.7 mile wide. Its maximum depth is 121 feet (Mills, 1951).

Glacial Features

An abundance of glacial erosional and depositional features testify to the effects of continental glaciation in this area. A detailed discussion of Pleistocene glacial features could well be the subject of another bulletin and therefore only a resume is included in this report.

Glacial striae and grooves indicate that ice moved in a south-southeasterly direction, with the average of some 40 readings indicating a direction of S 15°E. The northeasterly trend and differential hardness of the metamorphic bedrock locally controlled the movement of the glacial ice as illustrated by small rock ridges and cols eroded in the rock in the notch 0.4 mile S 50°E of Round Mountain, and at the notch on the east side of Burnside Mountain. At these two points where the Clough conglomerate crops out, the ice moved in a southwesterly direction. The regional trend and differential hardness of the various rock types along the mile-long ridge west of Stone Mountain also controlled ice movement with the result that a series of small, almost equally spaced notches trending N 20°E—S 20°W were formed.

Sizable talus slopes are present at a number of locations. Extensive aprons of talus repose on steep slopes on the southwest and west side of West Mountain, and also on the east side of Dennis Pond and on the south face of Burnside Mountain. Smaller, but still impressive talus slopes are situated on the southeast slope of Bear Mountain, on the slope 0.5 mile S 50°E of Round Mountain, and on the southerly slopes of Adden, Sheridan, and Duren Mountains.

Numerous glacial erratics are scattered about the area. Their size, shape, frequency, and composition are of some value in determining the bedrock where actual outcrops are absent. Noteworthy are the large granite blocks found 0.5 mile east and also 0.5 mile west of Unknown Pond. Some blocks on the west side of Unknown Pond average 30 feet by 20 feet by 15 feet. An abundance of somewhat smaller erratics strew the ground northeast and east of Tuttle Pond, and again in the flat swampy land south of West Mountain Pond.

The Maidstone cave situated on the west slope of Stoneham Mountain is particularly interesting. Vertical and almost horizontal jointing which developed in the bedrock prior to the glaciation produced huge blocks of rock. As a result of the glaciation the blocks were rearranged so that some are pulled apart by as much as 6 feet and all of them are moved to some degree downslope. Some of the upper blocks overrode the lower ones to produce the roof of the cave. The vertical joints are opened from a few inches to about 6 feet and some reach a depth of at least 30 feet. The vertical joints trend about N 70°E and are exposed for a distance of about 300 feet upslope from an approximate elevation of 1700 feet. At three locations along the strike of one of the vertical joints sufficient space exists to provide entrance into the cave.

Pre-glacial depressions were either ice scoured, or partially scoured and subsequently sealed off by glacial debris to form the seat of most ponds, lakes, and swamps in the area. Glacial ice effectively carved the basin that confines Maidstone Lake.

Stratified drift and till deposits are widespread. Kame terraces are readily discernible at a number of places and particularly evident where the lowlands begin to rise along the west side of the Connecticut Valley floor about 2.5 miles west of Guildhall. The broad kame terrace at Brunswick, which rises 65 feet above the Connecticut River, enjoys a national reputation because of the six adjacent mineral springs that pour from it and empty into the Connecticut River. The Brunswick Springs, as they are collectively called, was the site of a hotel until 1929, and visitors there who drank the mineral waters claimed them to be of great medicinal value. About 300 feet west of the springs there is a small kettle pond that owes its origin to a glacial ice cake long since melted, which was stranded in the sand drift. Seepage from the slope to the west and local runoff supplies the water for the pond which in turn feeds the springs (see Fig. 2). R. W. Chapman (1938), in a paper dealing with the origin of the springs, concluded that in spite of the belief that the six springs each yielded a different kind of mineral water, in reality there is no great difference in the waters. The water probably arises from one large spring, and he notes that hydrogen sulphide is common to all six springs. In 1935, the New Hampshire Board of Health made a sanitary

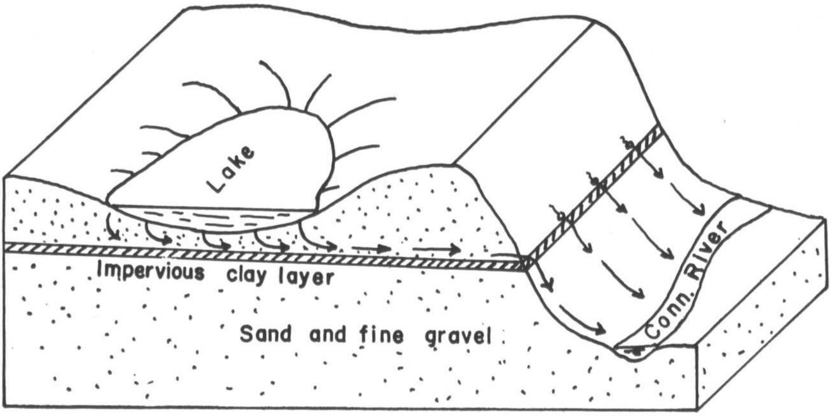

Figure 2. Diagram illustrating origin of Brunswick Springs which empty into the Connecticut River. Modified from R. W. Chapman, 1938.

analysis of water samples from the pond and the "arsenic spring," which showed the water from the two to be virtually the same. The slight difference in the composition of the water is probably due to the mineralogy of the sand and organic factors.

Evidence of the sinuous paths of glacial streams is found in the form of sand ridges or eskers which occur on the valley floors in the northern part of the area. These ridges range in height from 10 feet to greater than 60 feet, and in length from a few hundred yards to nearly 2 miles. The crests are characteristically sharply rounded and serrate. Examples are seen paralleling Paul Stream east of South America Pond, and between Walker Dam and Bullthroat. The finest example of an esker is the gravel sand ridge that extends from the vicinity of Browns Mill to the north end of Wheeler Pond and which is clearly visible on the topographic map. Other noteworthy examples can be seen paralleling Granby Stream near Granby Bog and 0.7 mile N 5°E of Walker Dam.

STRATIGRAPHY

Introduction

The Paleozoic metasedimentary rocks of this area range from Ordovician to Devonian in age and are assigned to 7 units. They underlie about 70 per cent of the area, with the remaining 30 per cent underlain by igneous rocks. The area is crossed by the northeasterly trending Monroe fault which serves to separate on its northwest side the Silurian and/or

TABLE I

CORRELATION TABLE

Modified from Billings (1956, Figure 7)

System	Series	West of Monroe Fault "Vermont Sequence"	East of Monroe Fault "New Hampshire Sequence"
Devonian	Lower	Meetinghouse* Gile Mountain* Standing Pond Waits River Northfield **	Littleton*
Silurian	Middle	Shaw Mountain	Fitch*
	Middle or Lower		Clough*
Ordovician	Middle and Lower	Cram Hill—Moretown	Partridge* Ammonoosuc Albee*
		Stowe	Orfordville

*Indicates formations present in the Lunenburg-Brunswick-Guildhall area.
**See Table II for alternate interpretations of the stratigraphy for these units.

Devonian rocks of the "Vermont sequence" from the Ordovician, Silurian, and Devonian rocks on the southeast which belong to the "New Hampshire sequence." Age relationships between the rocks on the two sides of the break are discussed later in this bulletin.

Description of Rock Units of the "New Hampshire Sequence"

ALBEE FORMATION

General Statement: The Albee formation (Billings, 1935) takes its name from Albee Hill, just north of Gardner Mountain in the Littleton, Vermont-New Hampshire quadrangle where a group of slates and quartzites are typically exposed. This formation extends northeasterly from the Bradford-Newbury, Vermont area in the Connecticut Valley to at least the Maine-New Hampshire border north of Umbagog Lake. About half of the map area is underlain by the Albee formation which comprises nearly 80 per cent of all metasediments mapped. Good exposures easily reached may be seen in central and northern Lunenburg particularly east of Neal Pond, and on the southwest side of Sheridan Mountain in Guildhall, in the vicinity of Stoneham Mountain, Maidstone, and west of Route 102 north of the village of Maidstone.

Lithology: A large variety of rock types are found in this formation. They are assigned to the chlorite, biotite, garnet, staurolite, and sillimanite zones of metamorphism (Harker, 1932). The thickest beds are in the southeasterly area while thin bedding is characteristic of exposures to the northwest. Metamorphism increases progressively from southeast to northwest with the result that the chlorite, biotite, and garnet zones strike clearly across the region appearing as a series of bands on the geologic map. For the most part the staurolite and sillimanite zones skirt the bodies of granite of Devonian age.

The rocks of the chlorite zone are classed arbitrarily into three groups by Billings (1937, p. 472). Using this classification which is based on the amount of quartz or quartz plus feldspar present, the following types are recognized: (1) those containing less than 60 per cent quartz or quartz plus feldspar, slate, phyllite, and feldspathic phyllite; (2) quartz or quartz plus feldspar ranging from 60 to 80 percent, quartzose phyllite and argillaceous phyllite; and (3) with more than 80 per cent quartz, quartzite or with quartz plus feldspar constituting 80 per cent or more of the rock, feldspathic quartzite.

The schistose, quartzose phyllite, and relatively massive, argillaceous quartzite are interbedded with massive quartzite to make formidable outcrops along the strike from 0.5 mile north-northeast of Lunenburg to 1 mile west of Flynn Hill. The individual quartzite beds range in thickness from a few inches to many feet (Pls. 5 and 6) and are accentuated by the differential hardness that exists between the bedded quartzite and other types. The thickest beds, some of which exceed 50 feet, are mostly pure, massive quartzite and occur along the southeast slopes of a series of hills (elevations from 1300 to 1500 feet) on the southeast, east, and northeast sides of Sheridan Mountain. The quartzite is gray when fresh, but weathers distinctly white (Pl. 7), and probably represents the eroded core of the Lunenburg anticline. Except for the diminishing thickness of the quartzites and rather uncommon occurrence of feldspathic types, these rocks are fairly evenly distributed and show little change in the western part of the chlorite zone. The less pure quartzite and other types generally range in color when fresh from gray to pale or dark green, and, when weathered, to white, gray, or buff. Staining due to the presence of pyrite is not uncommon.

The Albee rocks of the chlorite and biotite zones are converted to

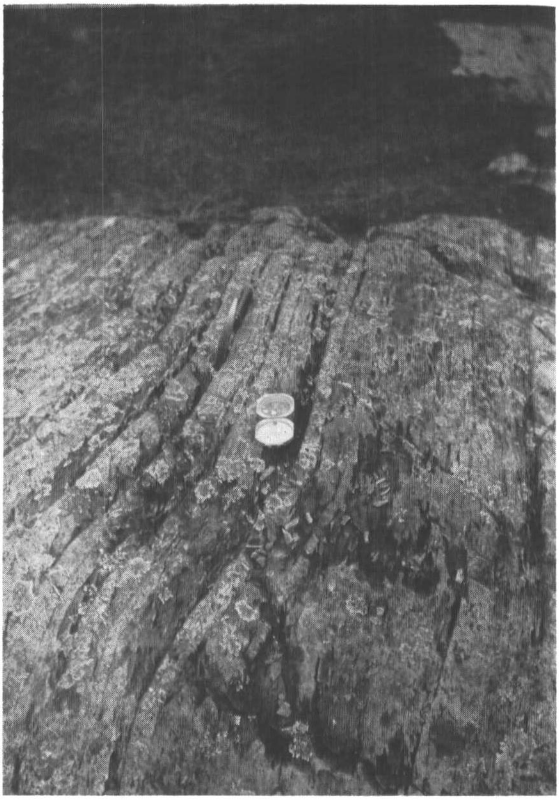

PLATE 5. Thin interbedded Albee quartzite and green schist or slate at a location 1 mile east of Mill Village, Lunenburg.

hornfels at some places. Good exposures may be seen at several easily accessible locations just west of Route 102 from Stevens to just southeast of Bear Mountain. Other locations of hornfels are found south of Guildhall. In all cases the hornfels is intimately associated with rocks of the Highlandcroft plutonic series. The hornfels consists of about 55 per cent quartz and 40 per cent micaceous minerals (mostly chlorite and biotite) with minor amounts of epidote, magnetite, and small cubes of pyrite.

The rocks of the biotite zone are largely similar to those of the chlorite zone except for the appearance of biotite porphyroblasts that range from minute to about 3 millimeters in diameter. The massive quartzite beds most commonly range in thickness from less than 1

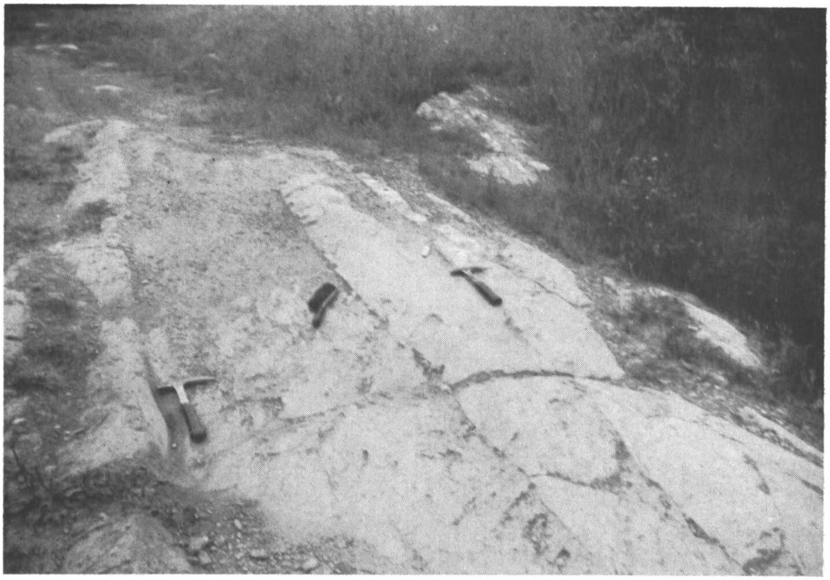

PLATE 6. Massive interbedded Albee quartzite and green schist or slate at a location 0.6 mile east of Mill Village, Lunenburg. Hammer handles parallel bedding. Brush handle parallels cleavage.

inch to about 6 feet. Mica-quartz schist takes the place of some types of phyllite.

The transition into the garnet zone is marked by the appearance of minute grains of garnet that cannot be detected by the unaided eye, but larger garnets, visible to the unaided eye and ranging from 0.5 to 3 millimeters, are found where the staurolite zone first makes its appearance. Most staurolite occurs as minute grains but at localities close to large igneous bodies the staurolite crystals occur up to 5 millimeters in dimension. Staurolite, garnet, or the two together generally form less than 7 per cent of the rock.

Greenish-gray to brown colored schistose rocks constitute the larger part of the garnet and staurolite zone, with thick beds of massive gray quartzite distinctly subordinate. It is difficult to distinguish bedding from schistosity in some of these rocks. Micaceous quartzite, quartz-mica schist, and mica schist make up the bulk of the garnet and staurolite zones. A distinct pin-striping of micaceous quartzite and more schistose types, with individual bands commonly 1 to 2 inches thick, characterizes some of the rocks in the western part of the map-area.

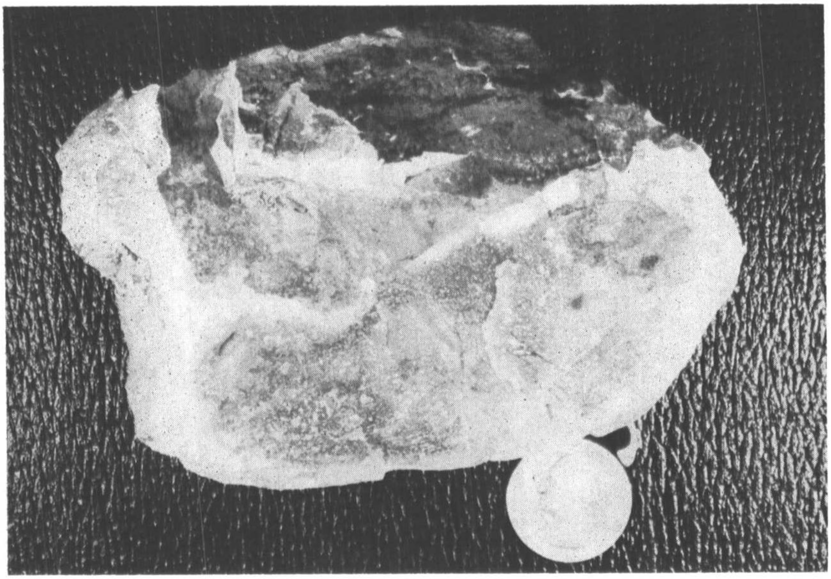

PLATE 7. Massive pure Albee quartzite with milky white halo produced by weathering.

An interesting pin-stripe horizon, not more than a few hundred yards in breadth, can be traced along its strike of about N 10°E from a hill (elevation 1965 feet) 1 mile south of Temple Mountain to an elevation of 1300 feet on Granby Stream. The pin-striping is the result of segregation of quartzofeldspathic and micaceous minerals respectively into alternating laminae, each less than 1 millimeter thick (Pl. 8). A similar pin-striping is found at numerous outcrops of Albee rocks from the vicinity of Stoneham Mountain to east of Paul Stream Pond.

The sillimanite zone lies close to the granites of the New Hampshire plutonic series. This rock is characteristically a medium- to coarse-grained micaceous schist with flakes of muscovite often attaining a diameter of from 1 to 3 millimeters. Some exposures resemble gneiss, but close examination indicates no preferred orientation of mineral grains as would be the case with gneiss. Sillimanite is associated with micaceous quartzite in eastern Victory. For any given location this mineral amounts to not more than 3 to 5 per cent of the total modal analysis. At a few localities there is pink andalusite in the sillimanite zone.

A number of exposures of rock transitional between those of the Albee and Ammonoosuc formations occur from just west of the Mt. Orne Bridge in Lunenburg located near the junction of U.S. Route 2 and the

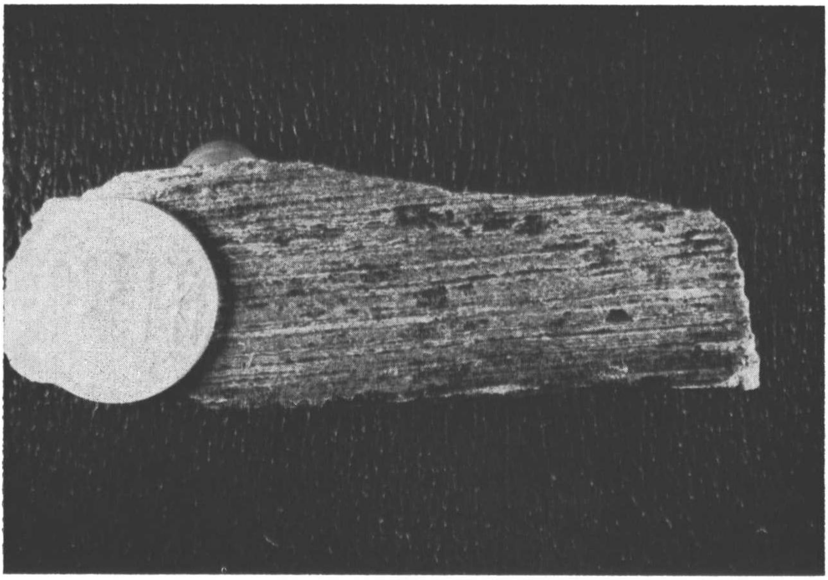

PLATE 8. Fine pin-striping of this type forms a distinct horizon in the Albee formation in the western part of the map-area.

