GEOLOGY OF THE VERMONT PORTION OF THE AVERILL QUADRANGLE, VERMONT

By

PAUL BENTON MYERS, JR.

VERMONT GEOLOGICAL SURVEY

CHARLES G. DOLL, *State Geologist*

Published by

VERMONT DEVELOPMENT DEPARTMENT

MONTPELIER, VERMONT

BULLETIN NO. 27 1964

TABLE OF CONTENTS

List of Tables

List of Figures

List of Plates

GEOLOGY OF THE VERMONT PORTION OF THE AVERILL QUADRANGLE, VERMONT

By

PAUL BENTON MYERS, JR.

ABSTRACT

The Averill quadrangle lies within a belt of Silurian and Devonian rocks which extends from east-central Vermont to the Gaspe peninsula in Quebec. Metasedimentary rocks in the quadrangle belong to the Gile Mountain Formation of Devonian age.

The Gile Mountain Formation in the Averill area is comprised of six mappable lithologic units forming an association which is typical of a eugeosynclinal sedimentary environment. These are: (1) phyllitic quartz-mica schist, (2) subgraywacke characterized by thick graded beds, (3) hornblende schist, (4) dark gray slate and phyllite containing lenses of (5) feldspathic grits, and (6) light gray phyllite with minor schist, quartzite, impure limestone, and calc-silicate rocks.

Two stages of deformation are represented in the area. The major structural feature in the quadrangle is a doubly plunging syncline. Associated with this structure are minor folds, cleavage, joints, and boudinage. Fold axes follow the northeast trend of the regional structures and the folds are overturned to the northwest. These structures were produced by a phase of regional folding probably related to the Acadian orogeny. A phase of igneous instrusion followed the regional folding. Emplacement of the plutons, doming of the sediments, and the development of secondary "slip cleavage" and "reverse drag folds" on the flanks of plutons were produced during this phase.

Three granitic plutons are present in the area. These are: (1) the Nulhegan pluton, composed of quartz monzonite, (2) the Averill pluton, composed of biotite granite, and (3) the Monadnock pluton composed chiefly of quartz syenite.

Four metamorphic zones are recognized: (1) the chlorite zone, (2) the biotite-garnet zone, (3) the staurolite zone, and (4) the sillimanite zone. Both regional and thermal metamorphism have affected the sediments of the area.

INTRODUCTION

Location

The Averill quadrangle is the extreme northeast quadrangle in Vermont (see Figure 1). The area mapped is bounded on the north by the International Boundary, on the east by the Connecticut River, on the west by 71°45′ west longitude, and on the south by 44°30′ north latitude. All of the map area lies within the bounds of Essex County, Vermont. The Vermont portion of the Indian Stream quadrangle, an area of approximately two square miles east of the northeast corner of the Averill quadrangle, is also included in this report.

Geologic Setting

The regional geologic pattern of the area which includes the Averill quadrangle is illustrated in Figure 2. The quadrangle lies within a belt of middle Paleozoic metasediments which extends from the Gaspe Peninsula in southeastern Quebec to east-central Vermont. This belt of essentially Siluro-Devonian metasediments forms the Connecticut Valley-Gaspe synclinorium. Granitic plutons of Devonian and Mississippian (?) age are present throughout the area. Three of these plutons are exposed in the Averill quadrangle.

The metasediments of the Averill quadrangle continue as the upper parts of the St. Francis group in Quebec. They are part of the so-called "Vermont stratigraphic sequence." A belt of lower Paleozoic rocks to the east, the "New Hampshire stratigraphic sequence," is separated from the Vermont sequence by the problematical Monroe line (White and Jahns, 1950). The Vermont sequence is believed to correlate, in part at least, with the New Hampshire sequence, although the exact correlation is not known. The structure in the quadrangle is complex and there is a general overturning of folds to the northwest.

Previous Work

Little geologic work has been done in the area. Early studies include those of Adams (1845), Jackson (1844), E. Hitchcock (1861), C. H. Hitchcock (1874, 1877, 1878, 1884), Richardson (1902 and 1906). All of these are reconnaissance reports. A brief study of the Averill Granite was undertaken by Schroeder (1920), and Wolff (1929) and Chapman (1954) published reports on the Monadnock pluton. The Coaticook-Malvina area which lies on the northern border of the Averill area was mapped by

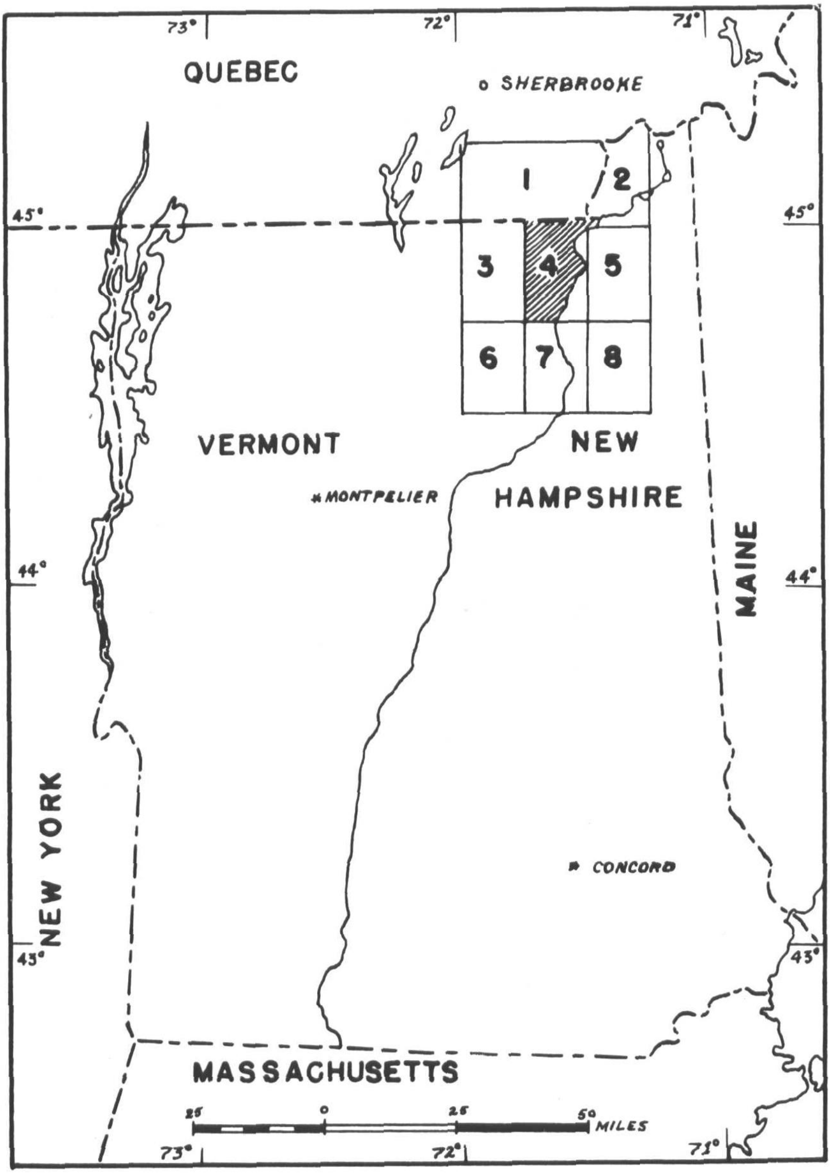


Figure 1. Index Map

Quadrangles numbered as follows:

1. Coaticook-Malvina	5. Dixville
2. Indian Stream	6. Burke
3. Island Pond	7. Guildhall
4. Averill (*This Report*)	8. Percy

SHADING INDICATES AREA MAPPED

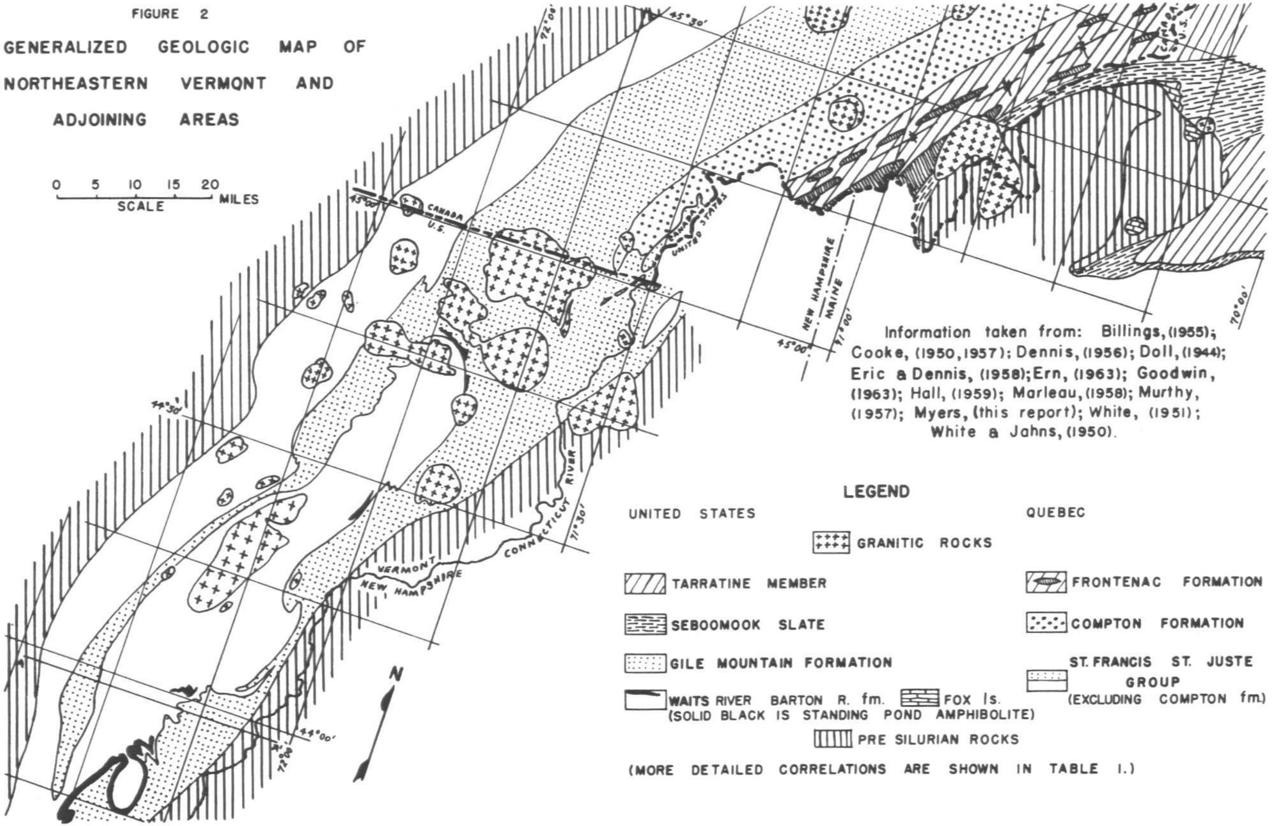


Figure 2. Generalized Geologic Map of Northeastern Vermont and adjoining areas.

Cooke (1957), and the three surrounding quadrangles in the United States have been mapped by B. K. Goodwin (Island Pond, 1963), W. I. Johansson (Guildhall, 1963), and N. L. Hatch (Dixville, 1963).

Purpose of Present Study

Geologic mapping in the Averill quadrangle was undertaken in order to:

1. Define mappable lithologic units within the Gile Mountain formation and determine their stratigraphic relations.
2. Determine the relation of the structures in the quadrangle to the Appalachian structures of the Connecticut Valley-Gaspe synclinorium.
3. Describe the rock types and study the mode of occurrence of the plutons.

Method of Study

The area was mapped on a scale of 1:62,500 during the field seasons of 1957, 1958, and 1959. Standard field mapping methods were employed. The maps prepared are shown on Plates 1 and 2. The field study was supplemented by petrographic examination of thin sections.

Acknowledgments

The field work for this study was supported by the Vermont Geological Survey under the direction of Dr. Charles G. Doll to whom special thanks are due for his generous help.

The author is indebted to Dr. J. Donald Ryan and Dr. Heikki V. Tuominen, both of the Department of Geology, Lehigh University, under whose supervision the study was undertaken. Dr. H. Richard Gault, also of Lehigh University, visited the author in the field.

The author was ably assisted in his field work by Robert W. Brecht in 1957, and John G. McGucken in 1958 and 1959. Their interest and cooperation made working with them a pleasure.

Many fruitful discussions in the field were held with Dr. James B. Thompson, Jr., of Harvard University, E. H. Ern, B. K. Goodwin, W. I. Johansson, and N. L. Hatch.

Finally, I would like to express my thanks to the residents of the area for their keen interest in the work and their kind hospitality during the three field seasons.

Physiography

The Averill quadrangle lies in the Northeastern Highlands of the Appalachian system in Vermont (Jacobs, 1950). This physiographic subprovince has been formed by the westward extension of the White Mountain uplift and is included in the White Mountain section of the New England Physiographic Province by Fenneman (1938). The maximum elevation of the area is 3,140 feet at the summit of Monadnock Mountain and the minimum elevation is 912 feet at Bloomfield, Vermont. Thus, the over-all relief is 2,228 feet. The area is mountainous and heavily forested. The largest mountains in the area are underlain by granite. The large topographic depression forming Yellow Bogs is also believed to be underlain by granite as granite outcrops can be found surrounding this area.

Most of the area is part of the Connecticut River drainage basin. However, the Averill Lakes empty into Averill Creek which is part of the Memphremagog drainage basin and drains northward through the Coaticook River to the St. Lawrence River.

The structure of the underlying rocks appears to have had considerable influence on the physiographic features of the area. All of the major streams, the Averill Lakes, and the topographic highs are aligned parallel to joints, foliation, faults, or some other structural feature.

Continental glaciation has profoundly modified the surface features of the area. Glacial erratics some tens of feet in diameter are common and many of the mountains show evidence of glacial abrasion and plucking. Glacial striae in this area commonly are oriented N 30°W. A pronounced lineation in the surface alluvium of the Yellow Bogs depression is visible in aerial photographs. This lineation also is oriented in a N 30°W direction and consequently is thought to be of glacial origin. Terraces along the Connecticut River contain dark, bluish gray, varved clays which probably were laid down in a large post-glacial lake that covered this region. At several localities these clays contain fossil leaves. A particularly good exposure of the clays containing these fossils is at a location approximately 500 yards south of Columbia Bridge in Lemington. According to Lougee (1953), birch, poplar, and willow leaves and a tundra flora of *Dryas* and heath are present. This area, as far as is known, is the only locality in eastern North America where the fossil *Dryas* flora, now extinct in New England, has been found. A fossil *Dryas* flora has been found in the glacial deposits of Europe.

The upper terraces of the Connecticut River Valley contain many kames and other features of glacio-fluvial origin. Gravel prospects in this area are excellent.

STRATIGRAPHY

General Statement

The Gile Mountain Formation is the only metasedimentary formation which crops out in the area mapped, and, with the exception of the Averill, Nulhegan, and Monadnock plutons, underlies the entire Vermont portion of the quadrangle. Neither the top nor the bottom of the formation is exposed in the area mapped.

No fossils were found in the Averill quadrangle but fossiliferous rocks to the northeast, which are presumed to correlate in part with the sediments of the Gile Mountain Formation indicate an Upper Silurian or Lower Devonian age for the Gile Mountain Formation. A summary of the ideas on the sedimentary column in this area and the correlation of various formations is shown in Table 1.

The Gile Mountain Formation

The name Gile Mountain Formation was first proposed by Doll (1944) for Richardson's Vershire schist which crops out on Gile Mountain in the Strafford quadrangle of east-central Vermont. This belt of phyllites and schists with lesser amounts of limestone and quartzite extends from Ascutney in southeastern Vermont to the International Boundary where it becomes the non-calcareous member of the St. Francis-St. Juste sedimentary sequence in Quebec.

The Westmore formation, named and described by Doll (1951) crops out in the Memphremagog quadrangle and extends southwestward to an area just south of the Randolph quadrangle. Goodwin (1963) has shown the Westmore Formation to be equivalent to the Gile Mountain Formation by pointing out that the two formations unite around the structural closure of the Willoughby arch. Doll (1951) had previously noted the similarity of these two lithologic units and their identity had been proposed, although not proven, by Murthy (1957).

Recent work in Canada (Marleau, 1958) and in northwestern Maine (Boucot, 1953) has shown that the Compton Formation, the upper member of the St. Francis-St. Juste group is equivalent to the Seboomook slates of northwestern Maine. These two formations occupy similar stratigraphic positions on either side of the Frontenac syncline (Figure 2). Since the Gile Mountain Formation of the Averill area is in strike

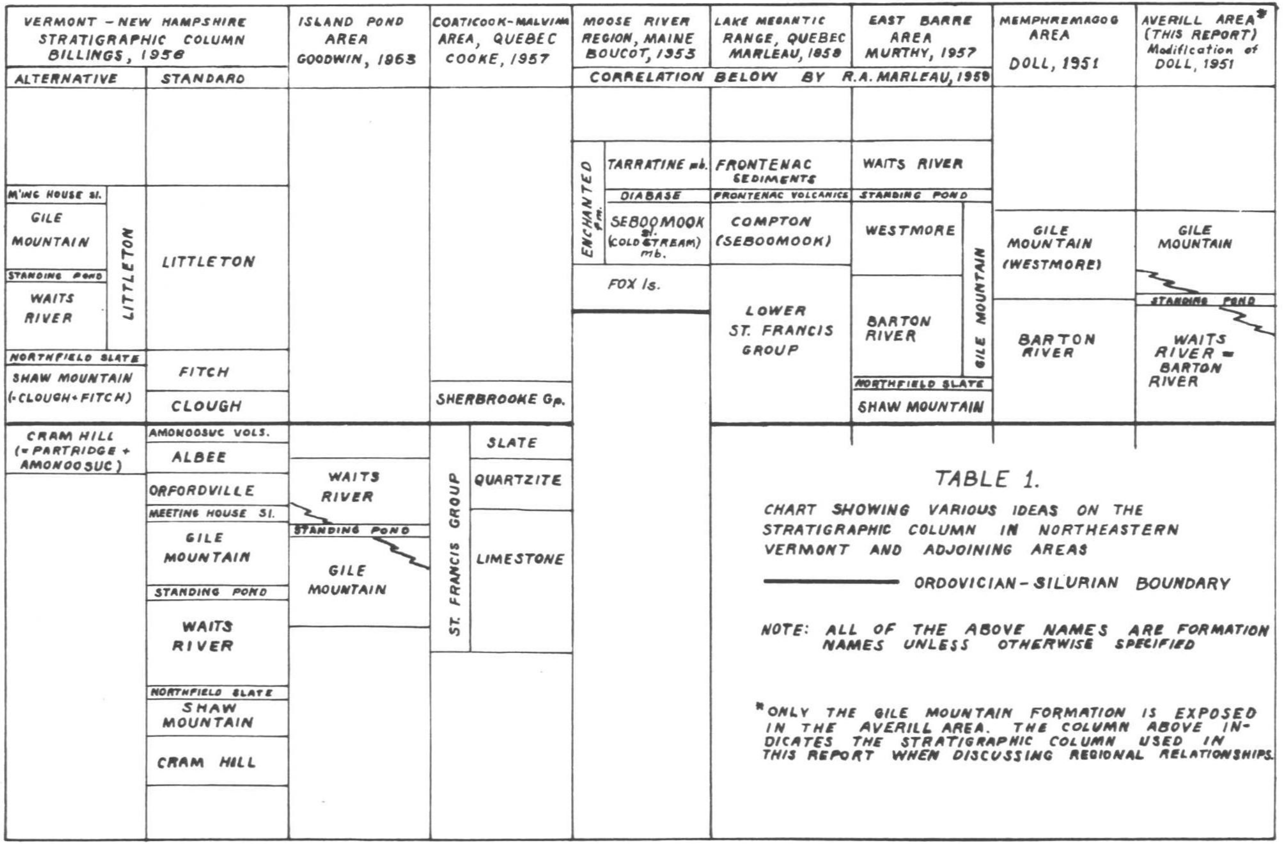


Table 1. Correlation chart showing various stratigraphic columns in Eastern Vermont which have been proposed.

continuity with the Compton Formation, and since there is fairly good fossil evidence to establish the age of the Seboomook slates, this correlation appears to be an important one and will be discussed in more detail at the end of this section when the problem of the age of the Gile Mountain Formation is considered.

Lithology and Stratigraphy

Six mappable litholigic units can be traced in the northeastern part of the quadrangle. These are, from oldest to youngest: (1) phyllitic quartz-mica schist, (2) graywacke and subgraywacke, (3) hornblende schist, (4) dark gray slate containing lenses of (5) coarse feldspathic grits, and (6) interbedded phyllite, dark gray schist, quartzite, limestone, and lime silicate rocks. These lithologic units are difficult to distinguish to the southwest because of changes in metamorphic grade, structural complexity, and changes in sedimentary facies.

Phyllitic quartz-mica schist: The phyllitic quartz-mica schist is the oldest rock which crops out in the area. It is confined to the easternmost portion of the quadrangle except for a small highly metamorphosed patch of this rock type rimming the northern portion of the Nulhegan pluton. Foliation is well developed and bedding is either absent or poorly defined. Estimated modes of this rock type are shown in Table 2. Quartz, the most abundant mineral, occurs in small, sub-rounded, tightly packed grains ranging from 0.1 to 0.2 mm in diameter. Biotite and minor amounts of muscovite are oriented parallel to the foliation of the rock. Interstitial sericite and other fine-grained minerals and accessory amounts of zircon, apatite, and pyrite are present. Quartz veins are common in this rock type. These veins are generally parallel to the foliation, although cross-cutting relationships can be seen. Several of them contain, in addition to quartz, feldspars, muscovite, brown and black tourmaline, an association which suggests that the quartz veins are hydrothermal in origin. However, this does not imply a source from without the system for these veins. It is possible that the veins in which these minerals are found represent zones of tension. Silica and other materials would migrate into these areas in response to pressure gradients forming the "hydrothermal" veins. In this type of vein formation a crack would never have developed in the metasediments as it would have been continuously filled with material while a dilation zone was widening. The chance that any of these quartz sills could be metamorphosed orthoquartzite beds is highly unlikely for several reasons. It would be unusual to find pure quartz sands in abundance associated with graywackes and related sediments. Furthermore, no evidence of sedimentary structures can be found in any of the quartz veins, although relict structures are common in the metamorphic rocks of the area. The cross cutting relationships mentioned above also suggest vein-filling rather than sedimentation.

Graywacke: Bedded graywacke and subgraywacke conformably overlie the phyllitic mica schist. The contact between the two lithologic units is gradational, the phyllite becoming more sandy toward the top. Estimated modes of this rock type are presented in Table 2. The graywacke sequence contains a series of strikingly graded beds which furnish the only conclusive evidence indicating the tops of beds that can be found in the area. Beds range from two inches to two feet in thickness and grade from a light gray-brown, fine-grained graywacke to black slate. Cleavage is refracted as it passes from the sandy to the more pelitic portions of the beds. The sequence as a whole has been more resistant to deformation than the underlying phyllites. The sandy portions of the beds exhibit a highly contorted banding consisting of thin pencil lines of biotite which are oriented roughly parallel to the cleavage. This phenomenon apparently was produced by the deformation of fine sedimentary laminations. Bedding surfaces are highly irregular. Although graded graywacke sequences generally have a number of irregularities in their bedding surfaces (e.g. flow casts, grooves, etc.), the irregularities described herein are predominantly tectonic in origin. Small blocks separated by cleavage planes have undergone differential movement producing microfaults which transect the bedding surfaces. Nevertheless, contacts between the individual beds are sharp. To the southeast the graded character of the beds becomes less and less distinct due to an increase in the percentage of pelitic material and a corresponding decrease in the coarser grained sediments. Finally, it passes imperceptibly into the underlying phyllite.

The graywacke sequence does not crop out on the western limb of the syncline which underlies the central portion of the quadrangle (Plate 1). This probably is due to the fact that the western limb of the syncline is much more gently dipping than the eastern limb; consequently, the graded graywacke sequence normally is not brought to the surface by the western limb. Graywacke which might have appeared on the western limb farther to the west must have been displaced by the Averill granite. It is also possible, however, that a change in sedimentary facies may have taken place between the two limbs of the syncline. Slump structures were observed at several localities and a few structures resembling flow casts were recorded. The intensity of deformation renders these interpretations questionable as it is difficult to distinguish secondary structures

Table 2

ESTIMATED MODES OF THE GILE MOUNTAIN FORMATION

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Quartz	53.1	63.3	52.9	52.0	30.9	34.6	40.3	51.0	39.5	19.3	40.5	30.3	29.8	68.5
Potash Feldspar	0.8	0.4	0.7	1.2			19.2	13.7	22.6					
Plagioclase	tr	tr	tr		tr	0.9	3.1	0.6	0.3			0.6		
Biotite	25.5	8.3			17.7		12.1	18.9	16.5	tr	25.5	33.1	20.4	16.8
Muscovite	2.1	6.1	1.8	1.5			11.0	1.1			19.3	34.1	29.6	
Hornblende					45.4	44.8			8.1	16.3				
Interstitial Clays	17.1	15.8	28.0	30.0			9.6							10.8
Rock Fragments							3.2							
Chlorite		4.4	1.3	1.7	1.3	12.6		5.1	8.3	2.0			tr	
Garnet		tr					tr	4.5	1.8	20.7				
Staurolite								3.2					tr	
Chloritoid											3.2			
Sillimanite												1.7	18.6	
Zircon	tr	tr	tr	tr		tr	tr	tr	tr	tr			tr	
Apatite	tr	tr	tr	tr	1.6	0.2	tr	tr	0.2		tr		tr	tr
Sphene						0.3				tr				
Tourmaline	tr		tr	tr			tr	tr			0.6		tr	tr
Epidote									tr	4.0				
Carbonate										36.0				
Graphite	1.0										9.0	tr		2.8
Metal Opaque	tr	1.6			2.9	6.6	0.8	0.9			1.3	0.2	0.9	1.1
Limonite			14.4	13.4	tr				2.6	tr				

tr—Indicates presence of minerals in trace quantities.