Gilman road, to a point 0.3 mile southwest of the junction of U.S. Route 2 and Route 102 in southern Guildhall. In some of the more southerly outcrops Albee quartzite predominates, with fine-grained soda-rhyolite subordinate; in those outcrops east-northeast of the Guildhall-Lunenburg town line the predominant fine-grained soda-rhyolite is massive to weakly schistose and locally distinctly schistose. Individual mineral grains are commonly only a fraction of a millimeter across. The scattered, fragmental quartz grains are colorless and transparent and lie in a groundmass of sericite, chlorite, and some feldspar. A pronounced mineral lineation in the massive rocks at some locations suggests flow structure. In southern Guildhall tongues of rock of the Highlandcroft plutonic series intrude the Albee Ammonoosuc transition zone to further alter the original character of the rock. The transition zone thins rapidly to the north and northwest and fails to appear elsewhere because of non-deposition of Ammonoosuc-type sediments within the map-area.

Soda-rhyolite tuff with its distinct angular fragments of bluish and colorless transparent quartz grains and subhedral feldspar is present at three separate locations within the Albee formation. All occur along the line of strike and probably represent the same horizon. The quartz

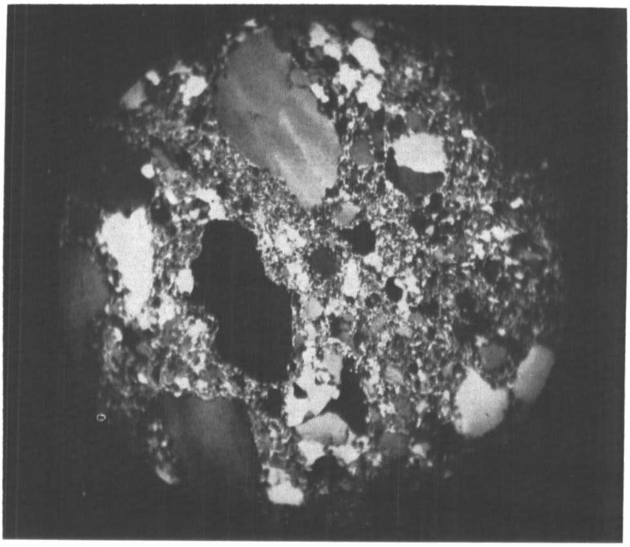

PLATE 9. Soda-rhyolite tuff from an occurrence 0.9 mile N 80°E of Mill Village, Lunenburg. Tuff appears close to the top of the Albee formation. Large phenocrysts of quartz show strain shadows with the groundmass composed of fine quartz granules, feldspar and sericite. Large phenocrysts of feldspar occur in some samples. Crossed nicols, X 25.

grains range in size from 1 to 5 millimeters in diameter, and the feldspar from 0.5 to 2 millimeters (Pl. 9). Exposures occur 0.7 mile south-southeast of Mill Village, Lunenburg, in a pasture on the east side of the road, 0.9 mile N 80°E of Mill Village at elevation 1380 feet and also 0.6 mile N 45°E of Lunenburg Village.

Thickness: Because the Albee rocks are intensely deformed, it is impossible to make an accurate determination of their thickness, but Billings (1956) gives 5000 feet as an estimated thickness for the Albee formation.

Age: There is general agreement among geologists who have studied the Albee formation that it should be assigned to the Middle Ordovician, or possibly Upper Ordovician (?).

Partridge Formation

General Statement: The Partridge formation takes its name (Billings, 1935) from Partridge Lake in the Littleton, Vermont-New Hampshire quadrangle where good exposures of dull black slate are found. This formation crops out in the map-area at several scattered locations north of Granby Road. The best exposures, although rather inaccessible, occur along the steep ridge east of Round Mountain, and at Bear and Hedgehog Mountains.

Lithology: The Partridge formation is composed largely of dull gray to sooty black slate or phyllite. It is commonly stained yellow to brownish yellow where weathered. Distinct cleavage is common; bedding is rare. A comparison of hand samples from Bear and Hedgehog mountains with those collected from the northeast side of Partridge Lake in Littleton, New Hampshire, shows them strikingly alike. Much of the slate is fissile, but locally it is distinctly massive and tough. At a few areas it is more phyllitic than slaty in appearance. Biotite porphyroblasts ranging from less than 0.2 to about 0.5 millimeters across are visible in thin section together with abundant sericite, some quartz, and about 15 per cent opaques. The opaque matter is chiefly carbonaceous matter and some pyrite.

At two locations beds of volcanics can be observed in the Partridge slate. On Hedgehog Mountain two beds of schistose, feldspathic soda-rhyolite tuff are noted. One bed is 5 feet thick and another nearby is 3 feet thick. At another location about 0.2 mile east of the notch on the east side of Round Mountain there occurs a bed of massive soda-rhyolite tuff at an elevation of 1950 feet. This nearly vertical exposure exceeds 20 feet in thickness and a substantial talus of rude polygonal blocks has formed on the steep slope below. Milky gray to clear blue quartz grains averaging 1 to 2 millimeters in diameter are conspicuous on the gray, weathered rock surfaces. The massiveness of this rock together with the rude polygonal structure it exhibits suggests a flow as its origin. Although the volcanics found here are thicker than those found in the basal member of the Partridge formation in the Littleton-Moosilauke area (Billings, 1937, p. 481), it is likely that they are correlative and their presence indicates that at least the lower part of the Partridge formation occurs in the map-area.

Thickness: The Partridge formation, like the Albee formation, is intensely folded. Although the breadth of outcrop is about 3300 feet in the area east of Round Mountain Notch, the actual thickness is probably not more than 1400 to 1600 feet. The absence of the Partridge formation in many places is attributed to a pronounced and widespread unconformity at the base of the Silurian (Billings, 1937, pp. 517–518). It may be for this reason together with non-deposition of Ammonoosuc sediments that the Silurian Clough formation was deposited on the

PLATE 10. Clough conglomerate showing large and small angular blocks of quartzite set in a dark gray schist matrix. Southwest side of Bald Mountain near Cutler Mill Brook.

Albee formation as is the case in the notch on Burnside Mountain and southwestward to Stone Mountain and at a location along the small brook 0.7 mile N 10°W of Burnside Mountain.

Age: Like the Albee, the Partridge formation is of Middle Ordovician or possibly Upper Ordovician (?) age.

Clough Quartzite

General Statement: The Clough quartzite takes its name from Clough Hill in Lyman, New Hampshire (Billings, 1935). Although this formation was referred to as the Clough conglomerate for a number of years, in more recent papers it has been called the Clough quartzite because quartzite is more common than conglomerate at most exposures (Billings, 1956, p. 21). In this area the formation is typically conglomerate. The Clough is found in New Hampshire at locations from 5 miles south of Littleton to the Massachusetts border. In the Vermont area it has been found along the direction of strike from Stone Mountain, Guildhall, to Bald Mountain, Maidstone.

Lithology: The conglomerate is composed of boulders, cobbles, pebbles, and angular rock fragments and splinters ranging from about 24 inches to less than 1 inch in maximum diameter (Pl. 10). Most of these are quartzite and micaceous quartzite with pebbles and splinters of dull gray mica schist distinctly subordinate. The matrix is most commonly dark gray schist in the area from Burnside Mountain to Bald Mountain. Biotite porphyroblasts are widespread and commonly range from 0.2 to 0.3 millimeters in diameter. Garnet porphyroblasts ranging from 0.5 to 0.8 millimeters in diameter occur at Burnside Notch. The conglomerate thins from northeast to southwest and probably its original state in the vicinity of Granby Road and the summit of Stone Mountain was a sheet only a few feet thick which was deposited on the Albee formation. Where the Clough formation is thin, the matrix is either quartzite or quart-mica schist. It appears that the underlying Albee and overlying Littleton formations flowed around the massive blocks of Clough quartzite* during plastic deformation.

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*The strong similarity of the pebbles and cobbles in the Clough to the Albee quartzite strongly suggests that they were derived from the Albee at the time it underwent severe erosion in the area from just north of Granby Road to the summit of Stone Mountain. The writer recognizes that in the area mapped as Clough beginning at Burnside Notch and northeasterly to Bald Mountain that the lithology of some of the clasts shows much less similarity to the Albee lithology (quartzite) especially east of Round Mountain and at Bald Mountain. Here some of the cobbles and angular blocks occurring in gray schist and phyllite matrix appear to be similar to other lithologies such as the Moose River sandstone of Camden age found in Maine (personal communication, J. Thompson Jr., 1957). However, no fossils were found on which to base a positive correlation with the fossiliferous Moose River of Maine or other units. This does not rule out the possibility that the Moose River or its equivalent was deposited in this area above the Clough and that after its deposition early Devonian uplift locally resulted in vigorous erosion of it as well as the underlying units. Reworking of the rusty, black Partridge slate and schist to form a black mud and slate-schist splinter matrix together with limited attack of the Albee in positive areas, resulted in mixing of Albee, Clough, and Moose River-type lithologies to form the basal part of the Littleton from Burnside to Bald Mountain. Because this explanation is conjectural, the writer has mapped the entire conglomerate breccia zone as Clough, recognizing that at least some of it might be rightfully considered as basal Littleton from Burnside to Bald Mountain.

Since the writer completed his field work, Boucot and Arndt (1960) in a paper discussing fossils of the Littleton formation, establish the age of the Littleton on Dalton Mountain, New Hampshire, some 13.5 miles away, as Camden (Lower Devonian). Several of the fossils found at Dalton Mountain are correlative with those of the upper part of the Moose River sandstone of Camden age from Somerset County, Maine. The relatively short distance between the Dalton Mountain and Burnside Mountain synclines and similar structural setting support the idea that some of the quartzite clasts resembling the Moose River sandstone are in reality Moose River.

PLATE 11. Stretched sub-angular to well-rounded quartzite cobbles and pebbles of the Clough formation. Long axes plunge west-southwesterly at about 60°. Location is at base of fire tower on Stone Mountain.

The large, massive, angular quartzite blocks seen at Burnside Notch, in the notch southeast of Round Mountain, and in the vicinity of Bald Mountain show no preferred orientation, but small splinters and stretched pebbles often show a distinct lineation. Lineation of this sort is clearly visible on Stone Mountain at the base of the fire tower where the long axes of quartzite cobbles plunge west-southwesterly at about 60° (Pl. 11).

Thickness: The breadth of outcrop of the Clough conglomerate is greatest at Bald Mountain where it amounts to approximately 3100 feet. The conglomerate thins along the strike to the southwest as indicated by decreasing breadth of outcrop at a series of exposures between Bald Mountain and the summit of Stone Mountain. At the latter point the thickness is upwards of 40 feet; in the Bald Mountain area it may amount to about 1500 feet. The absence of the Clough conglomerate southwest of Stone Mountain may be for tectonic reasons. The calcareous Fitch formation which overlies the Clough quartzite in the Littleton-Moosilauke area is absent wherever the Clough crops out in the map-area. However, the Fitch is present southwest of Adden Mountain.

Age: Elsewhere the Clough quartzite grades laterally and vertically into the Middle Silurian Fitch formation and it is thought that the Clough lithology is Lower or Middle Silurian.

Fitch Formation

General Statement: The name of this formation was proposed by Billings (1935) for the typically calcareous rocks exposed at the famous Fitch Hill fossil location in Littleton, New Hampshire. More recent mapping has proven this formation to be widespread in western New Hampshire. Only two small patches of Fitch limestone, both somewhat exaggerated on the geologic map, are found in the map-area. One location is 2 miles north of Neal Pond and the other, first referred to by Jackson (1844), is 2.2 miles N 40°W of Lunenburg Center. Mildly calcareous rocks occur in drift a few hundred yards north of Camp Winneshewauka and south of Pond Hill. The two positive locations and distribution of drifted blocks are in perfect strike continuity.

Lithology: Bluish-gray, white weathering, arenaceous limestone is typical of both locations and in each case it overlies the Albee formation.

Thickness: The breadth of outcrop at each location is small, probably not more than 50 feet, but the precise relationship to the Albee formation cannot be determined because of glacial drift and forest cover. It appears that the calcareous rock is infolded into the Albee formation and that the thickness may be about 25 feet. It is probable that while the Clough conglomerate was being deposited in the area from Bald Mountain to Stone Mountain, the Fitch sediments were laid down simultaneously as a thin veneer in the Lunenburg area and they pinched out to the northeast. The Clough which was deposited from the northeast pinches out to the southwest, and an interfingering of the two lithologies probably occurred, although this relationship has not been observed in the field because of failure to crop out and for tectonic reasons. Furthermore, it is likely that the Clough thickened to the northeast at the expense of the Fitch and that the Fitch thickened to the southwest at the expense of the Clough. The possibility of the simultaneous deposition and resultant interfingering of the Clough and Fitch sediments in different parts of New Hampshire was recognized earlier by C. A. Chapman (1939, pp. 139–140) working in the Mascoma quadrangle, and by Hadley (1942, p. 130) who mapped the Mt. Cube

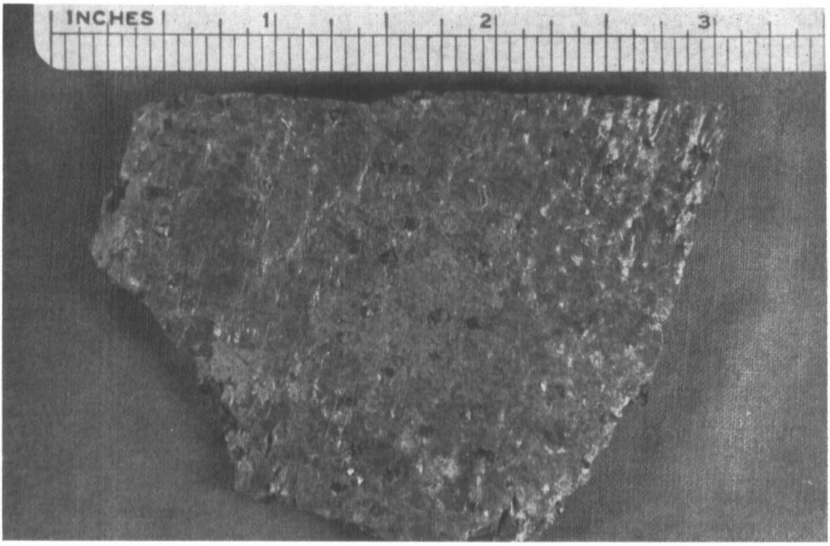

PLATE 12. Porphyroblasts of magnetite in Littleton biotite-garnet phyllite from Burnside Mountain, Guildhall.

area. The northernmost limit of the Fitch formation in New Hampshire, which is characterized by the pinching out of the calcareous sediments, is essentially along a line connecting Whitefield and Twin Mountains (Billings, 1956, p. 26). Extension of this line north-northwestward into Vermont would place it near the small exposure of Fitch limestone 2 miles north of Neal Pond, Lunenburg. Southwest of this line the Fitch sediments become increasingly thicker, and southwest of a line connecting Franconia and Lyman, New Hampshire, they overlie the Clough quartzite. Still farther south in the Mascoma quadrangle the Fitch formation is notably thinner than in the Mt. Cube quadrangle to the north and the Clough quartzite is very thick.

Age: The fossil dated Fitch formation is of Middle Silurian age.

Littleton Formation

General Statement: The term Littleton formation was proposed by M. P. Billings (1935) for typical exposures of slate, quartzite, and volcanics found on Walker Mountain and vicinity located west-southwest of Littleton, New Hampshire. The Littleton formation is widespread throughout New Hampshire and crops out at several areas in the Connecticut Valley of southern Vermont. In northeastern Vermont it overlies the Clough conglomerate and occupies the core of the north-

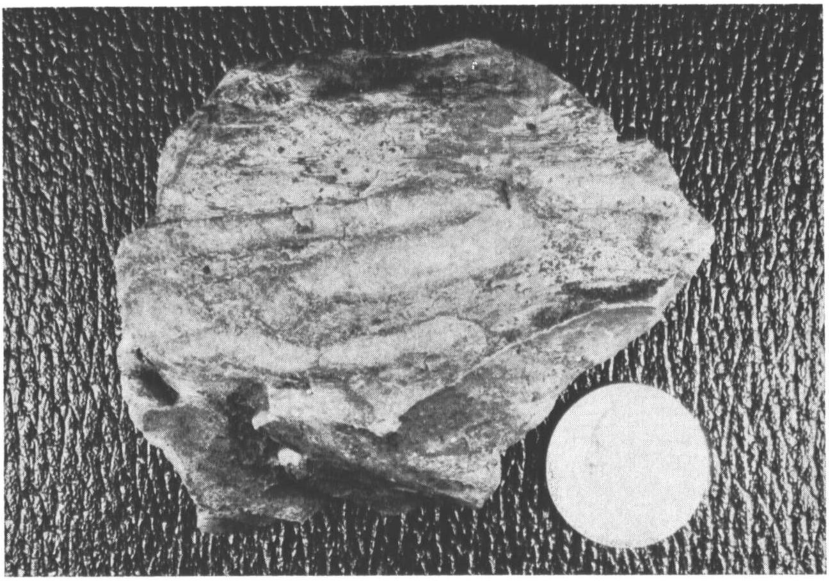

PLATE 13. Contorted band or ptygmatic fold of quartzite containing abundant minute garnets from the south slope of Burnside Mountain, Guildhall.

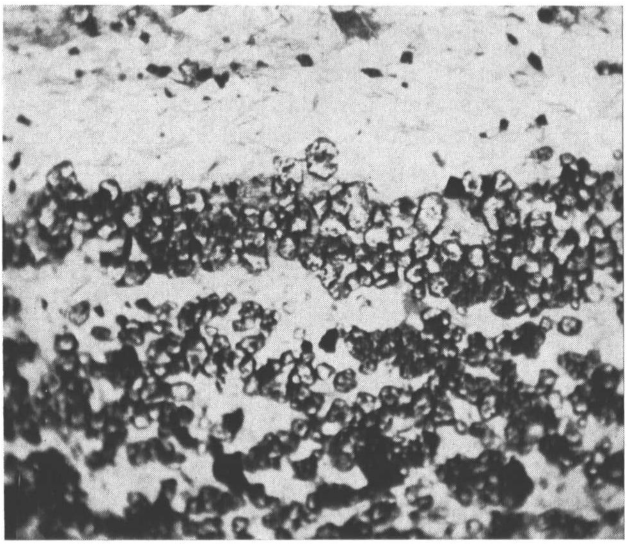

PLATE 14. Perfect euhedral garnets restricted to a portion of a contorted garnet-quartzite band. Opaque black mineral is magnetite which is found in both the phyllite (at top) and quartzite band. Nicols not crossed, X 100.

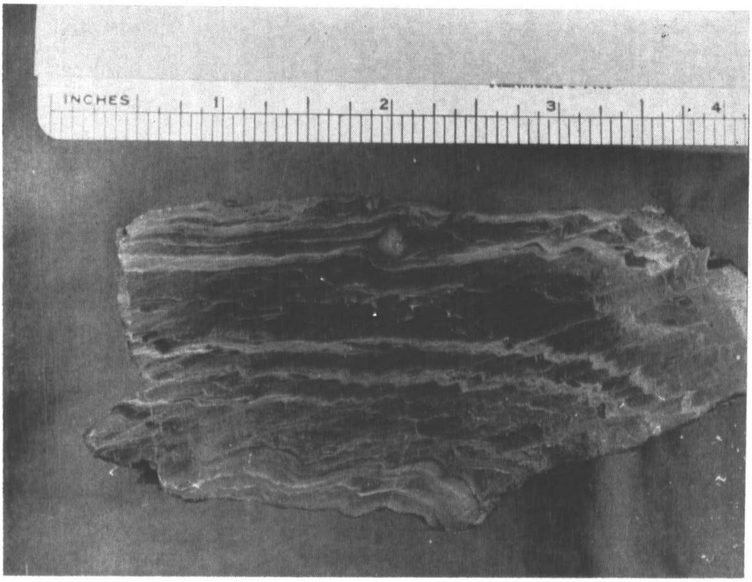

PLATE 15. Interbedded garnet-rich quartzite bands or beds and phyllite of the Littleton formation. Small displacements paralleling slip cleavage are seen right of center. Partially rotated lenticles at top center are probably derived from quartzite bands. Origin of sample about 100 yards north of Granby Road at an elevation of 1600 feet.

easterly trending Burnside Mountain syncline from the vicinity of Stone Mountain, Guildhall, to west of Bald Mountain, Maidstone.

Lithology: The Littleton formation lies in the garnet zone of metamorphism. It consists of lustrous, light to dark gray biotite-garnet phyllite and schist, some slate, and subordinate quartzite and impure quartzite. For the most part the quartzite overlies the phyllitic and schistose types and is confined largely to the northeastern end of the Burnside Mountain syncline. Porphyroblasts of small garnets and biotite ranging in size from 0.1 to 1.0 millimeter are common. In addition there are numerous small octahedral porphyroblasts of magnetite that occur in the phyllitic and schistose rocks (Pl. 12). The size and abundance of the magnetite makes it a useful horizon marker for tracing the phyllitic-schistose member of the Littleton formation in this area.

Good exposures of these fine-grained pelitic rocks are found along Granby Road at elevation 1600 feet and in particular to the northeast on Burnside Mountain. Several small patches, all too small to show on

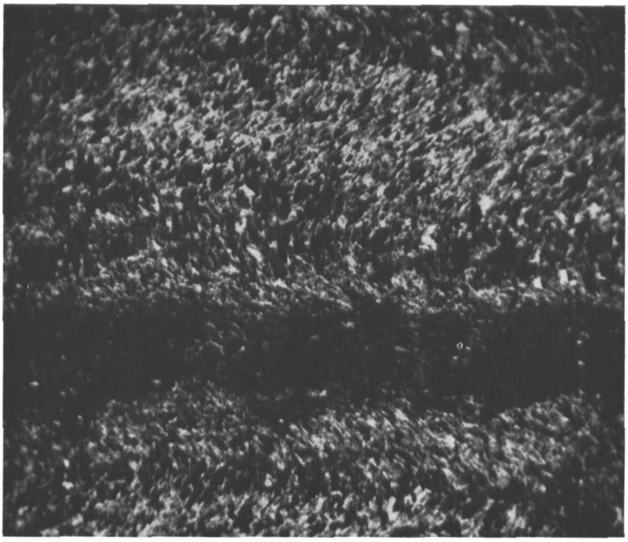

PLATE 16. Corrugated effect of herringbone structure illustrating slip cleavage in phyllite or schist from Littleton formation. Crossed nicols, X 100.

the map, occur on the west side of Stone Mountain at scattered locations beginning just west of the Ranger's cabin; others crop out at a number of points in and near the bed of a small brook (approximate elev. 1400 feet) located 0.7 mile N 10°W of the summit of Burnside Mountain where it overlies Clough conglomerate. The Clough and Littleton formations are absent in the bed of nearby Washburn Brook because that stream has cut through to the underlying Albee formation.

To the northeast coarser grained rocks consisting mostly of biotite-garnet schist, muscovite schist, and some quartzite occur on the southeast slope of Round Mountain and at several places between elevation 1100 feet and 1160 feet on Cutler Mill Brook. At exposures near elevation 1120 feet on Cutler Mill Brook, the Clough conglomerate overlies the Littleton and dips about 30° to the southeast indicating that the Burnside Mountain syncline here is overturned to the northwest.

Contorted bands or ptygmatic folds of quartzite are commonplace in and largely restricted to the various Littleton lithologies. They are characteristically gray to pale pink when weathered and range in thickness from 0.5 millimeter to 8.0 millimeters (Pl. 13). Some of the pinkish bands are garnet-rich: the approximate modal analysis of one band indicates 50 per cent garnet, 35 per cent quartz, 10 per cent muscovite and biotite, and 5 per cent magnetite (Pl. 14). The individual euhedral garnets are but a fraction of a millimeter in diameter.

Flow cleavage and slip cleavage are often more prominent than bedding, but in some places thin bedding is pronounced in the pelites (Pl. 15). Micro-herringbone structure and accompanying slip cleavage are easily distinguished under the microscope (Pl. 16).

Thickness: The maximum breadth of outcrop of the Littleton formation is at Burnside Mountain where it amounts to approximately 3300 feet. Its estimated thickness is about 1600 feet.

Age: Paleontological evidence found in the Littleton-Moosilauke area indicates that the Littleton formation is Lower Devonian (Billings and Cleaves, 1934).

Description of Rock Units of the "Vermont Sequence"

Gile Mountain Formation

General Statement: The Gile Mountain formation takes its name for typical exposures of schist found on Gile Mountain in the southern part of the Strafford, Vermont quadrangle (Doll, 1944, p. 18). This formation is continuous throughout much of northeastern Vermont from south of the type locality to beyond the Canadian border except where it is cut out by igneous intrusions. In the map-area it is restricted to two areas both of which lie to the northwest of the Monroe fault. One area is situated north-northeast of the village of Granby and the other occupies the extreme northern and northeastern part of the region. Most exposures are of gray schist or phyllite interbedded with micaceous quartzite, but those in the vicinity of the northern border from a mile east of Notch Mountain to the westernmost boundary are streaked with granite and pegmatite to form migmatite. A gradational contact exists between the Gile Mountain formation and the Meetinghouse slate.

Lithology: The principal rock types include dark gray phyllite or schist and interbedded micaceous quartzite. Migmatite is common in the northern and northwestern part of the area. A few lamprophyre dikes occur in the vicinity of Mitchell Mountain.

Exposures in the Granby area commonly consist of alternations of micaceous beds with ones of tan colored impure quartzite. Individual beds increase in thickness from east to west; the thinner average around 1 inch in thickness whereas some of the thicker along the western border in Granby commonly range from 1 to 2 feet in thickness (Pl. 17).

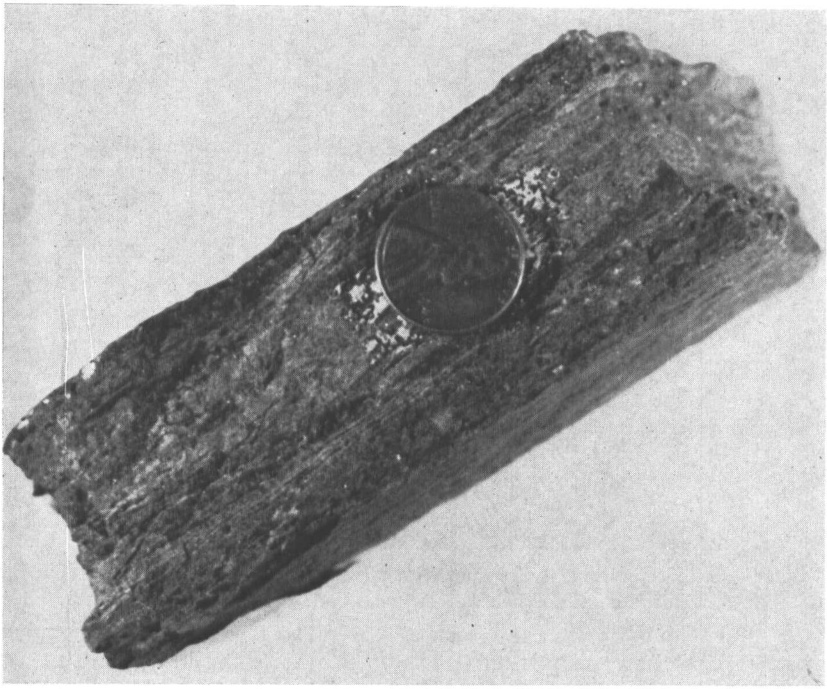

PLATE 17. Interbedded micaceous quartzite and quartz-mica schist characteristic of the Gile Mountain formation northwest of Granby Stream.

Microscopical examination reveals a few tiny corroded garnets scattered throughout the groundmass of laminated muscovite or sericite, biotite, and anhedral grains of quartz. Staurolite is generally absent except in exposures close to the granite. Thin sections of samples from Nurse Mountain show that the perfect euhedral garnet porphyroblasts are altered to pennine. Small porphyroblasts of randomly oriented biotite and chlorite are scattered throughout the groundmass.

The exposures of the Gile Mountain formation found north and northeast of Dennis Pond are similar to those in Granby, except that the garnet porphyroblasts are larger and contain abundant inclusions of opaque matter (Pl. 18). Crystals of pale pink andalusite are common in the outcrops on the west side of Route 102 about 0.5 mile south of the center of Bloomfield. They average 3 to 4 millimeters in diameter and 2 to 3 centimeters in length.

Sillimanite-mica schist occurs in several areas close to the large

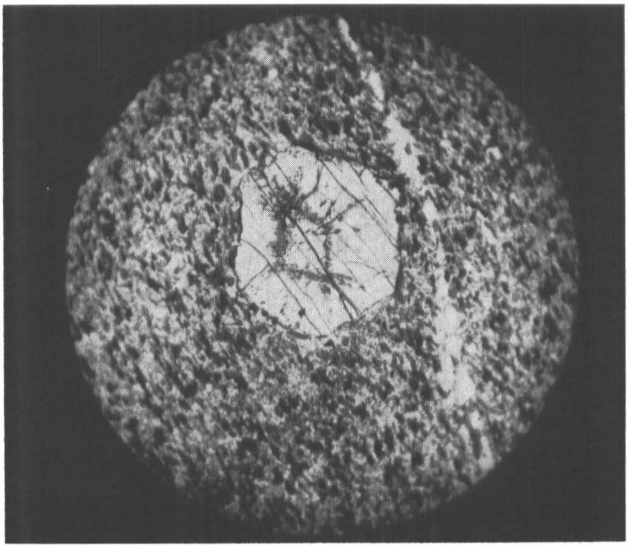

PLATE 18. Porphyroblast of garnet with opaque inclusions from a location in the Gile Mountain formation northeast of Dennis Pond.

pluton situated in the northern part of the area. The sillimanite appears in thin section generally as sheaf-like bundles or as isolated acicular crystals. The sillimanite constitutes as much as 5 to 10 per cent of the schist at some exposures on the east side of Wheeler Pond, and also at locations 1.8 miles north of the junction of Granby and Paul streams and along the west branch of Paul Stream one mile north of South America Pond. At the latter, andalusite largely altered to muscovite is common.

Lenses of calc-silicate rock generally averaging 3 to 15 inches in thickness are found in the intensely metamorphosed Gile Mountain sediments on Notch Pond Mountain and also at scattered exposures for more than a mile to the east. In the vicinity of Notch Pond Mountain and westward to the map boundary a good deal of the coarse quartz-mica schist is streaked with granite and pegmatite to form migmatite. Sillimanite and andalusite are widespread in this rock while kyanite and black tourmaline are limited to few exposures.

Thickness: The thickness of the Gile Mountain formation is estimated to be 6000 to 7000 feet in the Woodsville, Vermont-New Hampshire quadrangle (White and Billings, 1951, p. 656). It is estimated that the thickness in the map-area may attain 4000 feet.

Age: The Gile Mountain may be entirely Devonian or in part Silurian.

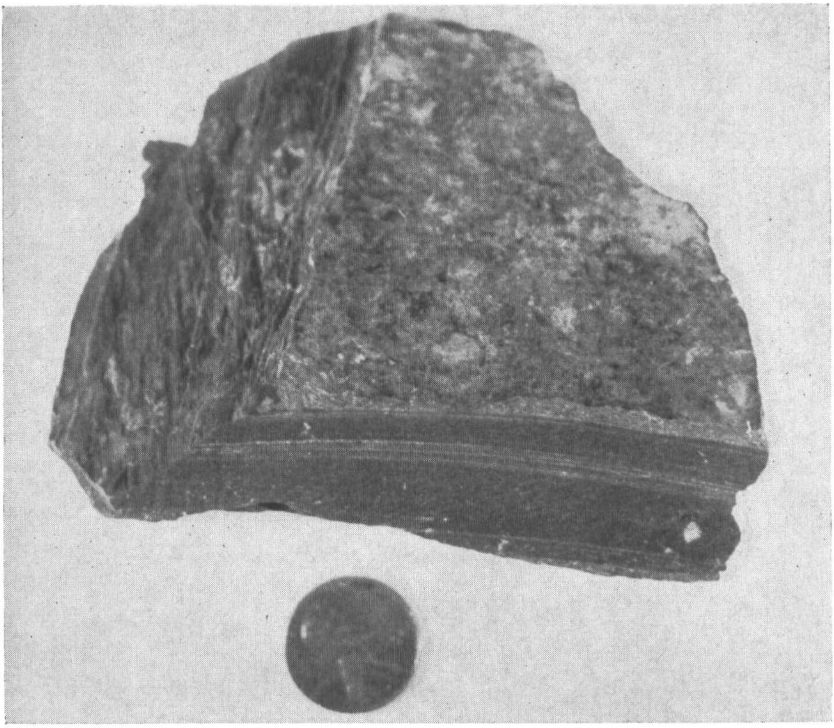

PLATE 19. Characteristic Meetinghouse slate lithology showing interbedded quartzite and slate. The slate is distinctly shiny and frequently finely crinkled. Specimen from an exposure about 0.3 mile southwest of Buzzell Gap, Granby.

Meetinghouse Slate

General Statement: The name of this unit was first proposed by Doll (1944, p. 19) for gray and black micaceous slates exposed on Meetinghouse Hill in the Strafford, Vermont quadrangle. A narrow band of Meetinghouse slate in the map-area crops out sporadically on the southeast side of the Gile Mountain formation and on the northwest side of the Monroe fault along the strike from a point 0.5 mile southwest of Buzzell Gap to north of the mouth of Stony Brook where its identity is lost.

Lithology: In the area southwest of Buzzell Gap the Meetinghouse is characteristically micaceous slate. It is of gun metal gray color, lustrous, fissile, and it possesses well-developed flow cleavage. The planes of cleavage frequently are slightly curved and distinctly crinkled. North-northeast of Buzzell Gap the Meetinghouse is usually a phyllite or schist. At all exposures the rock is thin bedded and contains quartzite bands seldom reaching a thickness of 1 inch. Frequently they are much thinner with the argillaceous beds thicker so that the overall appearance is distinctly pin-stripe (Pl. 19). Thin sections of the slate reveal very fine grains of quartz, abundant sericite, conspicuous porphyroblasts of biotite that average about 0.5 millimeters in diameter, shreds of chlorite, disseminated carbon, and a few minute garnets. Brown staining is due to the presence of pyrite.

Thickness: The amount of folding involved is indeterminate so the amount of thickness can only be estimated as ranging from 0 to a few hundred feet. The maximum breadth of outcrop is about 1000 feet. It is not clear whether the Meetinghouse pinches out or is cut out by the Monroe fault to the northeast of Stony Brook.

Age: The Meetinghouse slate is Devonian, or Silurian in age. Some detailed considerations regarding the age problem follow in a later section.

IGNEOUS ROCKS

Introduction

Igneous rocks account for about 30 per cent of the bedrock in the map-area. They have been assigned to the following plutonic series: the Upper Ordovician (?) Highlandcroft, the Late Devonian (?) New Hampshire, and the Mississippian (?) White Mountain. Granitic and dioritic rocks of the Highlandcroft plutonic series are confined to the east-central and southern portions of the region in the vicinity of the Connecticut River. Granitic rocks and associated pegmatite dikes and sills of the New Hampshire plutonic series are largely concentrated in the northern third of the area and in a small region of eastern Victory south of Granby. Widespread dikes and sills of metadiabase are assigned to an early stage of the New Hampshire plutonic series. Post-metamorphic dikes are scarce, and those that have been studied are thought to represent the Mississippian (?) White Mountain plutonic series.

Highlandcroft Granodiorite and Related Rocks of the Lancaster Pluton

General Statement: The type locality for the Highlandcroft granodiorite is located on the Highlandcroft Farm in the western part of Littleton, New Hampshire (Billings, 1935, p. 25). The granodiorite and associated intrusive rocks were assigned by Billings (*op. cit.*) to the Highlandcroft plutonic series. Similar rocks have been found elsewhere at scattered locations in the Connecticut Valley from Fairlee, Vermont, northeastward to near Bear Mountain in the map-area. In the vicinity of Bradford, Vermont, and Piermont, New Hampshire, they have been mapped as Fairlee quartz monzonite (Hadley, 1942). R. W. Chapman (1948, pp. 1072–1073) assigned similar rocks found in the Percy, New Hampshire quadrangle to the Lost Nation group. There they are chiefly quartz diorite with a minor amount of diorite. The various bodies appear to be comagmatic and show a tendency for elongation parallel to the northeast-southwest regional trend.

Description: In the area described in this report, a variety of rocks ranging from diorite to quartz monzonite are assigned to the Highlandcroft plutonic series. The largest body, consisting largely of granodiorite and quartz monzonite, is situated in Guildhall where it underlies most of the lowland and upholds Duren Mountain and Flynn Hill. A smaller area of diorite is located at South Lunenburg. In other areas adjacent to the immediate Connecticut Valley from South Guildhall to Bear Mountain, Maidstone, there are numerous dikes, sills, and tongues of the Highlandcroft plutonic series which intrude the Albee formation. On the slopes just west of Rogers Rangers Bridge and along the eastern end of the Portland Pipe Line crossing, quartz diorite is found in abundance. An epidotized diorite is found about 0.1 mile west of Route 102 along the southern boundary of the Guildhall quadrangle. Whether this rock is from a small dike or a stock could not be determined because of the heavy glacial drift cover. A small body of quartz monzonite shown on the geological map is located 0.3 mile west of Bear Mountain. Small dikes of granite pegmatite cut the quartz diorite in South Guildhall.

At no point is a sharp contact found to exist between the main body of the Highlandcroft plutonic series and the Albee formation. Rather the contact zone from Duren Mountain to Bear Mountain is marked by tongues, dikes, and sills cutting the Albee rock, while south of Duren Mountain much of the contact zone is characterized by mixed rock some of which is distinctly gneissoid in appearance. Uprising magma here has thoroughly soaked and fractured the Albee formation with the resultant development of prominent xenoliths (Pls. 20 and 21). Locally the contact zone is distinctly schistose and crushed, but everywhere there is evidence of intense deformation. The Albee rocks have been converted to hornfels at numerous locations.