1. Phyllitic quartz-mica schist
2. Quartzitic schist
3. Subgraywacke
4. Subgraywacke
5. Hornblende schist
6. Hornblende schist
7. Halls Stream feldspathic grits
8. Halls Stream feldspathic grits
9. Halls Stream feldspathic grits
10. Lime silicate rock
11. Quartz-mica schist with garnet and chloritoid
12. Quartz-biotite-muscovite schist with sillimanite
13. Quartz-biotite-muscovite schist with sillimanite
14. Schistose quartzite

All estimated modes done by the point count method as described by Chayes (1949).

Mineral percentages express volume per cent.

from deformed flow casts. In all cases, however, these "flow casts," where they were measured, were found to parallel the trend of the eugeosynclinal trough, a phenomenon which is common in unmetamorphosed graywackes (Prentice, 1960). An estimate of the thickness of the graded graywacke sequence was made based on the following assumptions: (1) the average dip is 45° to the northwest, (2) the average surface outcrop thickness is 4,000 feet, and (3) there has been no repetition due to folding. From studies of many surface outcrops of this lithology, it appears that these assumptions are reasonably valid. The estimated thickness of the graded graywacke sequence is approximately 2,800 feet.

Kuenen and Migliorini (1950) undertook a comprehensive investigation of the cause of extensive graded bed sequences in which they combined laboratory experiment with field observation. This work is significant in that both investigators, pursuing different lines of investigation, Kuenen in the laboratory and Migliorini in the field, arrived independently at the same conclusion for the origin of graded bed sequences. They postulated that repeated slumps or turbidity flows along a continental slope give rise to the graywackes, which are characterized by poor sorting, graded bedding, and the presence of slump structures and flow casts. The thick sequence of graded graywackes in the Averill quadrangle exhibit all of these features. Consequently, it is concluded, in light of the work done by Kuenen and Migliorini (1950), that the graded graywacke of this area was deposited from turbidity currents produced by slumping along the slope of the Siluro-Devonian geosyncline of New England.

As far as is known by the writer, no thick sequence of graded graywackes occurs to the south of this area in the Gile Mountain Formation. Hall (1959, p. 41) recently referred to these graywackes in connection with his discussion of the age relations of the Vermont sequence. He mistakenly located them in the "northeast part of the Island Pond quadrangle and the southeast part of the Indian Stream quadrangle." The graywacke sequence continues northeastward from the Averill quadrangle at least to the southwestern portion of the Indian Stream quadrangle (Plate 1). It is not known, however, how far northeastward this lithologic unit continues as the Indian Stream quadrangle to date has not been mapped in detail. Marleau (1958) reports a series of graded beds in the Compton Formation cropping out in the area northeast of the Indian Stream quadrangle. These may correlate with the graded graywacke sequence in the Averill area since the Compton Formation in Quebec is the equivalent of the upper portion of the Gile Mountain Formation in Vermont.

The correlation between the Compton Formation and the upper portion of the Gile Mountain Formation provides one of the few clues to the age of the sediments in northeastern Vermont. A more detailed discussion of this correlation will be presented later.

Hornblende schist: Beds of hornblende schist and amphibolite with quite diverse lithologic characteristics occur in various parts of the quadrangle. They range from dense, black, amphibolite beds one to two inches thick to amphibole-rich lime silicate rocks.

One zone of hornblende schist has a fairly constant lithologic character and can be traced for a considerable distance along the regional strike of the sediments (Plate 1). The thickness of this zone is highly variable. In some places it is 250 feet thick, in other places it is absent. The hornblende schist zone lies immediately above the graded graywacke sequence on the eastern limb of the overturned syncline which bisects the quadrangle from north to south. Table 2 contains modes of hornblende schist collected from this zone.

The bulk of the rock is made up of green hornblende, biotite, quartz, with the remaining percentage divided among plagioclase, apatite, pyrite, magnetite, and chlorite. Garnet is also a common accessory in the rock. The quartz and plagioclase are very fine grained and make up the matrix of the rock. It is impossible to determine an accurate point count percentage of these two minerals. The predominant structural feature of the rock is a lineation of hornblende crystals parallel to the regional strike of the sediments. In thin section the hornblendes are subhedral to anhedral with irregular outlines (Plate 3). Quartz and apatite are poikilitically enclosed within many of the hornblende grains. The hornblende grains occur in a matrix of quartz and plagioclase. Magnetite and pyrite are present throughout the rock. Plate 3 shows the relationships of the minerals in the hornblende schist.

In places patches of a coarse-grained hornblende schist with the same mineralogy have been found in close association with the normally finer grained variety. The more massive hornblende schist, the coarser grained variety, does not exhibit the well-developed lineation of the finer grained hornblende schist. Also, the coarser grained hornblende schists appear to be richer in garnet than the finer grained portions.

Doll (1944) introduced the name Standing Pond for a group of amphibolites and garnetiferous feldspathic schists which occur near the top of the Waits River Formation in the Strafford quadrangle. Doll furthermore proposed that these rocks are of volcanic origin. If this interpretation is correct, the Standing Pond would be an excellent time marker. If it could be traced accurately for long distances, it would be

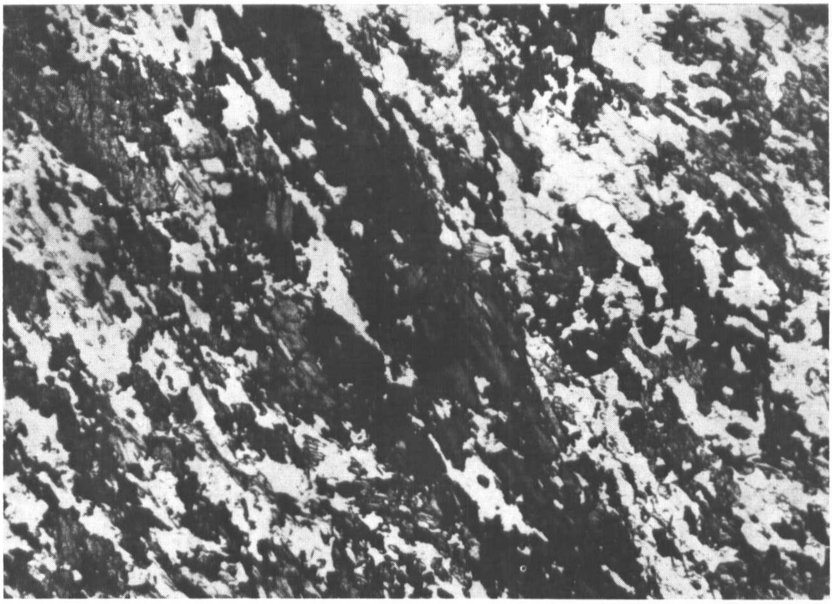


Plate 3. Photomicrograph of hornblende schist showing rough orientation of anhedral hornblende crystals (dark) in a matrix composed chiefly of quartz. Nicols not crossed (X25).

invaluable for purposes of correlation. Several writers have attempted to correlate amphibole-bearing rocks with the Standing Pond of the type area. Rocks petrographically similar have been reported by Dennis (1956), Murthy (1957), Hall (1959), and Goodwin (1963) in separated areas northeast of the type area. In all cases such rocks have been found near the contact of the Gile Mountain and the Waits River formations. From the areas where this rock type has been reported it appears that the Standing Pond is transgressive into the Waits River Formation to the south, crosses the contact between the Waits River Formation and the Gile Mountain Formation northwards, and is transgressive into the Gile Mountain Formation to the north.

The hornblende schist which occurs in the Averill quadrangle occupies approximately the stratigraphic position of the Standing Pond in this area. However, the hornblende schist cannot, at present, be correlated with the Standing Pond amphibolite. The hornblende schist of the Averill area is unusually low in plagioclase and contains no calcite. The Standing Pond of the type area is high in plagioclase content and calcite is a common constituent. No pillow structures were found in the horn-

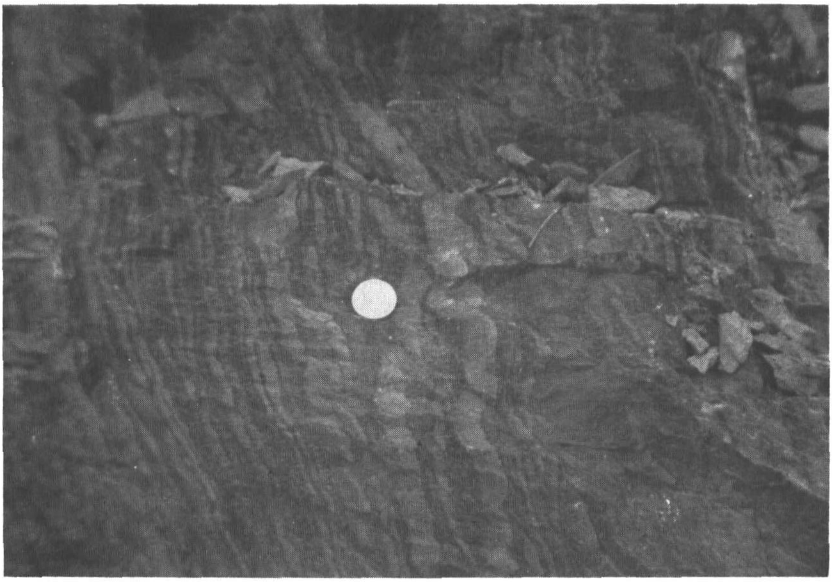


Plate 4. Interbedded siltstone (light) and slate (dark) in the dark gray slates. Photograph was taken looking North. Fifty-cent piece gives scale.

blende schist of the Averill area, although such structures have been reported in Standing Pond rock types by Hall (1959) and Dennis (1956). Finally, the Averill quadrangle is located over one hundred miles northeast of the Strafford quadrangle, the type area of the Standing Pond amphibolite, and several of the correlations made between the Strafford quadrangle and the Averill quadrangle are only tentative (Murthy, 1957, Goodwin, 1963).

Slates and feldspathic grits: A sequence of dark gray slates with thin sandy beds, gray phyllites, and light gray to buff feldspathic grits (Table 2) is closely associated with the graded graywacke sequence and the hornblende schist. The hornblende schist occurs at the bottom of this sequence, but where it is absent, the dark gray to black slates immediately overlie the graded graywacke sequence. The slates are composed of fine-grained particles of quartz and sericite with considerable chlorite present, due primarily to the metamorphic grade. Sandstone beds which range from a fraction of an inch to one or two inches in thickness are common throughout the slates (Plate 4). The sandstone is composed dominantly of very fine-grained sand or silt size quartz grains.

In many places, weathered surfaces of the slate are pitted due to the weathering of unknown minerals. The rhombohedral shape of the pits and the rusty color associated with them suggest that the mineral ankerite or another iron-bearing carbonate was removed by weathering. However, no such minerals were found in thin section.

Lithologically, these sediments appear to be quite similar to the Seboomook Slates of southeastern Quebec and northwestern Maine. This is to be expected since these rocks are represented to the northeast in Quebec by the Compton Formation which Marleau (1958) has shown to be lithologically similar to and correlative with the Seboomook Slates.

The thin sandstone beds in the slates give some evidence of grading, but generally it is difficult to determine tops in this lithologic type. The slate has been deformed to a much greater degree than the underlying massively bedded graywacke and minor structures are difficult to interpret. In places where the hornblende schist is not present, a gradation can be seen from the graded graywacke sequence into dark gray slate. The sandy beds of the graywacke sequence become progressively thinner upward and correspondingly the sand/shale ratio decreases. The dark gray slates are in turn gradational into the overlying sequence of phyllite, quartzite, and schist.

Lenses of coarse-grained, feldspathic grits are interbedded with the slate in some places and are believed to be of volcanic origin. These grits exhibit almost no indication of bedding. The most prominent structural feature is the mineral orientation which is parallel to the strike of the lenses. Jointing is the only other prominent structural feature. Outcrops showing well-developed joints resemble weathered granite when viewed from a short distance. Small, lenticular inclusions of dark gray slate are common in the grits and many of these inclusions are highly deformed. The fragments range from one to two inches up to two feet in length and vary from a fraction of an inch to five inches in thickness. Where they could be seen in three dimensions, it was found that these inclusions occurred as both sheet-like and rod-like fragments. Additionally, small (2″ to 3″ x ½″ x ½″) black inclusions of an unidentified aphanitic material were found at several localities in the grits. None of the minerals in these inclusions could be identified. Several of the inclusions were shaped like volcanic bombs.