The Highlandcroft is a typically hypidiomorphic granular coarse-

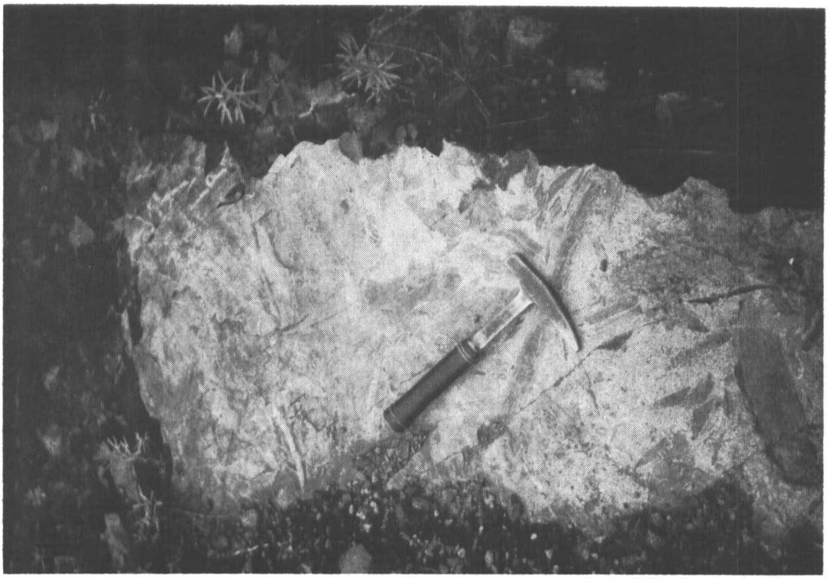

PLATE 20. Prominent angular xenoliths of Albee lithology in Highlandcroft granodiorite as seen at a location 0.4 mile west of Rogers Rangers Bridge, Guildhall.

to fine-grained rock. It is generally massive to weakly foliate, but at some locations it is distinctly foliate. It is composed principally of greenish plagioclase (andesine), pale blue to gray quartz, green biotite, chlorite, white to pale pink microcline, green hornblende, and epidote. Accessory minerals include chlorite, sericite, sphene, pyrite, apatite, magnetite, rutile, and zircon. The quartz monzonite facies is typically medium- to coarse-grained massive rock much of which is sub-porphyritic to porphyritic. The phenocrysts of microcline average about 10 millimeters in length.

The severely strained and fractured quartz grains, saussuritized plagioclase (andesine), and the small offsets or microfaults in this mineral are indicative of the intense deformation suffered by the Highlandcroft rocks.

Gray to white colored allotrimorphic granular aplite dikes are particularly abundant in the Highlandcroft granodiorite 0.2 mile west of the summit of Flynn Hill and in the outcrop close to the Connecticut River 1.5 mile N 23°E of Guildhall Center (Pl. 22). The dikes commonly range from 1 to 6 inches in thickness and show sharp boundaries and small offsets. Epidote druses are common along random fractures and

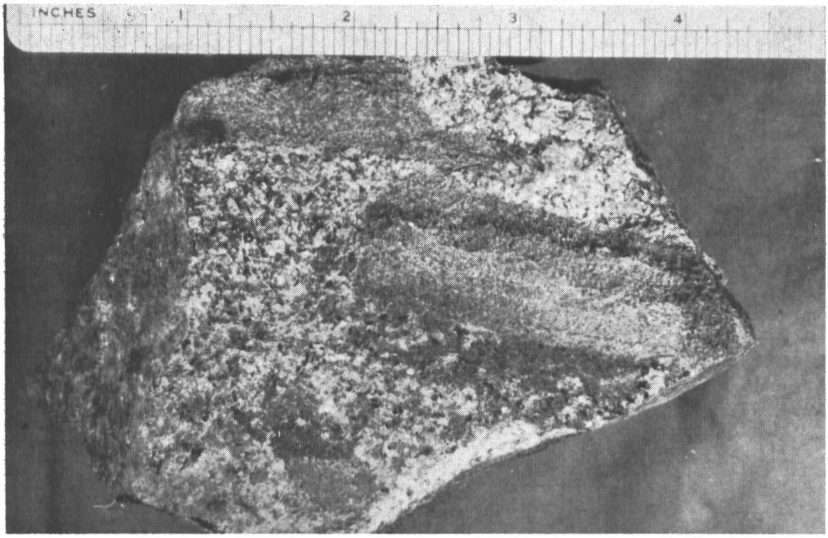

PLATE 21. Close-up of xenoliths shown in Plate 20. The chemical and mineralogical composition of the xenoliths is modified appreciably.

joints. The plagioclase reveals saussuritization and the quartz shows strain shadows. The aplite dikes appear to be of similar age as the main plutonic body, both of which underwent deformation after emplacement. The aplite dikes are cut by criss-crossing quartz veins of variable lengths averaging about 4 inches in thickness. The post-deformational mafic dikes cut granodiorite, aplite dikes, and quartz veins.

Aplite dikes and sills are rare in the metasedimentary rocks and where present they are close to the parent igneous body.

Age: The Highlandcroft plutonic series was emplaced in the Ordovician Albee formation. From lead-alpha age determinations by Lyons et al. (1957, p. 543), an age of 385 $\pm$ 32 million years is assigned to the Highlandcroft. Thus emplacement is synchronous to the time of the Taconic orogeny.

Granite of the Maidstone Pluton

General Statement: A large body of binary granite occupies the northern part of the map-area, extending from the region of Seneca and East Mountain in the Burke quadrangle to the vicinity of the Connecticut River Valley just south of Brunswick Springs. A southerly prong of this

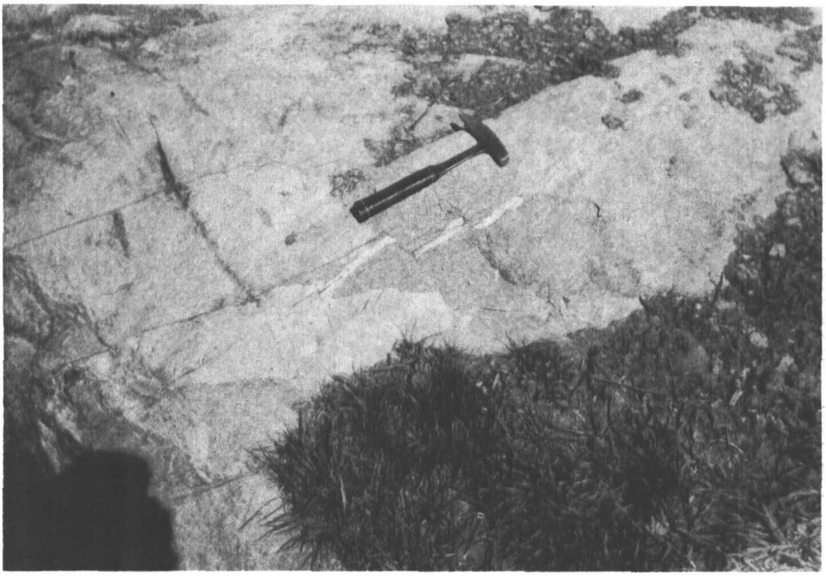

PLATE 22. Small offsets in an aplite dike cutting Highlandcroft granodiorite at a location 1.5 mile N 23°E of Guildhall Post Office.

massif underlies the region in the vicinity of Maidstone Lake (Pl. 1). Stoneham, Lake, and Willard Mountains all located east of Maidstone Lake are thought to be domical hills largely underlain by granite. Excellent topographic expression of this large granite body is seen along the northerly and northeasterly perimeter in the neighborhood of Dennis Pond. Much of the rock appears to border between a true granite and a quartz monzonite. Most contacts with the country rock are obscured by overburden and dense forest cover, but where they are exposed they are mainly gradational although some sharp contacts do occur.

Description: Several varieties of granite are associated with the massif. They are hypidiomorphic granular types. The majority are medium- to coarse-grained massive rocks, but locally the granite is sub-porphyritic. The color ranges from near-white to dark gray, and at a few locations (i.e., elev. 1600 feet on West Mountain Brook, 0.5 mile east of West Mountain fire tower, and at Mason) it is a delicate pink to salmon. Although the rock is a two-mica granite in many areas, muscovite is noticeably absent at some exposures and biotite is the prevalent type.

An average modal analysis based on 6 thin sections from representative locations is as follows: quartz, 28.8%; microcline, 25.1%; plagioclase, 19.5%; orthoclase, 17.8%; chlorite, 2.9% (some altered biotite); muscovite, 3.6%; biotite, 1.1%; accessories, 1.2%. Accessories include apatite, sphene, pyrite, and magnetite. The plagioclase is oligoclase. Generally the plagioclase displays good polysynthetic twinning which is sometimes combined with Carlsbad twinning. Sericitization occurs along feldspar cleavages. Most orthoclase has Carlsbad twinning. A little myrmekite and micrographic structure are present in most slides.

Especially good, sharp contacts between the granite and country rock have been observed in the bed of the west branch of Paul Stream 0.8 mile north of South America Pond and also in the bed of Dennis Pond Brook. The contacts are roughly concordant with the regional trend of the country rock. Chilled margins are not visible. The foliate country rock has been converted to andalusite-garnet schist. Where gradational contacts exist there is no sharp demarcation between the granite and country rock, but instead there exists a broad zone of migmatite or "soaked" crudely foliate country rock which overlies and often flanks the granite massif. Fine- to medium-grained granite apophyses and lenses, ranging from football size to more than 50 feet in diameter, break through the streaked or banded migmatite from place to place. Inclusions of glistening biotite schist are common in the granite. Because of contamination suffered by the granite as it intruded the country rock it is frequently rich in biotite. Occasional remnants of bedded country rock persist even though they have been engulfed completely by granite. Some of the "soaked" country rock is contorted, fractured, and offset.

The sedimentary inclusions in the migmatite as well as the attitude of the surrounding country rock show no consistent pattern of inward or outward deflection with respect to the granite body although a crude strike trend skirting the granite body does exist. Dips are generally moderate to steep. Exposures of interbedded schist and quartzite of the Gile Mountain formation located on the ridge east of Dennis Pond and only a few hundred yards from large outcrops of granite trend typically to the northeast. In the same area sills of granitoid rock are common.

Inclusions or xenoliths rarely occur in the deeply eroded granite core of West Mountain but they do occur with some frequency in the bed of Madison Brook and at several exposures between Bull Mountain and Unknown Pond. They range in size from about 1 foot to an estimated length of several hundred feet and all are thought to represent remnants of the overlying country rock. The larger inclusions are unfortunately obscured for the most part by overburden. Those found in the granite bed of Madison Brook include calc-silicate, amphibolite, schist, and hybrid rock types. They show a slight preference for north-south orientation and dip steeply. A number of small, oriented, tabular xenoliths occur in granite at the top of the falls at Browns Mill on Paul Stream, where they strike to the northeast and dip steeply to the southeast.

From the preceding observations it is clear that two distinct types of contacts are associated with the granite pluton in the northern part of the map region. They are (1) sharp contacts and (2) gradational or transitional types where mixed rocks occur. The sharp contacts favor forceful intrusion of magma together with limited stoping, whereas the gradational contacts suggest metasomatism in chemically and physically receptive wall rock as a result of diffusion from the direction of the granite body. The granite body itself is considered to be of magmatic rather than metasomatic origin.

Pegmatite dikes are rare in the major portion of the main body of granite at West Mountain, but occur sparingly in the granite at some locations close to the country rock. However, at Browns Mill on Paul Stream several generations of dikes probably of similar age show cross-cutting relations in granite (Pl. 23). Granite and granite pegmatite sills and occasional dikes unquestionably associated with the large pluton frequent the surrounding country rock at some locations. Several granite pegmatite sills ranging from 4 to 8 feet in thickness and concordant to the bedding of the Gile Mountain schist occur on the high ridge east of Dennis Pond. In addition there are several nearby dikes and sills of binary granite of variable length and thickness. Microcline appears to be the predominant feldspar in the pegmatite, with subsidiary plagioclase, and albite and a sizable amount of smoky quartz. Muscovite occurs sparingly as thin books less than 1 inch across. Graphic intergrowth of quartz and microcline is characteristic of some of the pegmatites. Several small, yellow, opaque crystals of beryl, none more than 3 inches long, were located in a loose angular block near one of the pegmatites, but none were in place.

North-south trending pegmatite dikes cutting migmatite and ranging in thickness from 3 to 12 inches are exposed in the walls and in some roof blocks of Maidstone Cave located on the west side of Stoneham Mountain at about elevation 1750 feet. The pegmatites exhibit beautifully developed quartz cores with well-formed orthoclase crystals

PLATE 23. Several generations of pegmatite dikes in granite illustrating cross-cutting relationship.

lining the outer margins. The quartz cores are penetrated by black tourmaline crystals some of which are 4 inches long and none of which exceed 3/8 inch in diameter.

Age: The granite and granite pegmatite dikes and sills were emplaced during the Late Devonian (?) and are assigned to the New Hampshire plutonic series.

Nulhegan Quartz Monzonite of the Nulhegan and Victory Plutons

General Statement: Two areas of Nulhegan quartz monzonite barely skirt the map-area and in each case positive outcrops occur beyond the map boundaries. The larger and northernmost body (Nulhegan Pluton) is confined principally to the Island Pond and Averill quadrangles whereas the smaller (Victory Pluton) lies for the most part in the Burke quadrangle to the south and southeast of the village of Granby in the eastern half of Victory. The two quartz monzonite massifs are separate and each occupies a topographic basin in which swamps and sluggish streams are prevalent. The topographic expression of both is shown clearly on the topographic maps.

Description: Samples are strikingly similar from both areas and probably correlative. Examination of hand samples shows this rock to be medium to coarse grained equigranular and of light to dark gray color. It is easily recognized because of the abundance of uniformly distributed flecks of glistening biotite. Occasionally the biotite is gathered into pods at random throughout the rock. Bruce Goodwin (personal communication, 1959), who has studied this rock in the Island Pond quadrangle and named it the Nulhegan quartz monzonite, found its approximate mineralogical composition based on thin sections from five typical exposures to be as follows: quartz, 14.0%; potash feldspar, 26.6%; plagioclase, 30.4%; biotite, 18.0%; hornblende, 1.7%; chlorite, 5.6%; sericite, 2.1%; accessories, 1.6%. According to Goodwin the accessories are sphene, apatite, magnetite, and zircon.

Age: Like the binary granite, this rock also intrudes the Devonian Gile Mountain formation. It is thought to be comagmatic with the binary granite and to have been intruded during the Late Devonian (?).

Metadiabase Dikes

Sills and dikes of metadiabase are widespread in the metasediments, particularly east of the Monroe fault. They range in thickness from a few inches to in excess of 50 feet. Most of the sills and dikes are composed of medium- to fine-grained rocks whose groundmass ranges from 0.05 to 2.0 millimeters. Hornblende crystals are usually unoriented. In one coarse grained dike the hornblende crystals attain unusual lengths of 120 to 150 millimeters. The rocks of medium and coarse texture are dark green, and those of fine texture are black. The majority of the amphibolites are massive, but a few are schistose, notably in the Lunenburg area (Pl. 24). A large schistose sill striking N 20°E for a distance of several hundred feet in open pasture land may be seen on the northeast side of Neal Pond near the road to the pond. Based on an examination of 8 thin sections, these greenstones show from 50 to 70 per cent hornblende and from 20 to 40 per cent plagioclase with small amounts of biotite, epidote, quartz, magnetite, and pyrite. In

PLATE 24. Albee quartzite, to right of knife, and schist, left of knife, cut by 2 small schistose dikes, each indicated by a pencil. Left-hand dike pinches out to left of compass. Dike farthest away from viewer is continuous. Compass points in direction of cleavage. Locality about 0.8 mile east of Mill Village, Lunenburg.

general the findings are in agreement with those of Billings (1937, p. 513) for the Littleton-Moosilauke area, and with those of Chapman (1948, p. 1074) for the Percy quadrangle. Billings (*op. cit.*, p. 512) considers these dikes and sills to have been originally diabasic in composition and they are assigned by him early in the Late Devonian (?) New Hampshire plutonic series.

Post Metamorphic Dikes

Mafic Dikes: Seven post metamorphic mafic dikes were observed, none over 3 feet in thickness. These dike rocks range in color from dark green to black, are fine grained, and diabasic in texture. The principal minerals are laths of soda plagioclase, chlorite, and calcite, with lesser amounts of pyrite, epidote, hornblende, and quartz. Two mildly altered dikes, trending N 22°W, and dipping 75°SW, cut the Highlandcroft granodiorite on Flynn Hill. One dike, striking N 50°E and with a vertical dip, cuts the binary granite along the stream between Little Wheeler and Wheeler ponds. Three dikes, trending N 30°E and with steep dips,

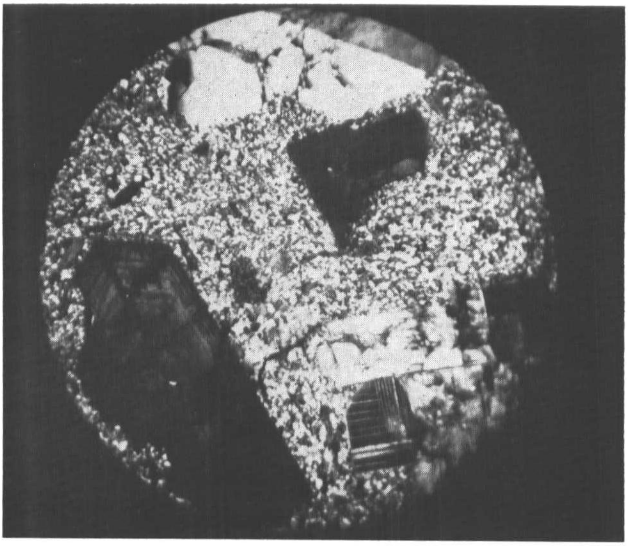

PLATE 25. Exceptionally well-zoned orthoclase phenocryst from a rhyolite porphyry dike of the White Mountain plutonic series. Groundmass consisting chiefly of undulating quartz grains. Crossed nicols, X 20.

were observed on Bear Mountain where they have intruded metasediments. An 18-inch thick dike of camptonite cutting Albee quartzite is found at an elevation of 1350 feet 0.7 mile west of Duren Mountain. It strikes N 28°W and dips 85°SW. Fresh samples of this dike are characterized by deep reddish brown crystals of hornblende ranging from 3 millimeters to 15 millimeters in length and they are set in a pitch black aphanitic groundmass.

Leucocratic Dike: A gray-colored, fine-grained, compact, rhyolite porphyry dike cutting amphibolite is found in the bed of Granby Stream at elevation 1285 feet. This dike, which is 10 inches thick, is exposed for more than 10 feet, strikes east-west, and dips 78° to the south. The surface of the dike has weathered to a dark brown hue. Phenocrysts of feldspar, quartz, and biotite constitute about 50 per cent of the rock. The predominant orthoclase phenocrysts show twinning according to the Carlsbad law, and they are exceptionally well zoned (Pl. 25). The groundmass consists of undulating quartz grains, each less than 1 millimeter across.

The post metamorphic dikes are assigned to the Mississippian (?) White Mountain plutonic series.