In thin section the grits contain large angular to sub-rounded grains of both plagioclase and potash feldspar ranging from 1/32 of an inch to an inch in length (Plate 5). The texture and structure of the grits vary slightly from one lens of grits to another, as does the mineralogy. Green

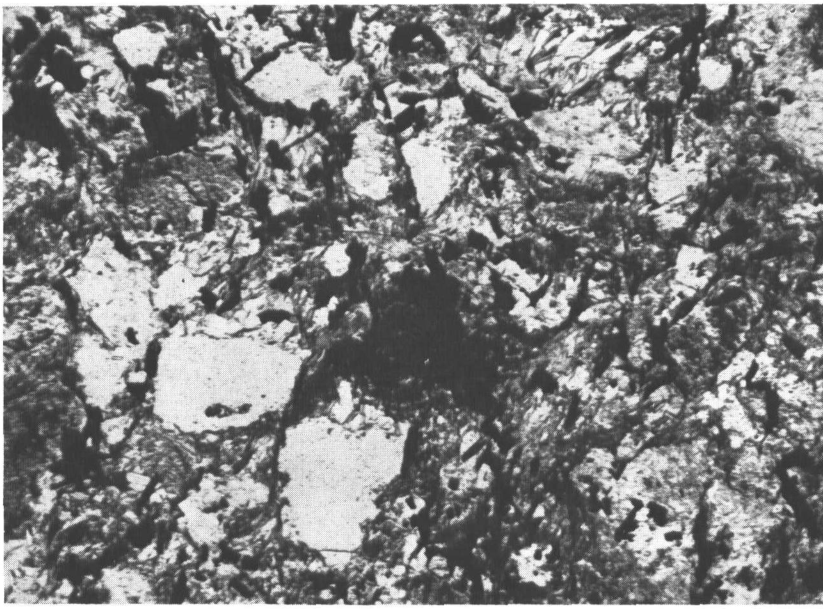


Plate 5. Photomicrograph of feldspathoidal grit showing large angular feldspars enclosed in a fine-grained matrix of quartz, biotite, and sericite. Nicols not crossed (X25).

hornblende was present in one lens but was absent in the others. Quartz occurs as sub-rounded grains and is abundant in all sections. Biotite is a common constituent. The large grains are enclosed within a fine-grained matrix of quartz sericite, muscovite, chlorite, and biotite. In places the grits exhibit a pronounced lineation of the minerals, chiefly the feldspars, which in these cases are anhedral and lenticular in shape. They have highly ragged edges and poikilitically enclose biotite, amphibole, quartz, and other small mineral grains. Zircon, apatite, garnet and opaques are the accessory minerals of the rock. Interstitial carbonate was seen in several thin sections.

The origin of these feldspathic grits is a problem. They have gradational to sharp contacts with the enclosing dark gray slates, contain inclusions of slate, and the grains within the rocks show evidence of wear. All of the above features would point to a sedimentary origin for these grits. On the other hand, the mineralogy of the grits is unusual for a sedimentary rock. There is an unusually high percentage of feldspar in the grits. Many of the feldspars are angular, indicating little wear. No evidence can be seen in the vicinity of these grits of a source for a sediment of this mineralogy. Also, these grits resemble grits in the region which are thought to be of volcanic origin. Consequently, it is thought that these feldspathic grits are of a volcanic, probably pyroclastic origin and that they owe their sedimentary features to reworking shortly after their deposition.

The feldspathic grits extend from the center of the Averill quadrangle northeastward across the international boundary into the Malvina area of Quebec where they become much more widespread. Cooke (1957) correlated the grits with the Sherbrooke volcanics of the Sherbrooke group which crops out a considerable distance to the west. Cooke believed that these grits, which he called the Sherbrooke grits, lay upon the underlying sediments of the St. Francis group (the Gile Mountain Formation in Vermont) with a pronounced angular unconformity. Consequently, he believed that the Sherbrooke grits were considerably younger than the surrounding sediments. He dated the Sherbrooke grits as Silurian and the St. Francis group as Ordovician. The writer has found that the grits in the Averill quadrangle do not lie on top of the Gile Mountain Formation in an angular unconformity but occur as lenses within the formation. Cooke (1957, p. 28) referred to outcrops in the Indian Stream quadrangle which he believed supported his conclusion that a pronounced angular unconformity exists between the grits and the enclosing sediments. These outcrops were visited by the writer and it was found that here, as in the Averill quadrangle, the grits and the enclosing sediments are conformable. The problem most likely arose from a confusion of bedding and cleavage. At the particular outcrop cited by Cooke (1957, p. 28), cleavage in the underlying sediments occurs at almost right angles to the bedding of the sediments and the grits.

Since the grits of the Averill area do not appear to be related to those of the Sherbrooke group, the name Sherbrooke grit does not apply. In its place the writer would like to propose the name suggested by Dr. James B. Thompson, Jr. (personal communication), the Halls Stream grits. This name is now in fairly common usage among the workers in this area. Excellent outcrops of these grits can be seen along the eastern slopes of the Halls Stream valley approximately three and one-half miles north of Beecher Falls, Vermont.

Marleau (1958) correlates the grits in the Malvina area with rocks in the Frontenac Formation which occupies a synclinal structure to the northeast of the Averill quadrangle (Fig. 2). However, the Gile Mountain Formation (Compton in the Malvina area) which contains these grits is stratigraphically below the sediments of the Frontenac syncline. Furthermore, aeromagnetic maps show the Frontenac sediments to contain strong positive magnetic anomalies associated with the mafic volcanics in the syncline in the Megantic area. No such magnetic anomaly occurs in the sediments of the Malvina area. Unfortunately, aeromagnetic maps have not been prepared for the northern New Hampshire and Vermont area and it is difficult to determine what happens to the Frontenac syncline when it crosses the Canadian border. The writer believes, however, that the Frontenac syncline probably lies considerably east of the Averill area in the United States.

Eric and Dennis (1958) mention volcanics in the Gile Mountain Formation in the Concord-Waterford area which is to the southwest of the Averill area. However, they present no lithologic descriptions of these rocks other than referring to them as "dense white felsites." The Halls Stream grits are much too coarse grained to fit this description and, although they weather light buff, they are more mafic in composition than the name felsite would imply.

Phyllite: A sequence of phyllite, quartzite, limestone, lime silicate rocks, and dark gray schist forms the uppermost unit of the Gile Mountain Formation in the Averill quadrangle. The most prominent rock type in this sequence is light gray phyllite occurring in beds one to ten inches thick and interbedded with thin beds (1/4" to 1 inch thick) of dark gray schist. The beds in this unit are not graded and the contacts between schist and phyllite are sharp. The contact with the underlying slates and grits is gradational.

The phyllite is composed chiefly of very fine sand size quartz grains which are sub-rounded. Muscovite and sericite are abundant in the matrix of the rock and large flakes of biotite are common constituents. Porphyroblasts of almandine garnet are also common in the phyllite, although they are more abundant in the dark gray schists which are interbedded with the phyllite. Carbonaceous matter, zircon, tourmaline, and pyrite, are common accessories of the rock. Biotite forms thin pencil line bands in the phyllite and these bands give some indication of the deformation in the area (Plate 6).

Beds of lime silicate rock occur at several stratigraphic levels throughout this lithologic unit. At one such level they dominate a sequence approximately fifty feet thick. In places enough carbonate remains in these beds to produce a strong effervescence. Essentially, however, the lime silicate beds are composed of hornblende, tremolite, grossularite, quartz, carbonate, and diopside. From the present mineralogy it is

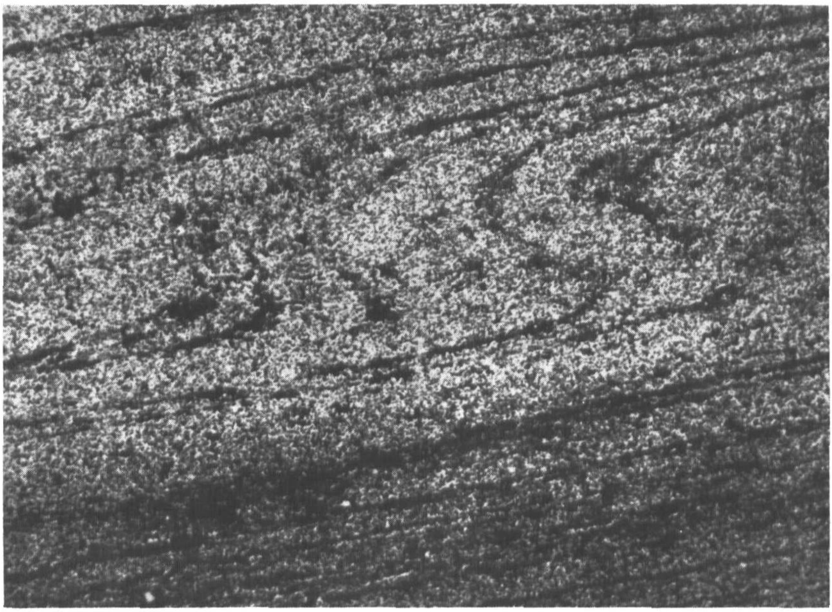


Plate 6. Microfolds in quartzitic phyllite. Dark bands are predominantly biotite, the lighter bands are predominantly quartz. Nicols not crossed (X10).

inferred that these rocks are the metamorphic product of marly clays.

A few impure limestone beds were found in this unit. Quartzite beds are fairly abundant and tend to have a purplish-gray color in contrast to the lighter gray color of the phyllites. Modes of the various rock types in this unit can be seen in Table 2.

Age

The first work done in this area which cited paleontological evidence for the age of the rocks was Logan's report on the Geology of Canada (1863), in which he traced his Gaspe series down to the International Boundary at Stanstead, Quebec. He divided this series into a lower calciferous member (the Waits River Formation in Vermont) and an upper phyllitic member (the Gile Mountain Formation in Vermont). Fossils found at three localities in the lower calciferous member were identified as Helderberg fossils and Logan assigned a Siluro-Devonian age to the sequence.

Richardson (1906), working on the southern end of the same sequence assigned an Ordovician age to the Waits River-Gile Mountain sequence on the basis of an erroneous correlation with graptolite-bearing shales at Castle Brook in Magog, Quebec. Many of the graptolite localities of Vermont and Quebec became questionable when Foyles (1930) showed many of the "graptolites" to be structurally produced mica streaks. Currier and Jahns (1941) later showed that the correlation of Richardson's Bradford schists and the graptolite-bearing rocks at Castle Brook was incorrect.

Doll (1943, 1944) proposed a Siluro-Devonian age for the Westmore Formation on the basis of several crinoid calyxes found in the Westmore Formation and a *Spirifer* found in the Gile Mountain Formation. Dennis (1956) after a comprehensive study of the various proposed ages of these rocks concluded that the Gile Mountain Formation is probably Devonian. Cooke (1957) on the basis of the "great angular unconformity" between the St. Francis group and the Sherbrooke grits stated that, "It seems impossible that any beds lying below this great angular unconformity can be other than Ordovician." However, the fact that this "great angular unconformity" does not exist means that the surrounding sediments must be the same age as Cooke's Sherbrooke grits (the Halls Stream volcanics in this report) to which Cooke himself assigns a Silurian age. Goodwin (1963) admitted the possibility that the Gile Mountain and Waits River formations in the Island Pond quadrangle might be of Siluro-Devonian age, but tentatively suggested an Ordovician age, mainly on the basis of Cook's work in the Coaticook-Malvina area and the work of others to the south (Lyons, 1955, Billings and White, 1951, and others). Since Cooke's interpretation of the age of the St. Francis group is questionable, Goodwin's interpretation of age also is subject to question.

Perhaps the most conclusive evidence for the age of the Gile Mountain Formation comes from fossil localities in southeastern Quebec and northwestern Maine. Marleau (1958), on the basis of lithologic similarity, and similar stratigraphic position on opposite limbs of the Frontenac synclinorium, has shown that the Compton Formation is essentially the equivalent of the Seboomook Slates in northwestern Maine and southeastern Quebec (Figure 2). Boucot (1953) has reported Oriskany fossils from the Cold Stream member (Seboomook Slates) of the Enchanted Formation. Fossil localities in the Fox Limestone which underlies the Seboomook Slates in this area have yielded fossils of Upper Silurian age. Consequently Marleau (1958) proposed a Siluro-Devonian age for the Compton Formation. Since the sediments of the Averill area are in strike continuity with the upper St. Francis group (Compton Formation) in

Quebec, it seems most probable that the Gile Mountain Formation is of Upper Silurian or Lower Devonian age.

Marleau (1958) also proposed a correlation between the Standing Pond amphibolite of the Vermont sequence and the volcanics of the Frontenac Formation in Quebec. This correlation, although not at all certain at the present time, would provide valuable evidence regarding the Vermont stratigraphic sequence if it could be established. The Standing Pond amphibolites in the Strafford quadrangle (Doll, 1944) occupy a position in the Waits River Formation a short distance from the contact of the Waits River Formation and the Gile Mountain Formation. In the East Barre quadrangle (Murthy, 1957) and the St. Johnsbury quadrangle (Hall, 1959), the Standing Pond amphibolite is at the contact between the two formations. Goodwin (1963) shows the Standing Pond amphibolite passing from the contact of the Gile Mountain and Waits River formations into the Gile Mountain Formation. If it can now be shown that the Frontenac volcanics do actually correlate with the Standing Pond amphibolite, an excellent time marker exists for a distance of over two hundred miles along the trend of the synclinorium. The Frontenac Formation is younger than the Gile Mountain Formation (Marleau, 1958). Consequently, if the Frontenac volcanics pass into the Gile Mountain Formation as the Standing Pond amphibolite, it can be concluded that the volcanics as correlated above transgress progressively older rocks to the southwest. This would mean that the Waits River Formation is older than the Gile Mountain Formation.

In summary, a Siluro-Devonian age has been proposed for the Gile Mountain Formation by Doll (1943, 1951), Dennis (1956), Cady (1956), Billings (1956, alternative suggestion), Murthy (1957) and Marleau (1958) and Hall (1959). An Ordovician age has been proposed by Lyons (1955), Billings and White (1951), Goodwin (1963) and Ern (1963). The writer feels that the evidence is heavily in favor of a Siluro-Devonian age for the Vermont sequence and that the Gile Mountain Formation is most probably of Lower Devonian age.

PLUTONIC ROCKS

Three large plutons of granitic rocks crop out in the Averill quadrangle. Two of the plutons lie on the western border of the quadrangle and are separated by a thin band of highly metamorphosed sediments, the Averill granite on the north and the Nulhegan quartz monzonite on the south. The Mount Monadnock pluton is the only pluton on the eastern side of the Vermont portion of the quadrangle. The entire area is cut by numerous dikes and sills of varying lithologies.

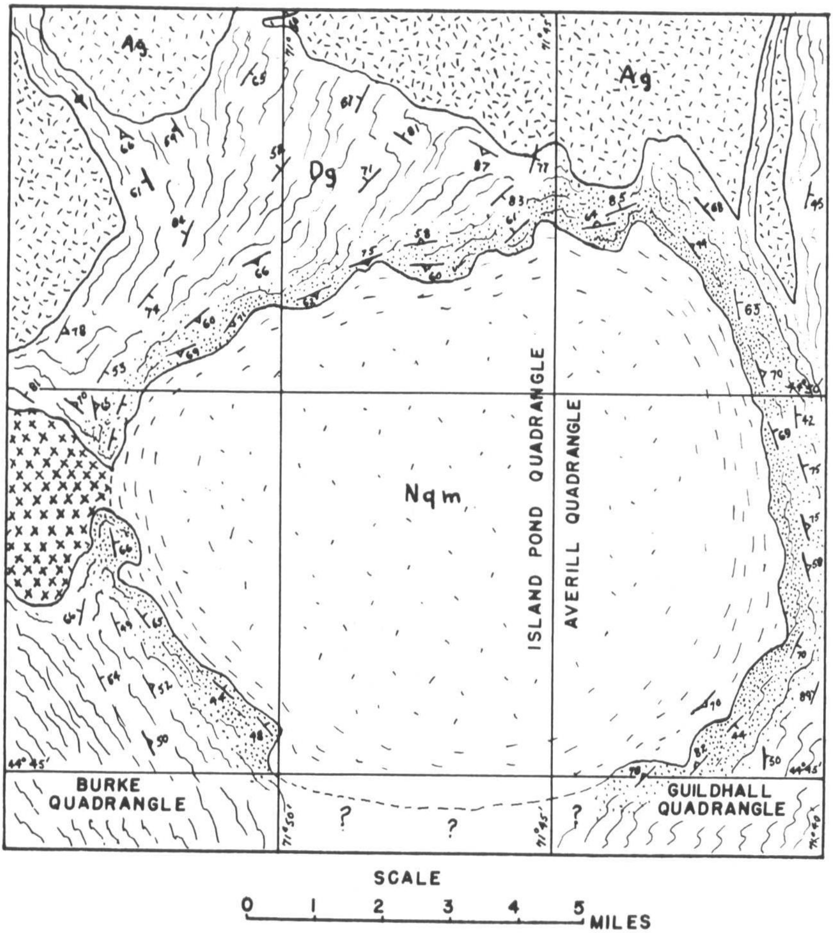


Figure 3. Map showing field relationships of the Nulhegan pluton. Stippled area indicates contact metamorphic zone. Formation symbols as shown on Geologic Map (Plate 1). (Data in Island Pond Area taken from Goodwin, 1959)

The classification used to identify the plutonic rocks of the Averill quadrangle is that followed by Williams, Turner, and Gilbert (1955). It is a classification based on the clan concept.

The Nulhegan Quartz Monzonite

The Nulhegan quartz monzonite underlies a roughly circular area, the location of which is shown in Figure 3. It covers approximately forty-five square miles with about three-fifths of this area lying in the southeast corner of the Island Pond quadrangle. The name Nulhegan quartz monzonite was proposed by Goodwin (1963) because the quartz monzonite occupies a basin drained by the Nulhegan River and its tributaries. The basin is surrounded by a rim of hills held up by the metasediments of the Gile Mountain Formation. Outcrops within the basin are scarce as it is filled with alluvium and covered by extensive swamps. However, outcrops of quartz monzonite are abundant along the edge of the basin and the few scattered outcrops on the basin floor consist of the same rock type. Consequently, it is inferred that the basin is underlain entirely by quartz monzonite.

The Nulhegan pluton is composed of two main rock types. One is a coarse-grained quartz monzonite close to granodiorite in mineral composition, and the other is a medium- to fine-grained quartz monzonite more granitic in composition. The mineral compositions and textures of the two rock types are similar except for differences in grain size and proportions of the minerals present. The relationships between the two types could not be determined from the few outcrops available. The coarser grained variety appears to be more abundant. In the one outcrop seen where both types occur, the contact is sharp. A rough foliation is present in the coarser grained quartz monzonite. It is sub-parallel to the contact and becomes less distinct inwards from the contact.

The mass is cut by a series of fine-grained granite dikes, one to five inches thick, and oriented parallel to joint planes which transect the pluton. Pegmatites are common near the contact of the pluton both in the quartz monzonite and in the country rock. Within the pluton the pegmatites appear to follow a northwest trend which is parallel to one of the joint sets. No pegmatites were found in the pluton beyond a distance of half a mile from the contact. However, this may be related only to the paucity of outcrops in this area. The pegmatites consist of potash feldspar, quartz, muscovite, black tourmaline, and almandite. A few mafic dikes cut the pluton and are the youngest rocks exposed within the mass.

Six thin sections of the Nulhegan quartz monzonite were studied. These indicate that the rock is a medium- to fine-grained quartz monzonite. The texture is hypidiomorphic granular with euhedral to subhedral grains of brown and green biotite, plagioclase (oligoclase-andesine), and potash feldspar. Quartz grains are interstitial and have no crystal form. Green hornblende is a common mafic constituent and occurs as subhedral grains, many of which are partially or completely replaced by chlorite. Small grains of diopsidic augite are present in every thin

TABLE 3
ESTIMATED MODES OF THE NULHEGAN QUARTZ MONZONITE AND AVERILL GRANITE

Sample No.	1	2	3	4	5	6	7
Quartz	22.8	26.2	27.5	32.3	43.1	33.2	31.4
Potash Feldspar	24.4	13.6	27.7	26.3	47.5	45.9	44.3
Plagioclase	24.3	31.6	28.6	26.5	0.5	8.1	14.6
Biotite	15.6	20.2	11.9	10.6	5.1	7.1	2.1
Muscovite		tr	0.2	1.5	1.2	1.4	4.7
Hornblende		5.7					
Myrmekite						1.7	1.2
Pyroxene	0.4	1.3	1.7	0.8			tr
Sphene	0.7	1.0	0.3	0.4			
Apatite	tr	tr	tr	tr	0.1	0.1	0.2
Zircon	0.3				0.1	tr	tr
Chlorite	8.3	0.1		0.4	0.3	0.8	1.3
Sericite	3.1	tr	2.2	1.2	1.6	1.7	
Opaque	0.1	tr		0.1	0.5	0.1	tr

tr—Indicates mineral presence in trace quantities.

1. Nulhegan pluton—Quartz Monzonite—Plagioclase is oligoclase.
2. Nulhegan pluton—Granodiorite —Plagioclase is andesine.
3. Nulhegan pluton—Quartz Monzonite—Plagioclase is oligoclase.
4. Nulhegan pluton—Quartz Monzonite—Plagioclase is oligoclase.
5. Averill Granite—Plagioclase is oligoclase.
6. Averill Granite—Plagioclase is oligoclase.
7. Averill Granite, near contact with Gile Mountain formation. Plagioclase is oligoclase.

All estimated modes done by the point count method as described by Chayes (1949). Mineral percentages express volume per cent.

section studied. They are commonly enclosed within clusters of biotite grains although they also occur in contact with other minerals in the rock. Other accessory minerals are, in decreasing order of abundance, sphene, apatite, zircon, magnetite, and pyrite. Secondary flakes of white mica present in trace quantities are associated with sericite which has been produced from the alteration of potash feldspar. Modes of the Nulhegan quartz monzonite are shown in Table 3.

Due to the scarcity of outcrops the structural relationships of the Nulhegan pluton are difficult to determine. No contacts between the pluton and the country rock were observed. Numerous dikes and sills of quartz monzonite cut the country rock in the vicinity of the pluton and all exhibit sharp contacts with the wall rock. However, the meta-

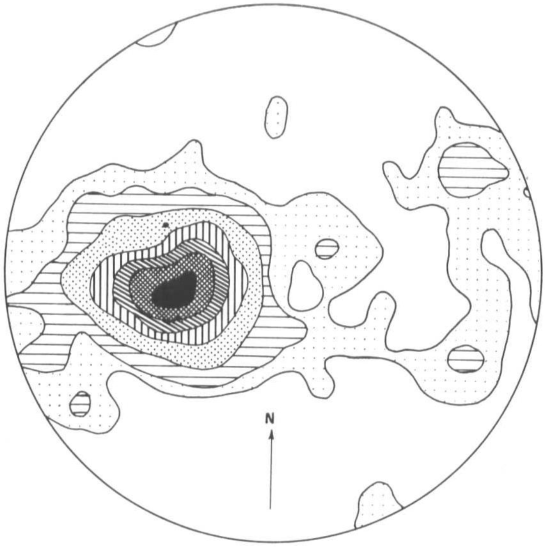


Figure 4a. Contour diagram of poles of foliation in the Averill quadrangle. 900 points plotted. ½ –1–2–4–6–8–10%.

sediments surrounding the pluton became markedly more coarse-grained and more granitic in appearance toward the contact with the pluton and, although the exact contact was never seen, it is believed to be gradational. Goodwin (1963) reports a similar gradation observed along the contact of the pluton in the Island Pond quadrangle.

The metasediments of the Gile Mountain Formation which surround the pluton stand up above the inferred contact as a high ridge broken by several notches. Their greater resistance to erosion may be the result of contact metamorphism. The most prominent characteristic of this contact metamorphic zone is an increase in grain size which tends to obscure traces of bedding. No change in composition can be inferred from the mineralogy.

The strike of the foliation in the metasediments which crop out near the pluton is sub-parallel to the strike of the contact (Figure 4). In Figure 4a, the poles of the regional foliation throughout the quadrangle have been plotted. The diagram shows a strong point maximum representative of a regional foliation which strikes slightly west of north and dips approximately forty-five degrees east. In Figure 4b, poles of the foliation have been plotted for outcrops within three-quarters of a mile of the Nulhegan pluton. Again, there is a strong point maximum

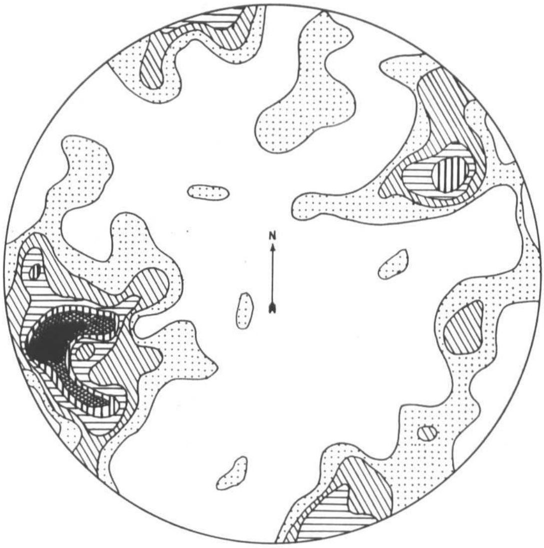


Figure 4b. Contour diagram of foliation in the metasediments within ¾ of a mile of the Nulhegan quartz monzonite. 100 points plotted. 1–2–3–4–5–6–%.

representing foliation which strikes slightly west of north, but the dip has been increased roughly twenty-five degrees. Also, the poles are more scattered, indicating that the strike of the foliation follows the strike of the contact. Judging from the data presented on the geologic map of the Island Pond area by Goodwin (1963), it seems reasonable to assume that if the poles of the foliation were plotted for all the outcrops around the entire circumference of the pluton, the stereodiagram would show a girdle around a roughly vertical axis. It should be pointed out that if the poles of the foliation in diagram 4b were not included in the regional diagram (Figure 4a), the latter would exhibit an even stronger maximum than is now the case.

Inclusions are common in the pluton near the contact with the country rock. The inclusions consist of slightly altered phyllite, quartzite, and amphibolite, all of which correspond to the various rock types in the Gile Mountain Formation. The inclusions are tabular and strike sub-parallel to the contact of the pluton (Figure 5). Contacts of the quartz monzonite and the inclusions are either sharp or show a reaction rim up to three inches wide. The inclusions range from a fraction of an inch to several feet in length.