STRUCTURAL GEOLOGY

Introduction

The rocks of the Lunenburg-Brunswick-Guildhall area are intensely folded, cut by a major fault and several minor faults, and further complicated by several igneous bodies whose rocks represent the Highlandcroft and New Hampshire plutonic series. Most of the sediments of the "New Hampshire sequence" are assigned to the Albee formation. The general absence of post-Albee rocks and their corresponding outcrop patterns in the "New Hampshire sequence" (with the exception of the region from Stone Mountain to Bear Mountain where younger rocks are found) further hindered depicting the overall structure. Minor structural features have proven valuable in determining major structural relations.

Minor Structural Features

General Statement: Useful minor structural features include minor folds, flow cleavage or schistosity, slip cleavage, shear planes and lineations. Most of these features were the subject of detailed studies in other quadrangles (White and Jahns, 1950; White and Billings, 1951; Eric and Dennis, 1958), and descriptive terminology similar to that used by those workers is used in this paper.

Minor Folds: Minor folds occur in rocks of both the "New Hampshire sequence" and the "Vermont sequence." Because they are relatively small, ranging from a few millimeters to perhaps several hundred feet in wave length, their details are best seen in exposures occurring in open pastures where the rocks tend to be bleached and are relatively free of moss and other vegetation. Minor folds in the Albee formation are nicely exposed in open pastures and fields in Lunenburg, and at a few scattered locations in Guildhall and Maidstone. On the contrary, study of minor folds and related structures in the "Vermont sequence" has been greatly hampered by the limited number of small, scattered exposures just about all of which lie in deep forest where only minimum bleaching has occurred and vegetation is dense. However, data of some value were obtained from minor folds which occur at a few exposures on the northwest side of the Monroe fault southwest of the junction of Paul and Granby streams. In the far northern area where the Gile Mountain formation is greatly deformed and converted to migmatite, no consistent pattern of folding can be observed nor can younger and older folds usually be distinguished. Minor folds and slip cleavage are

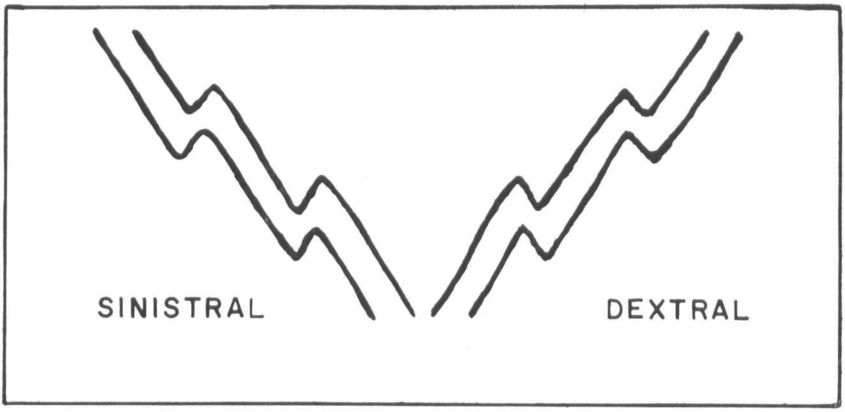

Figure 3. Sinistral and dextral pattern of folds.

rare in the Gile Mountain rocks underlying the Connecticut Valley slope of the high ridge situated east of Dennis Pond. Minor folds occur in abundance in the Littleton formation in the Burnside Mountain area.

The minor folds are of two types, each of which was produced at a different time. Those resulting from the first stage of deformation are called early folds, and those that developed during the second stage of deformation are called late folds. The early folds may be distinguished from the late folds by the behavior of the schistosity. In the early minor folds the schistosity or flow cleavage transects the bedding at a high angle close to the noses, while in the late minor folds so characteristic of the "Vermont sequence" the early schistosity wraps around the noses of folds.

The terms sinistral and dextral are used to describe the patterns of asymmetrical minor folds. In tracing asymmetrical folds away from oneself, where each succeeding long limb is offset to the right, the fold pattern is dextral; where each succeeding long limb is offset to the left, the pattern is sinistral (Fig. 3).

Early Minor Folds: Early minor folds are common in the Albee rocks of the region. They range in size from minute crinkles or crenulations in bedded phyllite or schist to relatively large folds 50 feet or more in wave length in massive quartzite. Isoclinal or near-isoclinal folding characterizes the argillaceous rocks and thin-bedded quartzites, whereas more open folds typify the massive quartzites whose beds range from a few inches to more than 20 feet in thickness. There is some concentration of open folds in the eastern part of the Albee formation from

Granby Road south to Lunenburg Center. Particularly good examples of open folds are seen $5/8$ mile east and also $1/2$ mile north-northeast of Mill Village, Lunenburg. The axial planes of the isoclinal folds are essentially parallel to the schistosity, but in the open type folds they may depart by as much as 35° from the trend of the nearby schistosity. The great majority of the folds trend northeasterly with an average plunge of 50° to 60° to the southwest. Eric and Dennis (1958, p. 33) also found a predominance of southwesterly plunges at approximately 40° to 50° which they note as being in accord with the regional structure southeast of the Monroe fault. On the south, southeast, and easterly sides of Colby Mountain and eastward to the vicinity of Hudson Brook there is a pronounced divergence from the northeasterly trend of bedding and schistosity. Throughout this area, axes of highly contorted minor folds in massive schist and quartzite trend from southeast to northwest to east-west; the relationship of schistosity to bedding indicates that nearly half of the folds are very slightly overturned in an easterly or southerly direction. It may be that the abnormal trends found here reflect the presence of Highlandcroft plutonic rocks at relatively shallow depths. In passing to the southwest or northeast of this area, the average trend of N 20°–30°E is observed.

About two-thirds of the minor folds in the Albee formation exhibit a sinistral pattern. White and Billings (1951, p. 673) noted that a slight majority of the folds east of the Monroe fault in the Woodsville, Vermont-New Hampshire quadrangle are sinistral.

Although early minor folds are relatively uncommon in the Gile Mountain formation and the Meetinghouse Slate, they have been observed northwest of the Monroe fault by several workers. White and Jahns (1950, p. 207) working in east-central Vermont observed that the pattern of early folds is mainly sinistral in the eastern tectonic belt immediately west of the Monroe fault. White and Billings (1951, p. 679) in mapping the Woodsville, Vermont-New Hampshire quadrangle found the patterns of 11 of 15 early folds to be sinistral. Eric and Dennis (1958, p. 35) found the early fold patterns at 13 out of 15 localities to be sinistral. In the map-area a few early sinistral folds are found 1.4 mile west of Buzzell Gap. In all areas these folds plunge in a northerly direction. Even though evidence for a predominance of sinistral patterns in early folds is not conclusive in the area northeast of Granby Center, it is likely that this is the case in accord with the regional pattern found in the more open country to the southwest. The predominant sinistral pattern of earlier folds suggests that during the earlier deformation rocks on the east moved upward with respect to rocks on the west. Considering these folds as normal drags, they do indicate that older rocks are to the west and younger ones to the east, and that a syncline lies to the east.

Late Folds: A small number of late minor folds are found in rocks of the "Vermont sequence" northwest of the Monroe fault. They are also associated with the schistose rocks of the Littleton formation ("New Hampshire sequence") in the vicinity of Burnside Mountain some distance to the southeast of the Monroe fault. In the argillaceous rock west of the Monroe fault the late minor folds are tight, ranging from 2 to 3 inches to as much as 2 feet across. They exhibit a dextral pattern with plunges averaging 60° in a northerly direction. Axial plane slip cleavage strikes to the north or northwest. Many of the late minor folds found on the southwest side of Burnside Mountain exhibit a dextral pattern with most folds plunging northeasterly from 10° to 40°. Axial plane slip cleavage associated with chevron folding in the same general area on Burnside Mountain strikes N 30°E, with an average dip of 70°SE.

Cleavage: Two types of axial plane cleavage are associated with the folds: flow cleavage or schistosity forming at the same time as the early folds developed, and slip cleavage associated with the development of late folds (Pl. 26). Flow cleavage is found throughout the area of metasedimentary rocks, but it abounds in Albee rocks where it commonly parallels or sub-parallels the bedding except in the noses of small folds where it cuts the bedding at a high angle. The schistosity is due to nearly perfect parallel orientation of micaceous minerals. The average strike trend for flow cleavage in all metasediments is about N 25°E. Late stage slip cleavage is common in rocks of the "Vermont sequence," but it has also been observed in the Albee formation not more than a few hundred feet east of the Monroe fault at elevation 1205 feet on Granby Stream, and in the Littleton formation of the Burnside Mountain syncline. It is a planar feature due to slips developing along the axes of microfolds that formed during the later stage of deformation. The slip cleavage northwest of the Monroe fault strikes to the north or northwest and dips to the east or northeast, but on the southeast side of the fault on Granby Stream it strikes to the northeast and dips steeply to the southeast. When flow cleavage and slip cleavage are detected in the same outcrop, the slip cleavage displaces the flow cleavage. Superposition of late stage minor structures on those of the early

PLATE 26. Bedding, flow cleavage or schistosity, and slip cleavage in interbedded micaceous quartzite and quartz-mica schist of the Gile Mountain formation. Bedding and flow cleavage parallel hammer handle and knife, respectively; both strike northeast and dip southeast. Trace of slip cleavage indicated by pencil right of center. Slip cleavage strikes northwest and dips northeast. Location west of Wilke Brook at approximate elevation 1430 feet.

stage is particularly obvious in rocks of the Gile Mountain formation. This phenomenon supports the conception of two distinct stages of deformation.

Shearing: Shearing is common throughout the interbedded Albee quartzite and schist. Small offsets due to shearing of the bedding are common and thin quartzite beds appear to have been dragged apart and embedded in the soft schist. In some outcrops 0.5 to 0.7 mile east of Mill Village, Lunenburg, it has been noted that where schistosity intersects a shear plane at a low angle, the schistosity is curved or crumbled.

The Linear Element: The linear element is represented throughout the metamorphic rocks by a variety of features. Mineral lineation or parallelism is shown sometimes by mica flakes and other minerals with a long dimension that have developed on bedding and cleavage planes. At some locations on Bear Mountain, sulphides in the Partridge slate distinctly illustrate linear parallelism. The thick bed of amphibolite exposed by Granby Stream at an elevation of 1290 feet shows dimensional orientation of hornblende needles parallel to the regional trend of the metasedimentary rocks.

Stretched quartzite cobbles have developed a pronounced lineation in the relatively thin bed of the Clough conglomerate exposed at the summit of Stone Mountain (Pl. 11). The average plunge of the long axes of the cobbles sub-paralleling the bedding schistosity is WSW at about 60°. Farther northeast, the large angular blocks of quartzite that occur in the Clough formation show no marked linear structure or evidence of stretching but the splinters and small pebbles in the same exposures frequently do.

The intersection of planes or surfaces of bedding and cleavage result in three distinct kinds of lineation. Lineation resulting from the intersection of bedding and flow cleavage or schistosity is common in the Albee formation and is associated with the noses of early folds. The lineation parallels the plunge of the early folds.

Intersections involving slip cleavage are confined largely to rocks of the "Vermont sequence" and the Littleton formation. Where slip cleavage and bedding intersect, the resulting lineations parallel the minor fold axes. Lineations resulting from the intersection of slip cleavage and schistosity or flow cleavage also parallel the axes of minor folds as well as the lineations produced by the intersection of slip cleavage and bedding planes.

Boudinage is uncommon, but it is developed on a limited scale at some localities. Quartz boudins, indicating stretching, have been noted at a number of locations in the Albee formation. The calc-silicate lenses found in the vicinity of Notch Pond Mountain may in reality be boudins that resulted from the stretching of thin competent beds.

Joints

Steep to vertical joints are common throughout the area. Although joints do strike in nearly all directions, there are two prominent strike trends which range (1) from N 20°E to N 60°E, and (2) from N 25°W to N 60°W. The northeast and northwest trending sets are most conspicuous in the granite and are also present in the metasediments and igneous rocks of the Highlandcroft plutonic series. Near-horizontal joints are common in the pink granite exposed in the bed of a brook a mile south-southeast of West Mountain.

No examples of unusual mineralization or filling along joint surfaces were observed, but limonite staining, sericite, and chlorite is prominent along the surfaces of many joints.

Major Structural Features

General Statement: The major structural elements in the southern part of the area include, from southeast to northwest, the Lunenburg anticline, and the northerly end of the Partridge syncline. In traversing the central part of the area from southeast to northwest the major structures include the western limb of the Lunenburg anticline, the Burnside Mountain syncline, the Monroe fault, and the St. Johnsbury homocline (Eric and Dennis, 1958, p. 30). Innumerable minor folds are associated with the major folds.

The Partridge Syncline: The Partridge syncline (Eric and Dennis, 1958, p. 29) takes its name from Partridge Lake which occupies the trough of one of several minor synclines located about 5.5 miles west of Littleton, New Hampshire. It lies between the Gardner Mountain anticline to the northwest and the Walker Mountain syncline to the southeast. In the Vermont portion of the Littleton quadrangle, the axis of the syncline trends about N 35°E passing just east of the Moore Dam on the Connecticut River to a point about 1 mile west of East Concord. From here it continues to trend northeasterly into the western part of the Lunenburg-Brunswick-Guildhall area, and finally its identity is lost in the region between Temple Mountain and Baldwin Hill.

The Partridge formation occupies the core of the syncline in the vicinity of Partridge Lake. To the northeast in southernmost Concord, the stratigraphically lower Ammonoosuc formation crops out in the core, but in the East Concord-Lunenburg area only rocks of the older Albee formation occur. Thus the Partridge syncline plunges southwesterly with successively younger rocks occupying the core in that direction. It is likely that the two patches of Fitch limestone found north of Lunenburg are parts of small folds associated with the northern end of the Partridge syncline. The absence of the Ammonoosuc formation is attributed to non-deposition, and the absence of the Partridge formation to a widespread unconformity occurring at the base of the Silurian. The schistosity and axial planes of minor folds associated with the syncline dip to the northwest at 60° to 90°. They indicate that the syncline is slightly overturned toward the southeast. Accompanying minor folds almost invariably plunge moderately or steeply to the southwest.

The Lunenburg Anticline: The name for this anticline is taken from the town of Lunenburg where it is typically exposed. It lies southeast of the Partridge syncline, and northwest of the Dalton Mountain synclinal trough (Billings, 1956, p. 112), and trends N 20°E from a point 1.4 miles southeast of Baptist Hill, Lunenburg, through Lunenburg Center and Colby Mountain to just east of Sheridan Mountain where it is cut out by rocks of the Highlandcroft plutonic series. The Lunenburg anticline plunges in a southwesterly direction, disappearing near Gilman. The overall schistosity as well as the axial planes of minor folds associated with the Lunenburg anticline generally dip to the northwest at 60° to 90°, but steep southeasterly dips occur just east of the crest of the anticline. The anticline is slightly overturned to the southeast. This is borne out by the attitude of bedding and cleavage in many of the minor folds found in the open areas east of Mill Village, Lunenburg. Locally, east of Mill Village and also in the vicinity of Sheridan and Halibut mountains, the axial planes of minor folds swing to the northwest, but steep southwesterly dips persist.

The core of the anticline is marked by interbedded massive quartzite and light to dark green slate or phyllite with the individual beds of both types ranging in thickness from a few inches to many feet. Farther north and northeast, similar lithology is found at numerous outcrops from an elevation of about 1050 feet on Washburn Brook to the eastern end of Bear Mountain. Although a thick mantle of glacial drift overlies much of the bedrock, excellent exposures are found at elevations of 1000 to 1200 feet on the eastern slope of the ridge 1.8 miles S 60°E of Round Mountain. It is a matter of conjecture whether or not the massive quartzite found here marks the continuation of the core of the Lunenburg anticline. R. W. Chapman (1948, p. 1083), in mapping the Percy quadrangle, suggested that a large anticlinal fold strikes north-northeast along Stratford Mountain which is located along the northwestern border of the Percy quadrangle. The axis of this fold is in close strike continuity with the strike of the thick-bedded massive quartzite found on Bear Mountain and to the south-southwest, suggesting that the two are correlative. This fold may represent the continuation of the Lunenburg anticline northeasterly into New Hampshire.

The Burnside Mountain Syncline: The Burnside Mountain syncline is named for Burnside Mountain in the central part of the map-area where excellent exposures occur. This tight fold trending N 35°E for about 6 miles from Stone Mountain to the vicinity of Bald Mountain plunges gently to the northeast at its southern end and gently to the southwest at its northern end. The core of the fold is occupied by the

Littleton formation for most of its length. The older Clough conglomerate extending along the northeast limb overlies the Albee formation to the southwest of Washburn Brook and the Partridge formation to the northeast of this brook. The Clough is also associated with at least a small portion of the northwest limb 0.7 mile N 10°W of Burnside Mountain. Its disposition on the west side of Burnside Mountain is in doubt because of a widespread covering of glacial drift and failure to crop out. The absence of the Clough conglomerate in this locality could also be due to pinching out. Along the west side of Burnside Mountain near the base the Albee formation reappears.

The Northwest limb of the syncline has been eliminated by the Round Mountain fault north of Washburn Brook in the area of Round Mountain; the northeast end of the fold, about 0.3 mile north of Bald Mountain, is probably also eliminated by the same fault. Failure of the Partridge and Clough formations to crop out north-northeast of Bald Mountain has left the exact relationship in this area in doubt, and the Partridge has not been represented on the geological map as extending to the postulated position of the fault although this is probably the case.

The axial plane of the Burnside Mountain syncline dips steeply to the northwest at Burnside Mountain. Southeast of Round Mountain it is approximately vertical or dips slightly to the southeast. At Bald Mountain moderate to steep southeasterly dips predominate and the actual contact between the Clough and Littleton formations as seen close to Cutler Mill Brook at an elevation of 1125 feet dips gently to the southeast. Furthermore, it has been found that at the contact the Clough overlies the Littleton formation indicating that the southeast limb of this portion of the fold is distinctly overturned to the northwest. There is no evidence of a faulted contact. Since the axial plane of the fold is overturned to the northwest, the southeasterly limb of the fold in the vicinity of Bald Mountain is distinctly exposed thus accounting for the great breadth of outcrop of the Clough conglomerate seen there.

The plunge of the minor folds found on Burnside Mountain suggests a gentle northeasterly plunge of the major fold. Further evidence supporting the direction of plunge is shown in the beds of Washburn and Jones Brooks which flow roughly parallel to each other where they cut the axis of the major fold. Washburn Brook, situated about 2 miles to the northeast of Jones Brook and flowing at an elevation averaging about 350 feet lower than Jones Brook, cuts through the Littleton and Clough formations and into the Albee formation. However, Jones Brook cuts through most of the Littleton formation. This relationship indicates a very gentle plunge to the northeast.

At Dalton Mountain, Dalton, New Hampshire, and also at Slate Ledge, Littleton, New Hampshire, the lower portion of the Littleton formation, amounting to hundreds of feet in thickness, is principally black slate above which volcanics and arenaceous types constitute the larger portion of the formation. It is believed that the slate, biotite-garnet phyllite, and schist of the Burnside Mountain area are correlative to the black slate of the previously mentioned New Hampshire locations, and the stratigraphically higher arenaceous types there are essentially equivalent to the quartzite (overlying biotite-garnet phyllite and schist) found on the slopes just east of and at the summit of Round Mountain. The presence of the higher and somewhat younger quartzite only in the northerly part of the syncline further corroborates the northeasterly plunge of the fold. However, since some minor folds near Bald Mountain suggest a gentle southwesterly plunge in that area the overall structure is considered to be doubly plunging.