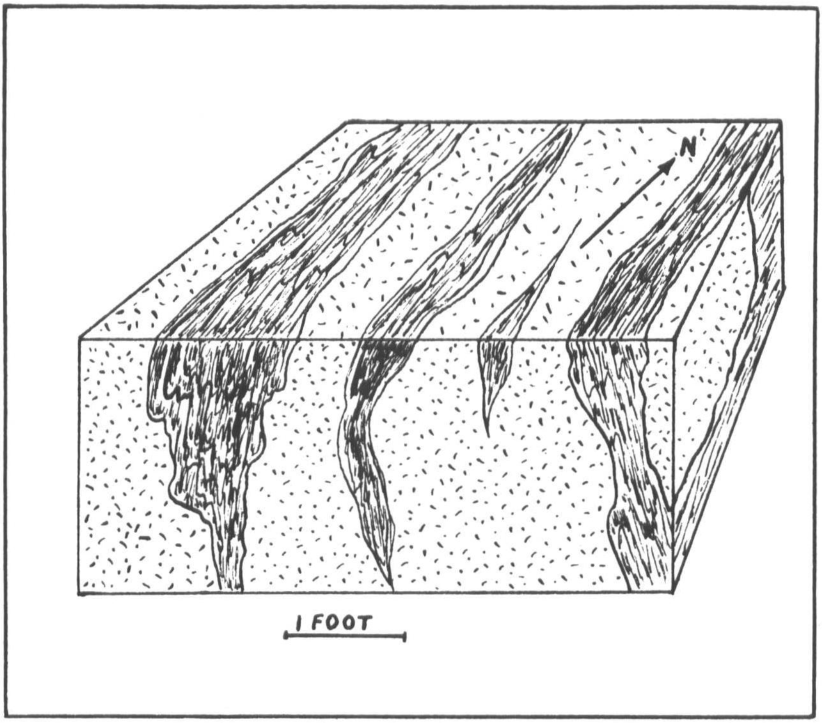


Figure 5. Diagrammatic sketch of inclusions of metasediments in the Nulhegan quartz monzonite. Contact of the country rock and the pluton lies approximately 75 feet to the right of this sketch.

Contacts between the pluton and the country rock, although never actually observed, appear to dip under the sediments at a moderately steep angle. This inference is largely based on the observation that outcrops of quartz monzonite extend into the ridge of sediments at all places where a notch cuts the ridge. The presumed contact metamorphic zone is approximately three-quarters of a mile wide. It is unlikely that a contact aureole of this magnitude would occur if the contact were vertical or nearly so. The inferred contact in the Averill quadrangle dips in the same direction as the foliation in the sediments but at a slightly more moderate angle. Since the quartz monzonite extends into the ridge of sediments at notches throughout its circumference and since the contact aureole surrounds the pluton with little variance in outcrop width, it is assumed that the contact dips under the sediments at all localities. This would indicate that the pluton is dome-shaped (Figure 6).

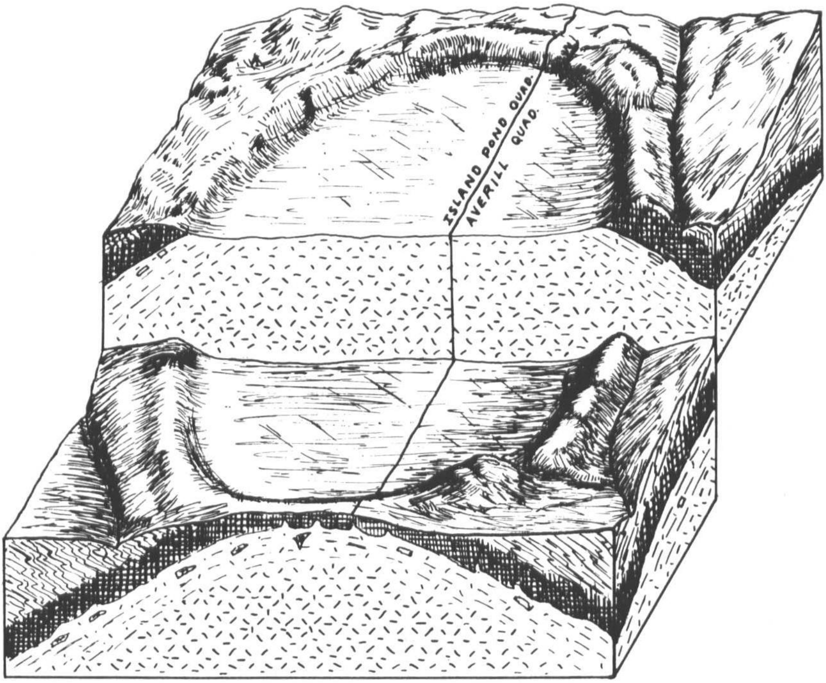


Figure 6. Schematic block diagram of supposed form of Nulhegan pluton. Shaded area in cross sections indicates contact metamorphic zone.

Although the contact between the Nulhegan quartz monzonite and the Gile Mountain Formation appears to be gradational, there are several reasons to suggest that the pluton is the result of magmatic intrusion: (1) In the vicinity of the pluton the foliation in the metasediments dips more steeply than the regional foliation (Figure 4). This suggests that the sediments were pushed aside by the intruding magma. (2) Dikes and sills of quartz monzonite identical in composition with that of the pluton cut the metasediments. The contacts of the dikes and sills are sharp. These features suggest that the dikes and sills are igneous and represent apophyses of a larger magmatic body. (3) Inclusions of all of the several different metasedimentary rock types which occur in the vicinity of the pluton are found in the pluton and, in most cases, the contacts of the inclusions and the quartz monzonite are sharp. Since these inclusions are oriented with the strike of their long axes parallel to the strike of the contact of the pluton and since in many cases the foliation in the inclusion is conformable with the foliation in the country rock, it is possible that the inclusions could be considered as relicts left behind by the selective granitization of the metasediments. Because the inclusions are so many different rock types, this seems unlikely. Remnants of selective granitization would tend to be of one rock type which had a greater resistance to granitization than the other rocks in the area. Also, the sharp contacts between the inclusions and the country rocks would not be expected if the pluton were the product of granitization of the country rock. It might be argued that granitization is independent of rock type and is controlled by fractures and other zones of weakness in the rocks. If this were the case, one would expect to find inclusions of one particular rock type systematically repeated somewhat resembling boudinage in a single bed. This situation was not found in the field. (4) The nature of the metasediments in the vicinity of the pluton suggest contact metamorphism by an intrusive mass.

The Nulhegan quartz monzonite is considered to be a late kinematic intrusion for the following reasons: (1) From the diagrams in Figure 4, it appears that the regional foliation has been tilted in the vicinity of the pluton. This would indicate that the foliation was in existence prior to the intrusion of the quartz monzonite. Since the foliation was produced by the regional deformation the intrusion of the pluton followed the major tectonic activity. (2) Foliation in the pluton is not pronounced. A well-developed foliation is common although not always present in syn-kinematic intrusions. (3) The shape of the pluton is not in complete harmony with the tectonic pattern of the sediments. This would not be expected if the intrusion occurred at the time of the regional deformation. The Nulhegan pluton would be considered a pluton of the mesozone according to the classification of Buddington (1959).

The topographic expression of the Nulhegan pluton is difficult to understand as one would expect the quartz monzonite to be more resistant to erosion than the metasediments. Lord (1935) (in Marleau, 1958) postulated that the Spider Lake pluton, a pluton of similar rock type which occupies a topographic low in southern Quebec and western Maine, appears to be a "barely unroofed stock." A similar explanation could be suggested in the case of the Nulhegan pluton, but the scarcity of outcrops precludes a detailed study of the fracture pattern of the pluton.

The Averill Granite

The Averill granite forms an irregularly shaped pluton covering approximately seventy-five square miles in the northwestern corner of

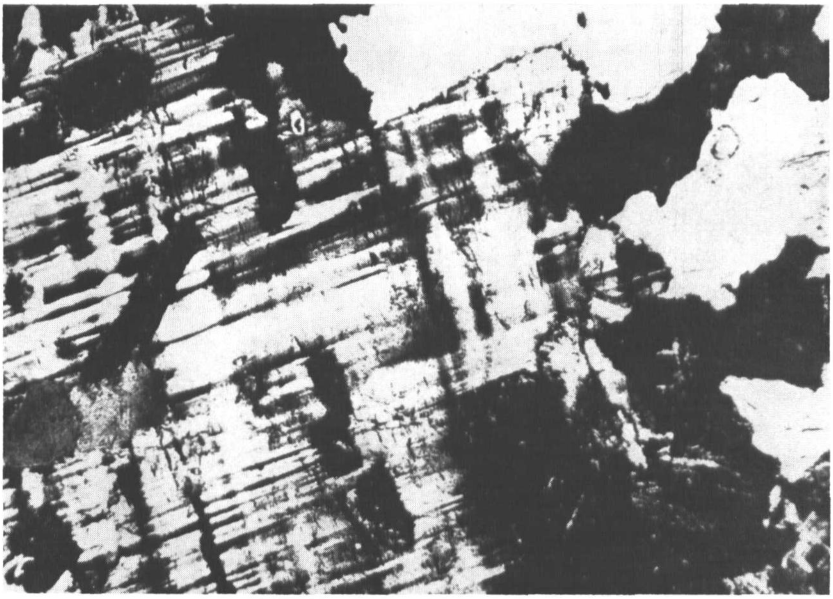


Plate 7. Photomicrograph of Averill granite showing polysynthetic twins of potash feldspar, biotite (dark) and quartz. Crossed Nicols (X25).

the Averill quadrangle, the northeastern corner of the Island Pond quadrangle, and a small area in Quebec (Figure 2). Approximately one-quarter of the outcrop area is in the Averill quadrangle (Plate 1). Schroeder (1929) proposed the name Averill granite for granite which crops out in the vicinity of Averill Lake. The surface expression of this pluton is irregular. Mountains such as Sable, Brousseau, Averill, and Black Mountain are all held up by the Averill granite. The Averill lakes and the headwaters of the East Branch of the Nulhegan River also are underlain by this rock type.

The Averill granite is a medium- to coarse-grained, grayish-white to pink granite. The rock is homogeneous and structureless.

Six thin sections of the Averill granite were studied. The rock contains potash feldspar (partly replaced by sericite), quartz, biotite (slightly chloritized), and plagioclase (oligoclase) (Plate 7). Accessory minerals are apatite, pyrite, muscovite, and zircon. Typical modes of the Averill granite can be seen in Table 3. The texture is hypidiomorphic granular and, in places, subporphyritic due to the presence of large potash feldspar grains.

Plate 8. Pegmatite cutting Averill granite on the top of Averill Mountain showing aplitic border. Large crystal next to hammer is potash feldspar.

Pegmatite dikes are common in the Averill granite. The dikes generally strike N 20°E and are parallel to one of the joint sets which transect the granite.

The mineralogical composition of the pegmatities is the same as that of the granite except that the pegmatites contain more muscovite. Graphic granite is a common constituent of the pegmatites and almandine garnet is found in both the pegmatites and aplites near the contact of the pluton and the country rock. Many of the pegmatites in the Averill granite have aplitic borders (Plate 8) and some have aplitic cores. At least two generations of pegmatites are present. In many places, one dike has been cut by another and, generally, there is an offset in the first dike.

Contacts between the Averill granite and the country rock are sharp. Megascopically the metasediments in contact with the pluton appear to be unaltered. However, in thin sections of the metasediments, needles of sillimanite are visible. The presence of these needles is interpreted as evidence of contact metamorphism.

Outcrops of Averill granite which are close to the contact contain more muscovite than the pluton as a whole and within an few tens of

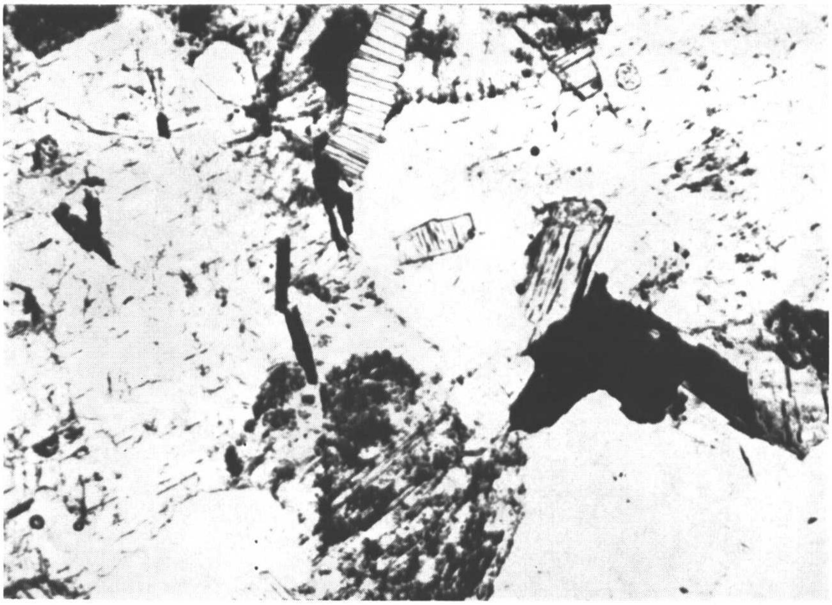


Plate 9. Photomicrograph of Averill granite near the contact of the pluton with the country rock showing large muscovite flakes in addition to the usual mineralogy of the granite. Nicols not crossed (X25).

feet of the contact the rock is essentially a binary granite (Plate 9). Since the concentration of muscovite appears to be confined to an area near the contact, it is believed that the increase is a result of the incorporation of aluminous material from the metasediment.

Along the eastern border of the pluton, the contact of the pluton is generally parallel to the strike of the bedding in the metasediments. Since the bedding planes do not appear to have been disturbed by the emplacement of the pluton, it is thought that emplacement of the eastern portion of the pluton was along previously tilted bedding planes. Many sills of granite, ranging from a few inches up to 100 feet in thickness, intrude the metasediments eaxt of the contact of the pluton and the metasediments (Plate 10). In all cases the contacts between the sills and dikes of Averill granite and the metasediments are sharp. On the southern border of the pluton, the contact is discordant. The easternmost portion of this contact, although never observed, may be a fault contact (Figure 11). A fault contact also occurs on the east side of the small block of metasediments to the east of Averill Mountain. The contact

Plate 10. Sill of Averill granite cutting the Gile Mountain Formation. Bedding is nearly horizontal. Outcrop is on the western flank of Averill Mountain within two hundred feet of the contact. Photograph is taken looking eastward toward the contact.

on the western side of the block was never observed. Thus the discordancy of the pluton is partly a function of original mode of emplacement and partly a function of later faulting. It is possible that the faulting represents a late phase of the intrusive mechanism. Slickensides were observed on joint surfaces at a number of localities in the vicinity of the Averill lakes. The slickensided joint surfaces are generally oriented north-south, although slickensides were observed on joint planes with other attitudes. The grooves plunge north at a gentle angle and indicate a relative movement of the eastern block north. It is not known whether these slickensides are associated with faulting or whether they were produced by late movements related to the intrusion of the pluton.

Inclusions of metasediments are not common in the Averill granite. Those that were seen had sharp contacts with the granite (Figure 7) and, megascopically, showed no characteristics which differed from those of the metasediments outside of the pluton. No preferred dimensional orientation of the inclusions was observed.

The complete lack of foliation, the discordancy of the pluton in general,

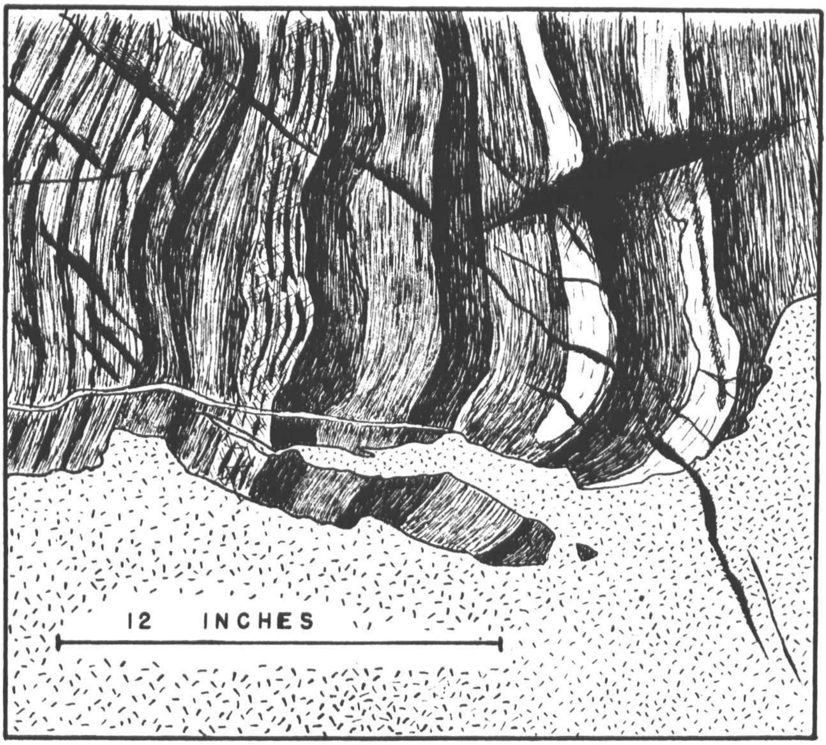


Figure 7. Inclusion of Gile Mountain Formation in the Averill Granite illustrating Sharp Contact Relationships. (Sketch Made from Photograph)

and the apparent deformation of the metasediments prior to the intrusion of the pluton indicate that the Averill granite forms a post-tectonic pluton. From the similarity between the Averill granite and the Conway granite, as described by Billings (1956), it is concluded that the Averill granite is related to the White Mountain Magma series to which Billings has assigned a late Paleozoic, Mississippian (?) age. No absolute age determinations have been run on any of the rocks of the Averill quadrangle.

Other granites which are similar to the Averill granite include the Newark granite in the Burke quadrangle (Doll, personal communication) and the Stanstead and Hereford granite of Quebec (Cooke, 1950, 1957).

The Monadnock Pluton

Monadnock Mountain, which is held up by a quartz syenite pluton,

TABLE 4

ESTIMATED MODES OF THE ROCKS OF THE MONADNOCK PLUTON

Sample No.	1	2	3	4	5	6	7
Microperthite	71.4	80.5	76.3	54.0	47.4	48.2	
Potash Feldspar	1.3	5.6	4.3	14.0	14.9	6.6	0.5
Plagioclase	1.0	0.2	6.4	10.9	15.3	11.1	38.4
Quartz	20.9	11.4	6.4	9.7	17.1	10.0	0.4
Biotite	3.6		4.5	2.1	2.2	9.0	22.2
Hornblende	0.4	tr	1.7	6.0	1.2	11.4	27.5
Pyroxene		tr		tr		3.2	2.3
Sphene		0.3		0.1	0.7	0.7	1.3
Magnetite	1.4	1.5	0.3	1.8	0.6	2.3	4.4
Apatite	tr	tr	tr	tr	tr	0.4	1.6
Zircon		tr	tr	tr	tr	tr	
Epidote		tr	tr			tr	
Chlorite	tr		tr	tr	tr	tr	0.7

tr—Presence in trace amounts.

1. Granite—Plagioclase is oligoclase.
2. Quartz Syenite—Plagioclase is oligoclase.
3. Quartz Syenite—Plagioclase is oligoclase.
4. Quartz Syenite—Plagioclase is oligoclase.
5. Quartz Syenite—Plagioclase is oligoclase.
6. Porphyritic Quartz Syenite—Plagioclase is oligoclase-andesine.
7. Essexite—Plagioclase is andesine.

All estimated modes done by the point count method as described by Chayes (1949). Mineral percentages express volume per cent.

crops out in the east-central portion of the quadrangle directly across the Connecticut River from Colebrook, New Hampshire. Its outcrop area covers roughly eighteen square miles. The Monadnock pluton forms the highest mountain in the quadrangle (Plate 11). Outcrops are abundant but the contacts of the pluton and the country rock are poorly exposed due to the presence of talus and glacial debris.

Previous work on the pluton has been done by Wolff (1929) and Chapman (1954). Wolff discussed the mineralogy in considerable detail and Chapman redefined Wolff's contacts between the different rock types and proposed a slightly different mode of emplacement for the pluton.

The principal rock type in the pluton is a greenish-gray to pink quartz syenite close to granite in composition. Table 4 contains modes of the various rock types in this pluton. The chief minerals are microperthite, biotite, hornblende (ferrohastingsite) and quartz. Accessory minerals

Plate 11. Monadnock Mountain. Photograph taken looking southeastward from Todd Hill.

are apatite, sphene, zircon, magnetite, and allanite. The texture is hypidiomorphic-granular, with interstitial grains of quartz surrounded by subhedral to euhedral grains of the other essential minerals of the rock. Grains of microperthite are large in comparison to the other minerals in the rock and commonly show a braided perthite pattern although patch perthites can also be seen (Plate 12). Boundaries between individual microperthite grains are commonly sutured due to the interpenetration of the two crystals by the plagioclase lamellae. This phenomenon is well described in Emmons (1953).

At several localities on the stock, the rock is granitic in composition (Plate 1). Chapman (1954) mapped these granite patches and considered them to be later intrusions into the quartz syenite stock. However, field relationships do not support this interpretation. The granite has the same structure and texture as the quartz syenite and differs from this rock type only in that it is slightly richer in quartz. No definite contact between the quartz syenite and the granite was observed by this writer, although at two localities, it is possible to pass from one rock type into the other through almost continuous outcrop. It appears that the granite belongs to the same intrusion in time and space as the quartz syenite and that the granite represents local enrichment in silica.

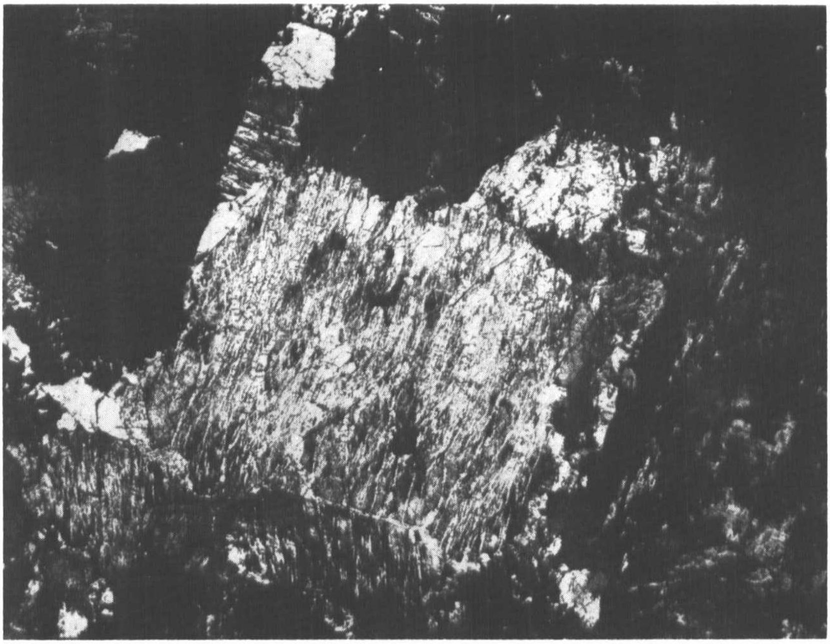


Plate 12. Crystals of microperthite in the quartz syenite of the Monadnock pluton showing braided perthite texture. Crossed nicols (X25).

Several granitic dikes cut the country rock in the vicinity of the pluton. The rock in these dikes is light-gray, fine-grained granite, richer in quartz and contains lesser quantities of mafic minerals than the granite of the pluton. These granitic dikes were not observed anywhere in the pluton.

Wolff (1929) presents chemical analyses of both the quartz syenite and essexite gabbro, another rock type in the pluton which is mentioned below. These analyses are given in Table 5. The silica content of the quartz syenite is within one per cent of the silica content of an average granite, but the sodium-potassium ratio is higher than that of the normal granite.

A small body of a gray porphyritic syenite is exposed in a stream bed on the southeastern corner of the mountain. This rock type was found only at this locality and attempts to trace it out of the stream bed were unsuccessful. The gray syenite consists of an equigranular to seriate groundmass of feldspar and quartz with phenocrysts of microperthite, biotite, and hornblende. Accessory minerals are sphene, magnetite,

Table 5

CHEMICAL ANALYSES OF THE QUARTZ SYENITE AND ESSEXITE OF THE MONADNOCK PLUTON*

	QUARTZ SYENITE	ESSEXITE
SiO_2	69.43	46.09
Al_2O_3	15.67	17.29
Fe_2O_3	0.36	1.63
FeO	2.50	7.26
MgO	0.12	8.04
CaO	1.13	7.89
Na_2O	5.11	3.68
K_2O	4.97	1.92
TiO_2	0.18	4.49
ZrO_2	0.06	n.d.
P_2O_5	0.06	0.90
S	0.07	0.10
MnO	0.06	0.16
BaO	abs.	0.09
SrO	n.d.	tr
H_2O+	0.42	0.77
H_2O-	0.01	0.12
	100.11	100.43

*From Wolff (1929)

apatite, pyroxene, pyrite, and allanite. The rock is older than the quartz syenite as dikes of quartz syenite are abundant in the gray porphyritic syenite and inclusions of the gray porphyritic syenite are common in the quartz syenite in the vicinity of the contact between the two rock types. Small, dark, rounded inclusions ranging from one inch to two feet in length occur in the gray porphyritic syenite. The inclusions are gabbroic in composition and highly altered. No correlation between these inclusions and the essexite gabbro could be drawn on the basis of mineralogy. The inclusions are more mafic than the essexite and contain a larger percentage of opaques. Since the gray porphyritic syenite is not in contact with the essexite, the relative ages of these two rock types could not be established.

An elongate body of essexite gabbro occurs on the eastern slope of the mountain. This body varies from 150 to 500 feet in outcrop width and extends for about a mile in a north-south direction. Contacts of the essexite with the quartz syenite are rarely exposed. The best contact

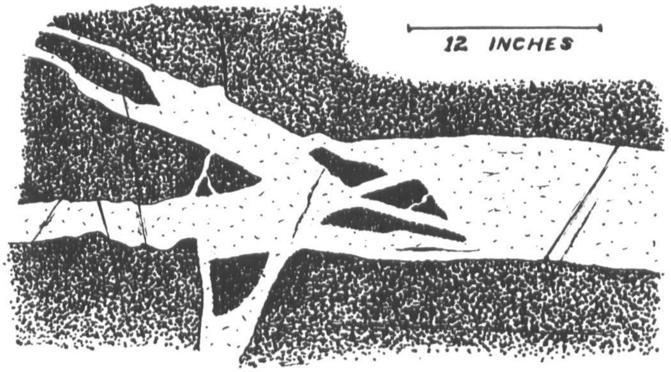


Figure 8. Dikes of Quartz Syenite (light) cutting Essexite (dark) indicating relative age of the two rock types.

is located in the bed of the stream which parallels the trail to the fire tower on the east side of the mountain. At this locality, the essexite is cut by a number of quartz syenite dikes (Figure 8).