Folds East of the Burnside Mountain Syncline: The great breadth of outcrop of the Partridge formation on the high ridge about a mile south of Bald Mountain is attributed to repetition by folding. Throughout the area east of the Burnside Mountain syncline and the northern end of the Round Mountain fault, the Ordovician rocks appear to have been thrown into a series of tight folds in which remnants or patches of the Partridge formation are preserved as doubly plunging synclines. Axial planes of the various small folds dip steeply to the northwest or southeast and sometimes they are vertical.

Folds West of the Burnside Mountain Syncline: The pattern formed by the dip and strike of the bedding and bedding-schistosity in rocks of the "New Hampshire sequence" west of the Burnside Mountain syncline suggests the presence of at least one small anticline and a small syncline still farther west on the east side of the Monroe fault in the area of Wilke Mountain in Granby. The infrequency of exposure in some parts of this area together with little available data pertaining to minor structural elements, and the presence of only one formation, has left the structural setting in this area open to conjecture. The rocks of the "Vermont sequence" west of the Monroe fault which constitute the St. Johnsbury homocline (Eric and Dennis, 1958, pp. 30–31) may drape a large body or dome of granite lying to the west. This body of granite at depth produces the metasedimentary Willoughby Arch found in the Lyndonville quadrangle and elsewhere (Dennis, 1956, p. 36).

The Round Mountain Fault: The principal evidence for this fault has been found just west of the summit of Round Mountain. The fault probably dies out to the southwest and its exact location to the northeast is inferred.

The evidence for the fault is stratigraphic. It has been clearly established that in traversing only a few hundred feet due west of the summit of Round Mountain there occurs an abrupt change in lithology from the Littleton quartzite to impure quartzite and phyllite or schist typical of the Albee formation. The contact between the Littleton and Albee types cannot be observed because of the limited number of exposures and the presence of abundant overburden. There is no evidence either in place or in loose blocks for mylonitization or silicification. The rocks of the two formations are of the same metamorphic grade. The rocks on both sides of the postulated trace of the fault plane dip steeply, with the prevailing dip to the northwest; some steep easterly dips do occur in the Littleton formation on the southeast slope of Round Mountain. Both formations strike about N 25°E. The fault plane is believed to dip steeply to the northwest with the hanging wall thrust upward so that nearly all of the northwest limb of the Burnside Mountain syncline is eliminated.

It might be argued that the absence of the Clough and Partridge formations on Round Mountain is due to pinching stratigraphically or thinning tectonically. The absence of the Partridge at this location could also be due to its removal by erosion when the pre-Silurian unconformity developed prior to the deposition of the Clough formation. It is difficult to visualize how the relatively thick Clough with its abundant quartzite blocks could be pinched out tectonically to zero in such a short distance. The thick basal part of the Littleton formation, which is so abundant in the Burnside Mountain area of the syncline, and also underlies the Clough at Bald Mountain, is missing near the summit of Round Mountain. Even by accounting for the absence of the Partridge and Clough as explained above, it is to be expected that the lower part of the Littleton, although perhaps diminished in thickness tectonically, would make its appearance between the Littleton quartzite and typical Albee lithologies along the northwest limb of the fold. Its failure to appear favors the fault hypothesis, with the fault being of considerable magnitude.

The inferred position of the fault to the northeast of Round Mountain is based in general on two observations. First, in the area east of the northerly end of the fault and the Burnside Mountain syncline, the Partridge formation occurs in relatively small patches some of which are large enough to be shown on the geological map. The nearest exposures of both Albee and Partridge types on the east side of the fault are found on the steep slope about 0.5 mile S 70°W of Hedgehog Mountain. Secondly, in the area to the west and north of the fault there are no rocks younger than those of the Albee formation in the "New Hampshire sequence." The exposures found closest to the fault on its north side occur on the steep slope south-southwest of Dutton Pond, and the lithology is not unlike that found west of the summit of Round Mountain. Other exposures to the north and west are also typically Albee in character. It might be expected that if the gently plunging northerly end of the syncline had not been faulted out that some remnants of post-Albee formations would appear on the slopes west of Dutton Pond. It is believed that to the northwest of the fault, erosion attacked and removed the Partridge and some of the Albee associated with the upthrown block. Had the thrusting been from the southeast as is suggested by the attitude of the axial plane of the syncline at Bald Mountain, the patches of the Partridge associated with the upthrown block would likely have been eroded away.

Minor Faults: At least two minor fault zones occur in the area. One, which is at least 25 feet in breadth, is located less than 0.1 mile west of the summit of Flynn Hill. It trends N 10°E for at least 1000 feet cutting the Highlandcroft granodiorite. Its identity to the northeast and southwest was not established. The Highlandcroft rock is brecciated, mylonitized, and in places reduced to a mylonite schist. Silica was active in cementing the crushed and fragmental rock. Quartz veinlets pocked with small quartz crystal-bearing vugs are common in the vicinity. The attitude of the fault plane was not observed, but it is believed to be steep.

On the south slope of Bear Mountain another small fault zone strikes N 15°E for about 1000 feet beyond which its identity is lost in both directions. The zone, consisting of brecciated Partridge slate cemented by silica, attains a maximum breadth of 50 feet, but is commonly only a few feet in width. Vugs and veinlets lined with quartz crystals and hematite are associated with the fault zone. The attitude of the dip of the Partridge slate on both sides of the fault zone approaches vertical, and it is believed that the attitude of the fault plane is also approximately vertical.

The Monroe Fault—Fault or Unconformity?

General Statement: Eric, White, and Hadley (1941, p. 1900) discovered a lithologic break, which they termed the Monroe fault, between the "Vermont sequence" and the "New Hampshire sequence" of rocks near Monroe, New Hampshire, in the upper part of the Connecticut Valley. Since then mapping has been conducted by a number of geologists who have traced the Monroe fault more or less continuously from about 2 miles southwest of White River Junction, Vermont (Lyons, 1955, pp. 133–134) in the Hanover, Vermont-New Hampshire quadrangle to North Stratford, New Hampshire, some 85 miles to the north-northeast. Evidence for a faulted contact in the Hanover quadrangle is meager. Published information regarding the break northeast of the North Stratford, New Hampshire area is based on reconnaissance mapping. Data based on the study of a limited number of exposures close to the break from just northeast of Granby, Vermont, to the Connecticut River in Brunswick are discussed below in this report. Between Granby and the southern terminus of the Monroe fault, evidence for a structural break was accumulated over a period of years by several workers (Hadley, 1950; White and Billings, 1951; Eric and Dennis, 1958; Hall, 1959). In central and lower eastern Vermont, beyond the southern terminus of the Monroe fault, the Meetinghouse slate of the "Vermont sequence" was thought to be conformably overlain by the Orfordville formation of the "New Hampshire sequence" (Lyons, *op. cit.*). Farther south in the Bellows Falls quadrangle where the Gile Mountain formation is absent* because it has pinched out to the north, the Waits River formation of the "Vermont sequence" was thought to be conformably overlain by the Orfordville formation (Kruger, 1946, p. 169). Thus, south of where the fault dies out, the break between the "Vermont sequence" and the "New Hampshire sequence" continues in the general direction of the strike as a sedimentary rather than faulted contact. Both Kruger and Lyons considered the age of the "Vermont sequence" to be Ordovician and earlier than the Ordovician Orfordville-Albee-Ammonoosuc-Partridge sequence of New Hampshire rocks. It is now generally agreed by most geologists that those units of the "Vermont sequence" (the Northfield slate, the Waits River and Gile Mountain formations, and the Meetinghouse slate) are Silurian and/or Devonian. This circumstance, together with the sedimentary

* The Gile Mountain is now recognized in this area as a narrow belt extending to the Massachussetts border.

contact existing southwest of White River Junction, strongly suggests an unconformity in that area with the Silurian and/or Devonian overlying Ordovician rocks. If the break to the north of White River Junction is interpreted as a thrust with younger rocks thrust over older the stratigraphic throw would amount to about 18,000 feet in the St. Johnsbury area (Hall, 1959, p. 88).

Location and Detail: In the area discussed in this report, the Monroe fault passes northeasterly from Granby Village to just north of Mud Pond, Granby, and then northeastward through Buzzell Gap to a point close to the junction of Granby and Paul streams. It lies close to and roughly parallels Wilke Brook and Granby Stream. It is believed to underlie the valley of Paul Stream to a point south of West Mountain Pond where the fault is cut out by granite. The distribution of Gile Mountain and Albee rocks on a hill (elevation of 1260 feet) located 0.9 mile east of Tuttle Pond suggests that the fault reappears again to the northeast of the granite and passes near the summit although the actual contact was not found.

Outcrops along the contact have been studied at Buzzell Gap, and elsewhere within a few feet to perhaps 100 yards of the fault at scattered locations from near the western boundary to near the junction of Granby and Paul streams and again near Route 102. Most of the exposures are small, discontinuous, badly weathered, and situated in dense forest cover.

Evidence for the fault is primarily stratigraphic. The Meetinghouse slate, as defined in the section under stratigraphy, lies on the west side of the fault from the western border of the map-area to a point north of Stony Brook where its identity is lost. Whether the Meetinghouse pinches out or is faulted out could not be determined because of the glacial drift cover. Farther north and near the fault on its west side, the Gile Mountain crops out on a small hill (elevation 1420 feet) southwest of the junction of Paul and Granby streams. On the east side of the break the Albee formation is continuous. The Albee lithology consists of thinly bedded pin-stripe schist together with considerable interbedded amphibolite, probably of sedimentary origin, impure quartzite, and greenish schist. Some amphibolite beds are several feet in thickness, with an exceptionally large one, averaging more than 20 feet in thickness, exposed in the bed of Granby Stream at an elevation of 1280 feet. At Buzzell Gap, where the contact of the Meetinghouse slate and Albee lithology can be seen for about 100 feet, the marker bed is a band of amphibolite about 26 inches thick. No evidence for a faulted contact was observed. Considerable amphibolite is also associated with loose blocks of the Albee quartzite and schist in the vicinity of the approximate position of the fault near Route 102 in Brunswick.

The lithology at most points on the east side of the fault is similar, with an exception being the exposures along Stony Brook. Here, the first exposure to appear east of the Meetinghouse slate (about 150 feet down stream) is a bed of yellowish-brown stained buff quartz-feldspar-mica schist about 20 feet thick, which mineralogically resembles the light-colored gneiss of the Orfordville formation found in exposures on the northeast side of Post Pond, Lyme, New Hampshire. If this exposure represents the Orfordville lithology, then its presence could be explained as a slice brought up by movement along the west side of the fault plane. This exposure represents the only known outcrop since it fails to appear along the strike in the bed of Tolman Brook about 0.4 mile south, nor has it been found to the north. Although it is conceivable that this rock may actually represent a slice of the Orfordville, it seems more likely that it is a lens of volcanic origin (probably soda-rhyolite tuff) situated between the Albee quartzite and the Meetinghouse slate and perhaps it is part of the Meetinghouse. Lenses of soda-rhyolite tuff have also been observed in the Meetinghouse slate at the old Waterford slate quarry (Eric and Dennis, 1958, p. 24). On the east side of the buff schistose rock there is a band of dark gray biotite-rich quartzite about 20 feet thick that is the fall-maker on Stony Brook. More massive, gray quartzite of the Albee formation can be seen in the bed of the brook for at least 100 feet beyond the waterfall. The quartzite is fractured with the minute offsets present in the quartzite cemented by biotite. Although the fractured quartzite suggests faulting as its origin, it could be attributed equally well to tectonic reasons other than faulting.

The strike of the bedding and schistosity or flow cleavage on the opposing sides of the break is essentially parallel. The average strike of the Monroe fault is about N 30°E. Dips are moderate to steep, with readings of 60° to 70° east common at Buzzell Gap and in the area to the southwest, while in the vicinity of Granby Stream they are commonly around 70° to 80° east. Steep westerly dips prevail in the vicinity of the lower 0.75 mile of Granby Stream and also near Route 102. The westward deflection of the break seen just south of Stony Brook probably represents distortion of the country rock coincident with the emplacement of granite plutons to the southwest, north, and northeast. If the yellowish-brown stained buff quartz-feldspar-mica schist mentioned above is a slice of the Orfordville, then it is also possible that the westward deflection is due to a fault slice lodged between the Meetinghouse slate and Albee formation. A sizable lens of volcanics in the Meetinghouse slate, adjoining the Albee formation, might also produce a similar deflection.

Thus, with one exception, it appears that within the map-area most exposures near the Monroe fault point to a sedimentary contact since there is no visible evidence of brecciation, silicification, subsidiary faulting or other features associated with large-scale faulting. However, depending upon interpretation of the observations made near the mouth of Stony Brook, one may be led to conclude either a faulted contact or sedimentary contact in that area.

Regional Evidence for Faulting: The interpretation of the break between the "Vermont sequence" and the "New Hampshire sequence" called the Monroe fault as either a faulted contact or sedimentary contact is discussed by Billings (1956, pp. 94–99), Dennis (1956, pp. 30–34), Eric and Dennis (1958, pp. 54–61), and Hall (1959, pp. 85–88) and summarized below. On a regional scale, data in favor of faulting and largely familiar to many students of New England geology include: (1) The Meetinghouse slate persists on the westerly side of the fault but exceptions occur in the northern part of the Woodsville quadrangle, in the southern part of the St. Johnsbury quadrangle, northeast of Stony Brook in the map-area, and elsewhere where truncated by intrusive rocks. On the east side of the break the Orfordville, Albee, and Ammonoosuc formations crop out at different locations and each is truncated by the fault. (2) The Moulton diorite is truncated on its southeast side by the fault in the Waterford-Barnet, Vermont area. (3) In the vicinity of North Concord, Vermont, northeasterly trending beds on the northwest side of the fault strike into northwesterly trending beds on the southeast side of the fault. (4) The biotite isograd in the northern part of the Woodsville quadrangle is displaced approximately 2 miles along the fault. (5) A narrow band of breccia occupies the approximate position of the Monroe fault immediately north of Monroe, New Hampshire. (6) Just north of Monroe, New Hampshire, in the St. Johnsbury, Vermont-New Hampshire quadrangle, several small faults and a silicified zone are located in the general vicinity of the break and are probably related to it. (7) In addition, south of McIndoe Falls the northeasterly attitude of the bedding and schistosity on the northwest side of the break truncates the more northerly strike of the bedding and schistosity on the southeast side. (8) Furthermore, Hall (*op. cit.*)

interprets the lack of late stage deformational features in the rocks southeast of the fault as additional evidence for a faulted contact.

Evidences for faulting, when considered individually, are rather weak, but when several different criteria for faulting occur within a small area, most certainly a fault hypothesis appears to be feasible for that location. This does not invalidate the possibility that on a regional scale the break represents an unconformity.

Opposition to Fault Hypothesis: Several points may be raised in opposition to the fault hypothesis. The truncation of the Moulton diorite by the Monroe fault in the Vermont portion of the Littleton, New Hampshire-Vermont quadrangle may be inferred. The evidence for truncation of structure in detail on the west side of Miles Mountain, North Concord, Vermont, is considered by the writer as highly unreliable in view of the intense deformation suffered by the Albee formation when it was intruded by granitoid rock. The displacement of the biotite isograd in the Woodsville quadrangle could be attributed to a difference in original rock composition found on the two sides of the break and hence movement is not essential for this displacement. Small patches of breccia associated with the expected position of the break north of Monroe, New Hampshire, is not strong evidence for a fault of great magnitude and displacement. Late stage slip cleavage is not totally restricted to the west side of the break in the Lunenburg-Brunswick-Guildhall area. The similarity of lithology and general stratigraphic position of some formations occurring on each side of the break favors a widespread unconformity of Silurian and/or Devonian over Ordovician. The presence of one unit, the Meetinghouse slate, on the west side of the fault for much of its length equally favors an unconformity of Silurian and/or Devonian over Ordovician.

AGE RELATIONSHIP BETWEEN THE "VERMONT SEQUENCE" AND THE "NEW HAMPSHIRE SEQUENCE"

Introduction

For a number of years many geologists considered the rocks on the northwest side of the Monroe fault in eastern Vermont to be of Middle Ordovician age. North of White River Junction, Vermont, it was believed that the Vermont rocks were thrust upwards and southeastward onto the younger Middle and/or Upper Ordovician (?) "New Hampshire sequence" of rocks. South of White River Junction, Vermont, where the Monroe fault dies out, it was thought that rocks of the "New Hampshire sequence" conformably overlie rocks of the "Vermont sequence." In other words the Orfordville formation was thought to conformably overlie the Meetinghouse slate. Within the "Vermont sequence" and according to convention, the rocks of the "Vermont sequence" become progressively younger eastward from the Green Mountain axis so that in upper eastern Vermont the Meetinghouse slate would be the youngest formation in the "Vermont sequence." This is essentially the age relationship adopted by Billings (1955) in the construction of the Geological Map of New Hampshire.

On the basis of paleontological evidence, Doll (1943a, 1943b, 1944, 1951) has advocated a Middle Silurian and/or Lower Devonian age for the Waits River and Gile Mountain formations, and the Meetinghouse slate, all of the "Vermont sequence." The assumption is that the whole sequence found on the west side of the break from the Northfield slate to the Meetinghouse slate is Lower Devonian and possibly some Silurian. Furthermore, the Famine series and the St. Juste group (MacKay, 1921, and Gorman, 1955), which are correlatives of these rocks in the eastern Townships of Quebec, are fossil-dated as Silurian and/or Devonian.

The age of rocks of the "Vermont sequence" in upper eastern Vermont is reasonably well established as Silurian and/or Devonian and accepted as such at present by most workers familiar with the region. There is little disagreement that on the east side of the break the rocks are no younger than Middle and/or Upper Ordovician.

In the preceding section dealing with the Monroe fault, some of the evidences for a faulted contact for the break north of White River Junction, Vermont, were mentioned. It was also pointed out that some of these evidences could equally favor an unconformity of Silurian and/or Devonian over Ordovician. Dennis, in Eric and Dennis (1958, p. 57), terms the break between the "Vermont sequence" and "New Hampshire sequence" the "Monroe contact," believing that it may represent the Taconic unconformity.

Discussion

The age relationships within the "Vermont sequence" have not been positively established and the decision has an important bearing on the interpretation of the break between the two sequences of rock as either a fault or an unconformity. If the conventional column of Ver-

Table II

VARIOUS STRATIGRAPHIC SEQUENCES

Sequence		
A	B	C
Meetinghouse slate	Waits River	Gile Mountain
Gile Mountain	Standing Pond	Standing Pond
Standing Pond	Gile Mountain	Waits River
Waits River	Meetinghouse slate	Meetinghouse slate
Northfield slate	= Northfield slate	= Northfield slate

mont rocks is invoked (Sequence A, Table II), then the youngest unit is the Meetinghouse slate, and the contact would be interpreted as a fault with much of the "Vermont sequence" faulted out. However, if the Meetinghouse slate is the oldest unit and the assumption is made that it is correlative to the Northfield slate which lies considerably to the west of the map-area, then the break would represent an unconformity. Lithologically, the Meetinghouse and Northfield slates are similar. In this case the rocks to the west become progressively younger up through the Waits River formation (Sequence B, Table II). The Waits River formation overlies the Northfield slate to the east. However, the correlative of the Northfield, the Meetinghouse slate, which crops out in the map-area, is overlain to the west by the Gile Mountain formation and the Waits River is absent. In the Vermont portion of the Littleton quadrangle Eric and Dennis (1958, p. 59) found the same situation. They considered the Gile Mountain formation to lie above the Waits River formation and to be downfolded in a syncline of regional proportion to the east of the Willoughby Arch and immediately west of the break (Sequence C, Table II). The absence of the Waits River here is attributed by Eric and Dennis to possible facies change or possible squeezing out farther west of the more mobile marble of the Waits River formation. Hall (1959, p. 88) found no evidence to substantiate a stratigraphic syncline of regional proportion lying in the corresponding area west of the break in the St. Johnsbury quadrangle and considers the Waits River most likely the youngest formation if the break between the two sequences is treated as an unconformity. In the southeastern part of the St. Johnsbury quadrangle, the Meetinghouse slate is again overlain by the Gile Mountain to the west and the Waits River is absent. By way of explanation, Hall has suggested that the absence of the Waits River could be due to thinning or faulting out during folding or facies change, even though no direct evidence supporting these possibilities occurs in the St. Johnsbury quadrangle. In the Lunenburg-Brunswick-Guildhall area there is also no direct evidence for these two possibilities. The Standing Pond amphibolite, considered as a time line (Hall, 1959, p. 38), deviates slightly from its usual position at the Waits River-Gile Mountain contact and extends into the Waits River at some localities (Murthy, 1957, p. 39), thus indicating partial equivalency of the Waits River and Gile Mountain formation. B. Goodwin (personal communication, 1959) found the Standing Pond amphibolite to extend well into the Gile Mountain formation in the Island Pond quadrangle. The time equivalency, at least in part, of the Gile Mountain and Waits River formations seems assured, but it is difficult to prove or disprove the complete equivalency of the two. It remains that the absence of the Waits River formation to the east and the absence of the Gile Mountain formation to the west can best be explained by facies change.

Still another interpretation of the Vermont stratigraphy suggested by Billings (1956, p. 97) is that the Meetinghouse, Gile Mountain, and Waits River formations collectively are an eastern facies of the Northfield slate and a western facies of the Littleton formation of the "New Hampshire sequence." A consequence of this interpretation is that a major unconformity lies at the base of the Meetinghouse slate. This would account for the Meetinghouse contact with several Ordovician formations on its east side.

In the map-area, the lithology of some of the lower part of the Littleton formation exposed on Burnside Mountain is similar to that of the Meetinghouse slate. There is also a pronounced similarity in appearance between the slate of the Littleton formation found at Slate Ledge, Littleton, New Hampshire, that at Dalton Mountain, Dalton, New Hampshire, and that found with phyllite in the Littleton formation at Burnside Mountain in Guildhall. As previously mentioned, the Meetinghouse and Northfield slates are similar and they are thought to be correlative. It is not unlikely that the Gile Mountain formation grades southeastward into the Littleton formation and that they are correlative since both of these formations overlie slate units which also appear to be equivalent. The bulk of the Littleton formation consists of argillaceous and arenaceous sediments. Calcareous sediments are minimal in the Littleton formation, but they are abundant in the Waits River formation lying west of the Gile Mountain formation and conceivably interfingering with the Gile Mountain formation to the east. It is likely that the absence of calcareous sediments in the upper part of the Littleton formation in New Hampshire is due to rather abrupt facies change in eastern Vermont, and the Meetinghouse slate, Gile Mountain, and Waits River formations could be a westernmost facies of the Littleton formation. The total thickness of the Waits River and Gile Mountain formations and the Meetinghouse slate in northeastern Vermont amounts to about 18,000 feet (White and Billings, 1951), whereas in northwestern New Hampshire the thickness of the Littleton formation is about 5,000 feet (Billings, 1956). However, in central New Hampshire, where the rocks are less disturbed and presumably less deeply eroded, the Littleton formation attains a thickness of ±15,000 feet (Billings, *op. cit.*). Thus, there is a similarity in thickness between units in Vermont and New Hampshire which have been suggested as correlative on the basis of stratigraphic position and lithology.

It is noteworthy that on a broad regional scale a number of geologists who have worked in eastern Vermont and western New Hampshire recognize a striking similarity among several formations on one side of the break to those on the other side. There is a strong lithologic resemblance between the Ordovician pre-Shaw Mountain rocks of Vermont and the Ordovician rocks of the "New Hampshire sequence" (Table I). An impressive fact is that Moretown and Albee lithology is remarkably similar. The Silurian Shaw Mountain formation of Vermont is similar to the Clough and Fitch formations found in New Hampshire and the assumption is that the two are correlative. Furthermore, a major unconformity separates the Ordovician rocks from the Silurian rocks both in New Hampshire and Vermont.

Summary

From the preceding discussion it can be seen that there is considerable regional evidence favoring correlation of each of several units in the two sequences of rocks and for an unconformity of Silurian and/or Devonian rocks of the "Vermont sequence" over Ordovician rocks of the "New Hampshire sequence." However, the equivalency of the Northfield and Meetinghouse slates which has important bearing on interpreting the age relationship in the "Vermont sequence" as well as the presence or absence of an unconformity has not been proven through fielded mapping, and the problem of equivalency must be treated as conjectural. Hall (1959, p. 86) concluded from his studies in the St. Johnsbury quadrangle that the break between the two sequences is a fault, but he adds that this does not prevent the break from also representing the unconformity between the pre-Silurian and Silurian and/or Devonian rocks. In this case the unconformity appears to have been faulted out in the St. Johnsbury area (Hall, *op. cit.*).

In the Lunenburg-Brunswick-Guildhall area, the evidence for faulting is rather weak and restricted to one small area in the vicinity of Stony Brook. It is probable that the break represents the widespread unconformity of Silurian and/or Devonian over Ordovician and again, as has been suggested for the St. Johnsbury area, it may be that the unconformity is faulted out. Until the problem is finally resolved, the author has chosen to retain the conventional stratigraphic sequence in the text and on the geologic map, and the term "Monroe fault" for the break between the "Vermont sequence" and the "New Hampshire sequence" of rocks.

METAMORPHISM

Introduction

Progressive regional metamorphism affected the sedimentary and volcanic rocks of the Lunenburg-Brunswick-Guildhall area. The chemical composition of the original sediments together with the effect of pressure, heat, and chemically active fluids on these sediments played an important role in developing the various grades of metamorphism. The usual minerals accepted as indicative of metamorphic grade show increasing intensity of metamorphism toward the northwest. The aureoles associated with granite of the New Hampshire plutonic series are in the high-grade zone, but the sedimentary rocks surrounding the rocks of the Upper Ordovician (?) Highlandcroft plutonic series are mostly in the low-grade zone. The latter was emplaced prior to the time of regional metamorphism. Porphyroblasts of biotite, and to a lesser degree those of staurolite and garnet, now largely altered to chlorite, suggest that retrograde metamorphism occurred during the period of falling temperature subsequent to the emplacement of the granite of the New Hampshire plutonic series.

Zones

The chlorite, biotite, garnet, staurolite, and sillimanite zones of metamorphism (Harker, 1932, p. 209) are present in the area, and are delimited by isograds on the geologic map. The distribution of the isograds indicated that the rocks were subjected to increasing temperature to the northwest resulting from the emplacement of igneous rocks of the New Hampshire plutonic series. No attempt was made to zone the northernmost area of the Gile Mountain formation, but thin sections suggest that much of the area lies in the garnet and sillimanite zones. The isolated body of Gile Mountain schist located near Wheeler Pond is sillimanite-rich.

Chlorite Zone: The chlorite zone is restricted to a belt situated between the biotite zone and the rocks of the Highlandcroft plutonic series in the southern and southeastern part of the map-area. The pelites of the Albee formation, which are derived from mud, are pale green to olive green color when fresh, but frequently weather to brown, gray, or near-white. They are interbedded with massive quartzite. In thin section the fine-grained pelites are seen to consist principally of chlorite, sericite, quartz, and albite together with traces of epidote, calcite, and opaque material.

The Biotite Zone: The biotite isograd marks the approximate geographical position where brownish biotite begins to appear in the rock. Both chlorite and biotite appear abundantly in the rock in the vicinity of the biotite isograd, but farther west the chlorite declines and the biotite increases in abundance and size with some of the porphyroblasts of biotite attaining a diameter of 2 millimeters. However, at some locations enough chlorite survives in equilibrium with biotite to give the rock a distinct greenish cast. The pelites of the Albee formation in the biotite zone largely resemble those of the chlorite zone except for the presence of biotite porphyroblasts and concentrations of biotite in narrow bands parallel to the schistosity.

Garnet Zone: Garnets occurring near the upper limit of the biotite zone are minute, often only a fraction of a millimeter in diameter. Westward, they increase in diameter to as much as 2 or 3 millimeters and they are scattered at random in the gray to near-white mica schist and feldspathic quartzite of the Albee formation. Abundant, tiny euhedral garnets occurring with quartz and magnetite are usually concentrated in pale pink or light gray bands in the gray schist, garnet-biotite phyllite, and slate of the Littleton formation found on Burnside Mountain, and also in the schist and quartzite of the same formation situated to the northeast. The bands frequently exhibit small drag folds. Although microscopic garnets tend to be concentrated in the bands and often constitute about 50 per cent of a given band, they do occur sparingly in the schist and phyllite too. Since the garnets show little or no evidence of the distortion that might accompany the folding, they probably formed after folding ceased. In addition, porphyroblasts

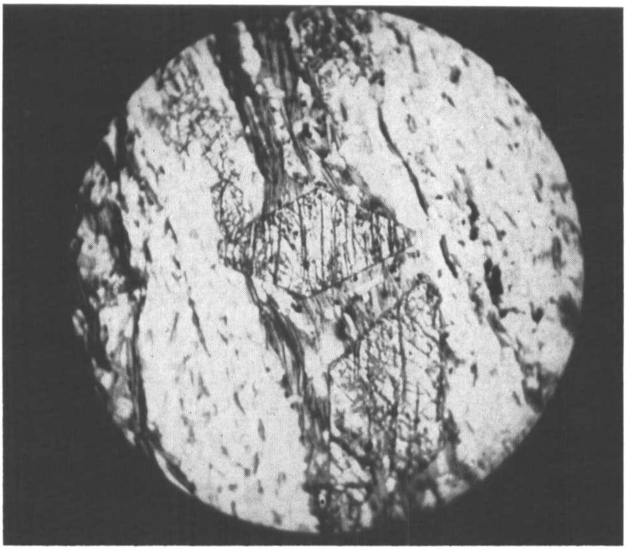

PLATE 27. Euhedral staurolite in staurolite-mica schist from lower east side of Stoneham Mountain, Maidstone. Center crystal lying athwart schistosity. Nicols not crossed, X 25.

of magnetite are abundant and widespread in the garnet-biotite phyllite, schist, and slate of the Littleton formation (Pl. 12). The garnets found in the Meetinghouse slate and the Gile Mountain formation are tiny grains of imperfect form scattered in a schistose groundmass. In the vicinity of Nurse Mountain euhedral garnet completely altered to pennine is common. Geometrically arranged inclusions of opaque matter often appear in the garnets coming from the Gile Mountain schist found northeast of Dennis Pond (Pl. 18). Other minerals associated with the garnet zone include oligoclase, hornblende, muscovite, and distinct porphyroblasts of biotite, many of which are altered to chlorite.

The Staurolite Zone: This zone is relatively narrow and crudely rims the igneous bodies of the New Hampshire plutonic series. The staurolite in the Gile Mountain formation and the Albee formation south of Granby appears in thin section as minute shapeless grains, but where the staurolite zone swings around Maidstone Lake and northeastward to Mason the staurolite often occurs as perfect euhedral crystals (Pl. 27) some of which attain a length of 5 millimeters. Garnet, biotite, muscovite, quartz, and oligoclase are also commonly found in this zone. Fissured and shattered garnet is found in the muscovite schist of the

PLATE 28. Granitoid sill in Gile Mountain schist. Pink andalusite abounds in schist on both sides of the sill for several feet. Exposure at a point about 0.5 mile south of Bloomfield on the west side of Route 102.

Albee formation about 100 yards east of the Monroe fault near the junction of Paul and Granby streams. The rock of the staurolite zone is chiefly tan to brown schist.

Sillimanite Zone: In the aureoles surrounding the Devonian granite, sillimanite occurs as unoriented acicular crystals or as bundles of fibers with individual crystals rarely exceeding 5 millimeters in length. The sillimanite schist is coarser than the schist of the other zones described above and is composed principally of quartz, biotite, muscovite, and oligoclase.

Additional Metamorphic Minerals

Lime Silicate Minerals: Lime silicate bands and lenses occur sparingly in the Gile Mountain formation in the vicinity of Notch Pond Mountain. Among the minerals seen in thin section are abundant quartz and grossularite, and some diopside, zoisite or clinozoisite, possibly scapolite, and a little calcite and actinolite.

Andalusite: This mineral was observed at relatively few locations and is associated with sillimanite. Pink crystals of andalusite occur in exposures of the Albee formation on the west side of the granite at Mason

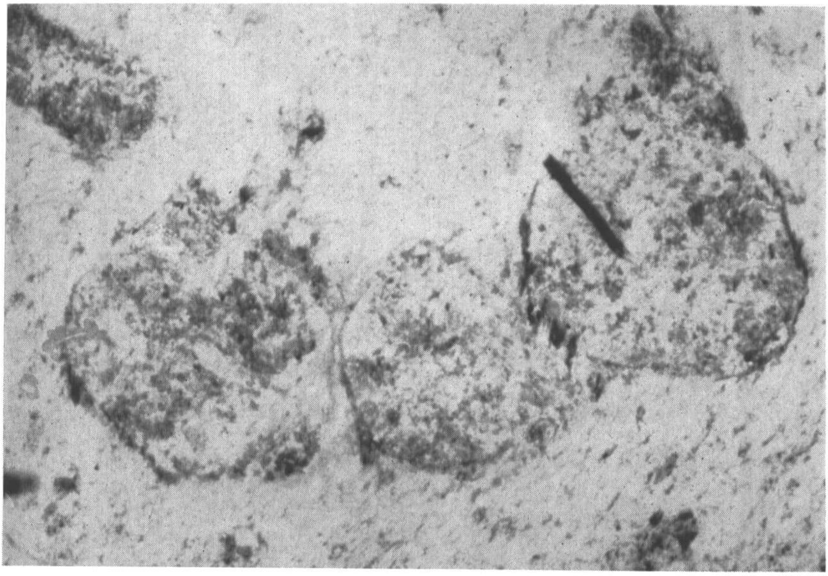

PLATE 29. Chloritoid in sericite schist from an exposure 0.7 mile east of Lunenburg Center. Borders are chlorite. Nicols not crossed, X 25.

where some crystals attain a length of approximately 5 to 7 centimeters. Smaller crystals, usually pale pink in color and with distinct black carbonaceous inclusions, occur in outcrops of the Gile Mountain formation at several localities near Wheeler Pond, and also near the granite contact north of South America Pond. Small crystals of andalusite are abundant close to granitoid sills found on the west side of Route 102, 0.5 mile south of Bloomfield (Pl. 28). Crystals with carbonaceous inclusions are frequently altered to muscovite or sericite.

Chloritoid: A horizon of chloritoid was traced northeasterly for 6 miles from 0.7 mile east of Lunenburg Center to a hill (elevation 1200 feet) situated 1 mile south-southwest of Duren Mountain in Guildhall. The chloritoid horizon lies slightly west of the area intruded by the Highlandcroft plutonic series. The chloritoid attains a maximum diameter of about 8 millimeters and occurs as randomly oriented euhedral, ragged, or spindlelike metacrysts in pelitic rock of the chlorite zone (Pl. 29). In thin section chlorite is seen to rim the metacrysts of chloritoid and it is sometimes drawn out in trains away from the metacrysts in the direction of the plane of schistosity. The groundmass is composed principally of fine-grained sericite, with subordinate quartz, chlorite, and an opaque mineral, probably ilmenite. The presence of the stress-

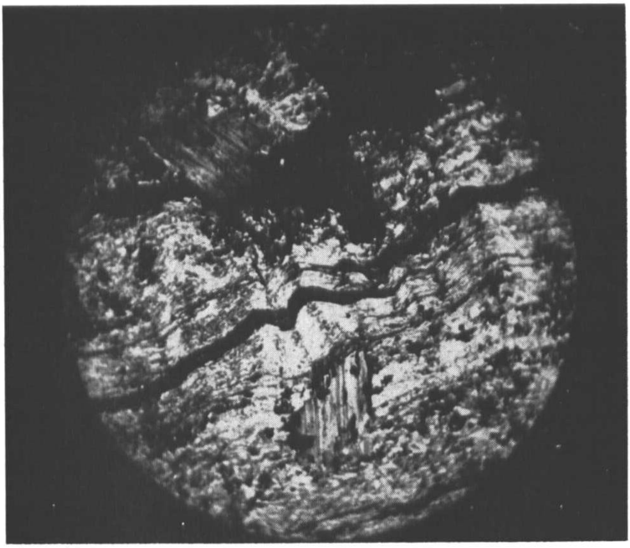

PLATE 30. Sericite schist from the Littleton formation with herringbone structure illustrating slip cleavage. Porphyroblasts of chlorite developed after folding ceased. Small irregular black bodies are magnetite. Crossed nicols, X 40.

mineral chloritoid suggests a rock rich in alumina and iron and poor in lime, potash, and magnesia. The chloritoid horizon probably represents an outer reactionary zone lying just beyond the zone of hornfels and fractured rock. The Albee hornfels rimming the rocks of the Highlandcroft plutonic series resulted from thermal metamorphism accompanying the emplacement of this series.

Hornblende: This mineral is quite widespread in the garnet and staurolite zones where it occurs as randomly oriented porphyroblasts ranging in size from less than 1 millimeter to as much as 10 millimeters in length. Recrystallization of the pre-metamorphic basic dikes and sills found in the biotite and higher metamorphic zones has resulted in a mineral assemblage consisting of abundant hornblende, biotite, andesine-oligoclase and other minerals. Dikes and sills of similar composition found in the chlorite zone are usually altered to feldspathic schists with minor amounts of hornblende and other minerals.

Stages of Metamorphism

Two distinct stages of metamorphic events affected the area. Widespread schistosity or flow cleavage resulted from the planar orientation of chlorite, sericite, and muscovite which accompanied folding during the earlier deformation. During the second or later stage of deformation, folding, faulting, and the intrusion of granite of the New Hampshire plutonic series took place. Heat generated by these igneous bodies and transferred largely by solutions resulted in recrystallization and growth of various mineral porphyroblasts. The randomly oriented porphyroblasts usually cut the flow and slip cleavage, thus suggesting that they developed soon after folding and flowage ceased (Pl. 30). Retrograde metamorphism accompanied the decline in temperature that followed the climax of the second stage of deformation with the result that much biotite, and some garnet and staurolite is altered to chlorite.

The massive rock of the Highlandcroft plutonic series was deformed during the second deformation so that the original physical form of the intrusion is unknown. Mechanical effects of the stresses in the massive igneous rocks are few and appear locally as a weak foliation, and as a straining of quartz grains. As a result of probable hydrothermal alteration, replacement of the original andesine by oligoclase, epidote, and sericite, and partial chloritization of the ferromagnesian minerals occurred.

Geologic History

The geologic history of the Lunenburg-Brunswick-Guildhall area is summarized in Table III.

ECONOMIC GEOLOGY

Granite

Small quantities of granite were quarried from some locations in the northeastern part of the area during the 19th and very early 20th centuries. The locations are shown on the geological map by the appropriate symbol. Most of the rock was utilized for construction purposes such as foundations for buildings and railroad bridge abutments. All operations were small and of short duration. The quarried stone is largely medium-grained binary granite, some of which is porphyritic. The presence of sparsely disseminated pyrite in some of the granite rules out its use as an ornamental stone. The pink medium- to coarse-grained granite, which is found about 0.5 mile southeast of West Mountain in the bed of West Mountain Brook, appears to be free of pyrite and would make a handsome ornamental and monumental stone. However, the closely spaced nearly horizontal joints (sheeting) limit the size of the blocks that can be quarried. Furthermore, the inaccessi-

AGE	FORMATION	SEDIMENTATION	THICKNESS (feet)	PLUTONIC SERIES	METAMORPHISM	DEFORMATION
Mississippian (?)				White Mountain plutonic series. Basic and acidic dikes.		Fracturing of crust. Intense igneous activity to east of map-area.
Late Devonian (?)				New Hampshire plutonic series. Binary granite.	Middle and high grade.	Late minor folds and cleavage. Acadian Orogeny
				Pre-granite basic dikes and sills.	Low grade	Early folds and cleavage. Monroe fault? Round Mountain fault?
Lower Devonian	Littleton formation of "New Hampshire sequence."	Largely argillaceous and arenaceous sediments. Limited volcanics.	0-1600			
Silurian and/or Devonian	Gile Mountain formation and Meetinghouse slate of "Vermont sequence."		±4500			
Middle Silurian	Fitch formation	Sandy limestone. Southern area only.	0-25			Gradual subsidence
Lower or Middle Silurian	Clough formation	Quartz conglomerate, quartz sand, mud.	0-1500			
(Unconformity)	(Unconformity)	(Unconformity)		(Unconformity)		
Upper Ordovician (?)				Highlandcroft plutonic series. Granodiorite, diorite, quartz monzonite.	Contact	Gentle crustal warping and uplift. Taconic Orogeny
Middle or Upper Ordovician (?)	Partridge formation	Mud.	0-1500			
		Transitional zone of Albee formation. Mixing of volcanic sediments of Ammonoosuc formation with Albee types. Extreme southeastern area only.	±5000			Eugeosynclinal subsidence.
	Albee formation	Argillaceous and arenaceous types. Some volcanics.				

Table III. Geologic History of the Lunenburg-Brunswick-Guildhall Area.
Following the Paleozoic, widespread prolonged erosion during the Mesozoic and Cenozoic Eras resulted in removal of large quantities of rock. Erosional and depositional features of the comparatively recent Pleistocene glaciation are abundantly represented. Following the Pleistocene, wind erosion and stream adjustment have been active.

bility of the location as well as the remoteness of this section of Vermont to existing markets makes it unlikely that a profitable operation could be conducted in the foreseeable future.

Magnetite

Magnetite, mostly occurring as small porphyroblasts, is disseminated throughout much of the phyllite and slate of the Littleton formation in the vicinity of Burnside Mountain. Magnetic separation of the magnetite from a finely crushed sample collected from one of the richer horizons occurring on the southwest side of Burnside Mountain showed the magnetite content to be about 22 per cent. However, the average content of magnetite in the area's rock is probably much less. In addition, some quartz veins and stringers appearing at scattered locations on Burnside Mountain contain small amounts of magnetite, ilmenite, and bornite. Benton (1886) refers to a bed of magnetic iron situated in the western part of Guildhall, but the location was not discovered during the course of field mapping. He may have had in mind the magnetite disseminated in the phyllite, schist, and slate on Burnside Mountain.

Copper

During the period 1860–1880, widespread search for metallic minerals in northwestern New Hampshire and southeastern Essex County, Vermont, resulted in the development of numerous mines and prospects, all eventually closed because of insufficient size and concentration of the ore bodies. In this area a very small copper mine was opened on the western slope of a small hill known locally as Bolles Hill, 3.5 miles S 65°W of Guildhall Center. Minor amounts of pyrite and chalcopyrite occur in the mine dump and are associated with quartz veins which crosscut Albee quartzite. In addition there are several very small prospect holes situated within a mile to the southwest. Cutting (1867?) notes the presence of copper in exposures about a mile south of Lunenburg Center and also about 2 miles northeast of the village. Examination of these areas revealed tiny amounts of pyrite in the rock.

In Maidstone, chalcopyrite, pyrrhotite, and galena are found in a vein of quartz and gray amphibole much resembling cummingtonite. The vein cuts black Partridge slate found in the bed of a small brook at an elevation of about 970 feet and situated about 0.7 mile northwest of Stevens Pond. The vein, averaging 3 feet in thickness, strikes N 18°E and dips 50°NW.

Copper minerals also occur in the bed of Granby Stream for a distance of several hundred feet at elevations ranging from about 1265 feet to 1285 feet. In this area numerous quartz veins or stringers, which pinch and swell from 1 inch to about 6 inches, are concordant to the bedded amphibolite in which they occur. They strike about N 20°E and dip steeply to the northwest. Some of the quartz veins contain considerable bornite and chalcopyrite. Pyrite and arsenopyrite is distributed throughout much of the quartz.

Lead

Traces of galena and pyrite are found in quartz associated with the fault zone lying just west of the summit of Flynn Hill, Guildhall. Other showings of galena and pyrite in small quantities occur on the west side of Bear Mountain, Maidstone, at an estimated elevation of 1650 feet. The minerals occur in shear zones in massive gray chert-like quartzite of the Albee formation.

Gravel and Sand

Gravel and sand deposits of variable sizes and types occur in some of the valleys. Kame terraces and eskers afford much of the sand and gravel that is used commercially, and several pits are presently in operation. Sizable deposits which are easily accessible occur in Brunswick and Guildhall. No attempt was made to map or classify surficial deposits.

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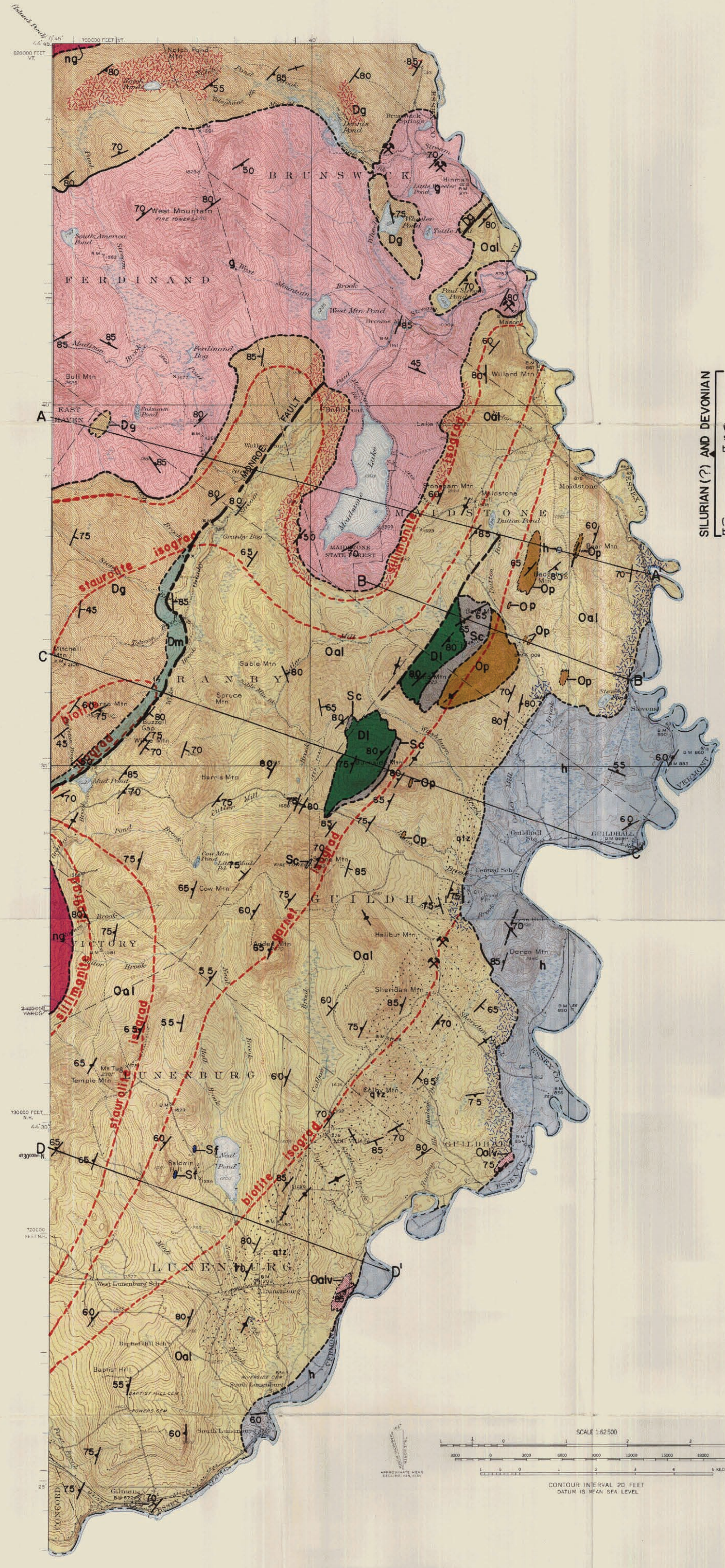
PLATE I



LEGEND

METAMORPHIC AND IGNEOUS ROCKS

LATE DEVONIAN — New Hampshire Plutonic Series

- **ng** — Nulhegan biotite granite (Nulhegan and Victory Plutons)
- **g** — Binary granite (Maidstone Pluton)
- Areas of abundant migmatite or granitoid dikes, sills, and apophyses (Migmatite confined generally to (1) the area of Notch Pond Mountain and westward to map boundary, and (2) the Maidstone Lake region)

"VERMONT SEQUENCE" (West of Monroe fault)

SILURIAN (?) AND DEVONIAN

- **Dm** — Meetinghouse slate (Largely slate and phyllite with some schist and very thinly-bedded quartzite)
- **Dg** — Gile Mountain formation (Dark gray phyllite or schist, interbedded micaceous quartzite)

"NEW HAMPSHIRE SEQUENCE" (East of Monroe fault)

LOWER DEVONIAN

- **Dl** — Littleton formation (Light to dark gray muscovite-garnet schist, biotite-garnet schist, and quartzite)

SILURIAN

Middle

- **Sf** — Fitch formation (Gray arenaceous limestone)

Lower or middle

- **Sc** — Clough quartzite (Boulders, cobbles, pebbles, and splinters of quartzite and micaceous quartzite in schistose matrix)

UNCONFORMITY

UPPER ORDOVICIAN(?) — Highlandcroft Plutonic Series

- **h** — Highlandcroft granodiorite (Lancaster Pluton) (Chiefly granodiorite; some diorite and quartz diorite)
- Intensely deformed contact zone of Highlandcroft and Albee rocks (Consists of numerous dikes and sills, hornfels, and "soaked" rocks. Small and large xenoliths common south of Guildhall)

MIDDLE OR UPPER (?) ORDOVICIAN

- **Op** — Partridge formation (Chiefly black slate)
- **Oalv** — Transition zone (Mixture of Albee quartzite and Ammonoosuc soda rhyolite tuff)
- **Oal** — Albee formation (Largely slate, phyllite, schist, and quartzite) (qtz. = abundant quartzite)

SYMBOLS

- Accurate, Approximate, Isograds — contacts
- Fault
- Dip and strike of beds
- Strike of vertical beds
- Dip and strike of foliation or schistosity
- Strike of vertical foliation or schistosity
- Dip and strike of joints
- Mines and quarries or prospects

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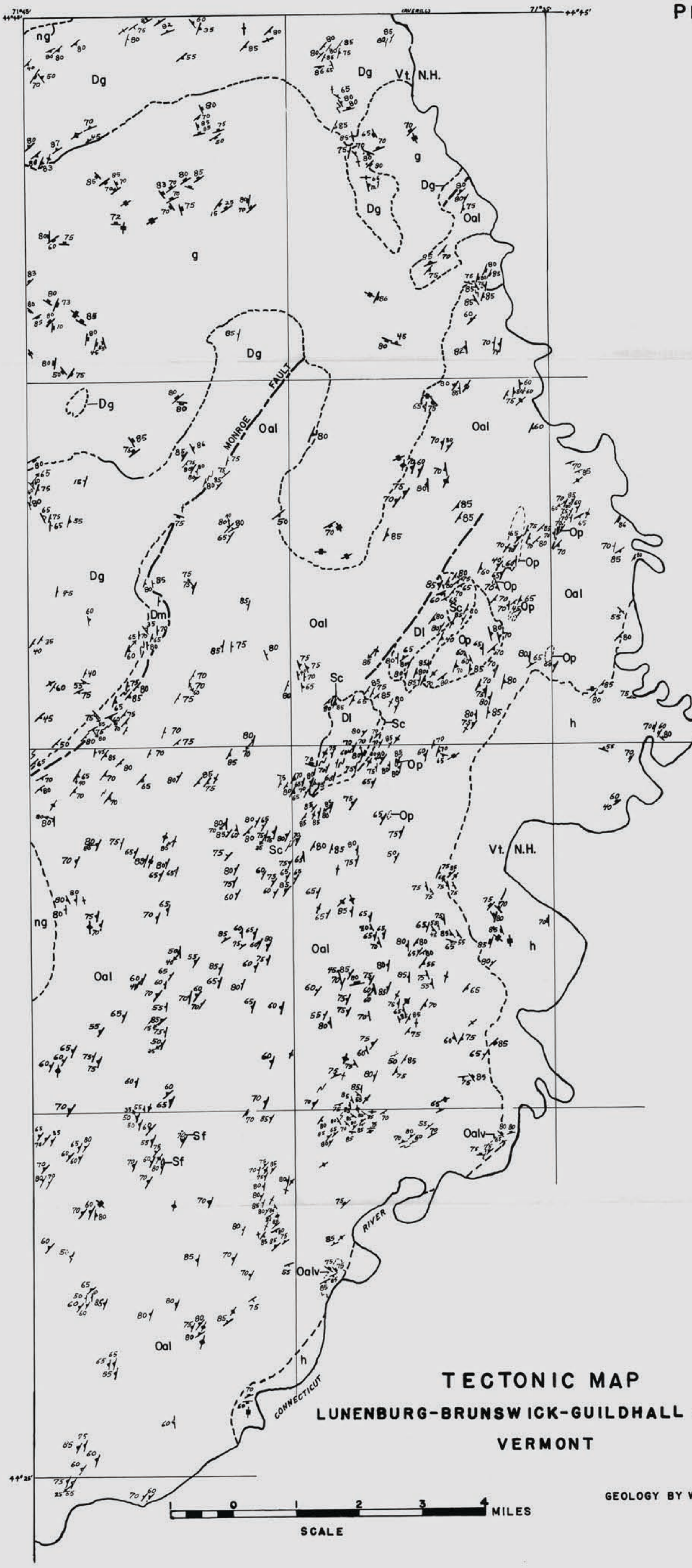
Published 1963

PLATE 2



LEGEND

- 70 Dip and strike of beds
- Strike of vertical beds
- 85 Dip and strike of foliation or schistosity
- Strike of vertical foliation or schistosity
- 65 Dip and strike of slip cleavage
- 80 / 60 Dip and strike of beds and lineation
- 70 / 65 Dip and strike of foliation or schistosity and lineation
- 75 / 70 Dip and strike of slip cleavage and lineation
- Sinistral pattern of minor folds
- Dextral pattern of minor folds
- 65 Dip and strike of joints
- Strike of vertical joints

Formation symbols as shown on the geologic map

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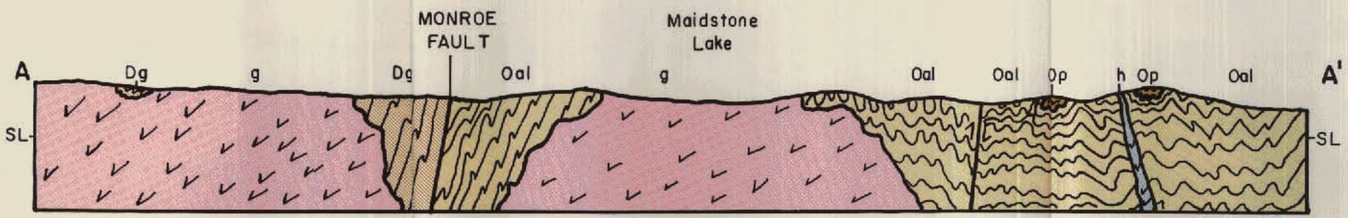
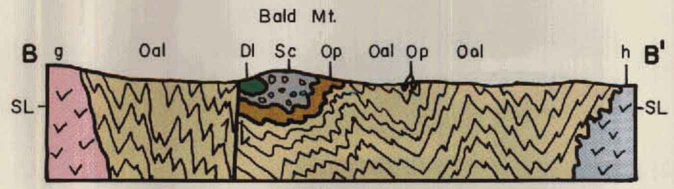
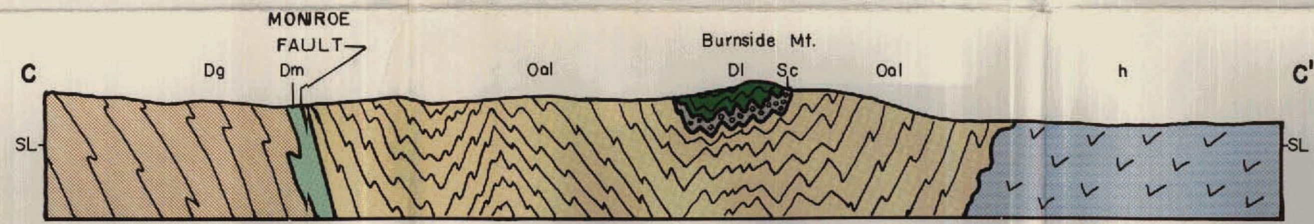
TECTONIC MAP
LUNENBURG-BRUNSWICK-GUILDHALL AREA
VERMONT

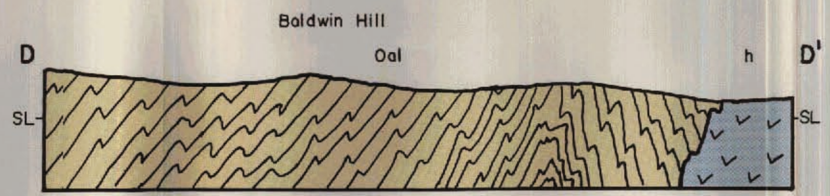
GEOLOGY BY WARREN I. JOHANSSON, 1956, 1957, 1958

1 0 1 2 3 4 MILES
SCALE









GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE LUNENBURG-BRUNSWICK-GUILDHALL AREA, VERMONT

Geology by Warren I. Johansson 1956-1958

Assisted by A. R. Tetreault, 1957, and C. P. Alex, 1958