The contact intersects the irregular surface of the outcrop in an essentially straight line, thus, the contact must be vertical. Although the contact was not seen elsewhere, the essexite can be traced in an almost continuous zone of outcrops throughout its length. The essexite is composed of hornblende, plagioclase (andesine), biotite, and pyroxene. The pyroxene is a light pink nonpleochroic variety with dark reaction rims of hornblende surrounding each grain. According to Chapman (1954), the composition of the pyroxene is within the diopside hedenbergite field. Accessory minerals include magnetite, sphene, apatite, quartz, and zircon. The amphiboles and biotite are partially altered to chlorite and the feldspars are partially altered to sericite. The grains of opaque minerals are commonly enclosed in a small rim of sphene. This suggests that the opaques are composed of titaniferous magnetite. The rock as a whole is xenomorphic-granular and there is a pronounced tendency for small grains of apatite and magnetite to be poikilitically enclosed in hornblende and biotite.

To the west of the essexite mass on the eastern slope of Monadnock Mountain, the quartz syenite contains an unusually high amount of mafic constituents. The rock appears to be intermediate in mineral composition between the essexite and the quartz syenite. The outcrop area of this rock type is not well defined and it has been mapped as a zone in which it occurs intermixed with pure quartz syenite. Contacts between the intermediate rock and the essexite and the intermediate rock and the quartz syenite are gradational. The intermediate character of the rock on the west side of the essexite suggests that the rock is a transition rock in which the quartz syenite has been contaminated by mafic constituents from the essexite mass. Chapman (1954) proposed that the transition rock is a hybrid between essexite and quartz syenite and listed several reasons to support this view. The fact that the transition rock occurs as irregular patches in a zone in the quartz syenite suggests that conditions of the intrusion were such that the system did not attain equilibrium.

Many problems are introduced by the presence of the transition rock and the essexite mass in this pluton. If this rock is actually a transition rock, why does it occur only on one side of the essexite? How did the essexite arrive at its present position in the pluton if the overlying sediments, less dense than the essexite, have subsided into the underlying magma chamber as assumed by Chapman (1954)? Why should the dikes and sills which cut the essexite be pure quartz syenite when a supposed transition rock has developed on the outside of the mass? Chapman (1954) believes that the essexite mass is a screen which has been torn from the wall of the country rock by the intruding quartz syenite magma in a typical cauldron subsidence type of emplacement. He points out, however, that there is no evidence that two generations of quartz syenite exist on opposite sides of the essexite mass as would be expected in this type of emplacement.

Inclusions of varying rock types are common in the pluton. Small rounded inclusions, ranging in composition from gabbro to quartz diorite, are common throughout the pluton. Subangular blocks of gabbro found in the bed of Willard Stream, could not be distinguished from the essexite megascopically. Fine-grained dioritic inclusions, ranging from six inches to approximately ten feet in length, are scattered through the quartz syenite in the northern part of the stock. Still other mafic inclusions, generally well-rounded, occur throughout the mass. These contain rounded clots of feldspar and quartz in a fine-grained dioritic groundmass. It is thought that these inclusions are highly altered xenoliths. Large blocks of apparently unaltered metasediments were observed at several localities in the quartz syenite (Plate 1) and also within the pluton near the contact of its western edge. These blocks have all of the sedimentary characteristics of the phyllitic schist of the Gile Mountain rounded clots of feldspar and quartz in a fine-grained dioritic ground-regional trend of the foliation in the quadrangle, but it could not be determined whether these large inclusions are roof pendants or whether they have been moved.

A cauldron subsidence mechanism has been proposed by Chapman (1954) for the emplacement of the Monadnock pluton. However, other interpretations are also possible. Several factors make the cauldron subsidence mechanism questionable. The incomplete ring of granite referred to by Chapman (1954) as a later intrusion is probably a differentiate of the quartz syenite magma. The reasons for this interpretation have been discussed previously.

The cauldron subsidence hypothesis is partly based on the supposedly elliptical outline of the pluton. However, it should be pointed out that the hills to the southeast of Monadnock Mountain, across the Connecticut River, are composed of the same quartz syenite. These may be part of the Monadnock pluton, and if so, the outline of the entire pluton, would not be elliptical. Chapman recognized this possibility but preferred to draw the contact on the western side of the Connecticut River. There appears to be no conclusive evidence to support either of these alternatives as the valley of the Connecticut River at this locality is filled with alluvium and completely devoid of outcrops. For this reason, the writer refrains from drawing any contact at all here.

Field relations suggest that the outline of the pluton may have been controlled considerably more by faulting than has been proposed (Figure 11). In any case, movement along the fault on the eastern side of the pluton indicates that the western block moved up, the opposite direction from a cauldron subsidence type of movement. The so-called screen of essexite does not appear to lie between two discrete intrusions.

The contact, where observed on the western side of the pluton, dips away from the pluton at a moderate angle. On the eastern side, the contact appears to be considerably steeper as it forms a relatively straight line across the Willard Stream valley.

Joints in the pluton are both radial and tangential (Figure 9).

Foliation is weakly developed locally but as a whole the rock of the pluton is structureless. Since there appears to be little evidence to support the cauldron subsidence mechanism for the emplacement of the Monadnock pluton, it is concluded that the mass was emplaced by the positive injection of magma, probably accompanied by considerable

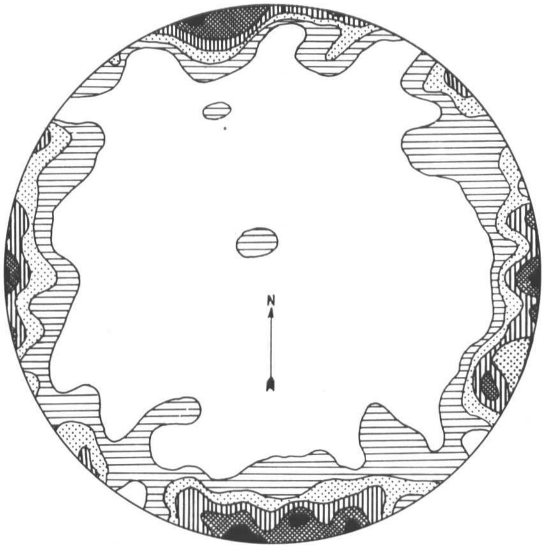


Figure 9. Contour diagram of joints of the Monadnock pluton showing girdle around vertical axis. 250 points counted. 1–2–3–4–5%.

stoping as evidenced by the large number of metasedimentary inclusions scattered throughout the pluton.

Dikes and Sills

The entire quadrangle is cut by numerous dikes and sills predominantly mafic in character. Aplite, granite, and rhyolite dikes were also observed.

The mafic dikes are lamprophyres and are so variable in mineralogy that it is impossible to trace an individual dike from one outcrop to another. These dikes generally range in composition from kersantite to camptonite, depending on the mafic constituents. Some dikes contain hornblende phenocrysts up to an inch in diameter and several inches in length. Plagioclase (oligoclase) and biotite also form large phenocrysts in many of the rocks. Angular inclusions of pink quartz syenite were found in abundance at two localities, one approximately six miles due north of the Monadnock intrusion, and the other, three miles south of the intrusion. No inclusions of quartz syenite were found in the dikes which cut the pluton. The mafic dikes occupy fractures which are parallel to joints. At no locality are the dikes deformed. Thus, they are interpreted to be very late intrusions. No relation to the Monadnock intrusion could be established. Calcite amygdules up to an inch in diam-

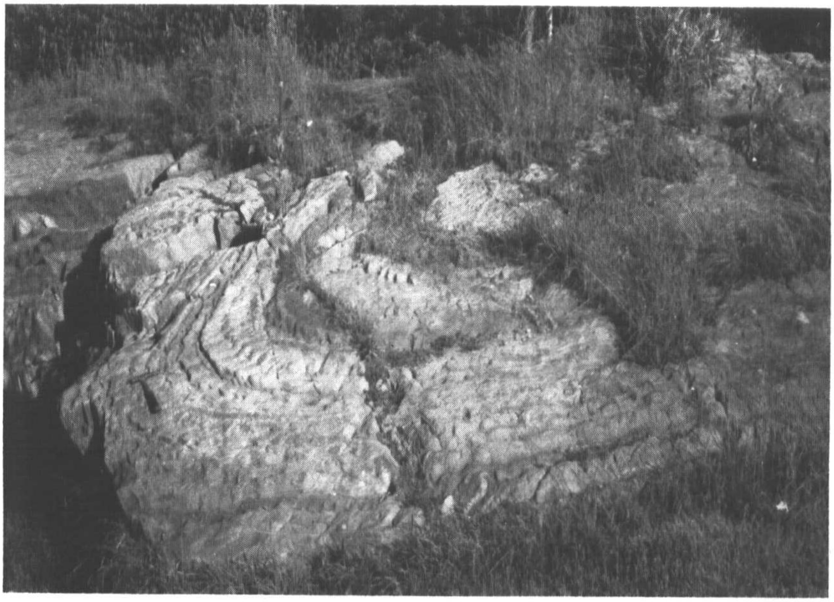


Plate 13. Second generation minor fold in light and dark gray phyllites plunging S 10°W at approximately 55°. Located on east side of Route 3, 500 feet north of the intersection with Vt. Route 105 in North Stratford, N.H.

eter in several of the lamprophyres indicate that the rock pressures must have been low or the vapor pressure high at the time of the intrusion of these dikes. Field relationships preclude the possibility that these "amygdaloidal dikes" can be flows.

Aplites and granitic dikes are restricted to the immediate vicinity of the plutons. Rhyolitic dikes are from a late stage of the Monadnock intrusion.

STRUCTURE

General Statement

The major structural features of the Averill quadrangle include a large overturned syncline, the axis of which follows a sinuous, roughly north-south course through the center of the quadrangle, and the three large plutons previously described. Minor structural features include smaller folds, faults, schistosity and slaty cleavage, slip cleavage, joints, intersection of bedding and cleavage, intersection of schistosity and slip cleavage, boudinage, and mineral streaks.

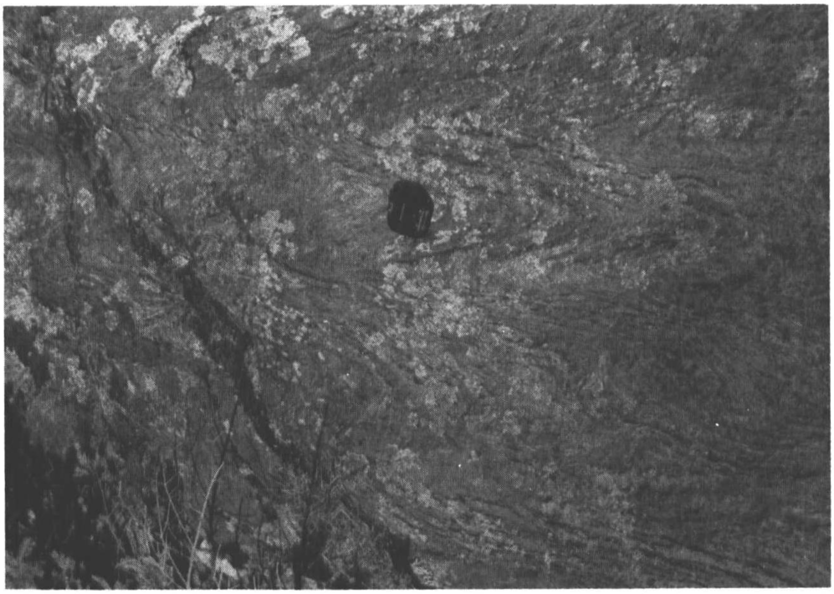


Plate 14. Second generation minor fold in phyllitic schist on Todd Hill. Folds plunge N 20°E at approximately 15°.

It seems clear that two stages of deformation can be recognized throughout the northern Appalachians of the Connecticut Valley-Gaspe synclinorium. When it was believed that the metasediments of this area were Ordovician, the two generations of folding commonly were assigned to the Taconic and Acadian orogenies respectively. However, since it now appears that the metasediments are Siluro-Devonian in age, the two generations of folding must be interpreted as evidence of a change in component during a single orogeny (Acadian). The older structures apparently were formed during a stage of horizontal compression and folding. A period of general doming associated with extensive igneous intrusion gave rise to the structures of the second generation.

Minor Structures

Minor Folds

Wave lengths of the folds herein described range from less than a tenth of an inch to several tens of feet (Plates 6, 13, and 14). Such folds are common in the metasedimentary rocks of the Averill quadrangle.

As in other parts of eastern Vermont (White and Jahns, 1950; Dennis, 1956; Ern, 1963; Hall, 1959; and others) two generations of folds are present. The two generations are believed to be related to the same period of orogenic activity but were produced at different stages of the orogeny.

The older folds were produced by ordinary compressive (horizontal) movements which set up a shear couple along the bedding planes causing minor folds to be "dragged" up so that their axial planes are parallel to the axial plane of the major fold upon which they are superimposed. The older folds commonly exhibit a bedding plane schistosity indicating that most of the older folds probably are isoclinal.

The early schistosity is folded indicating a second stage of deformation. The younger folds are more open than the older folds and they plunge more steeply. Associated with the younger folds is an axial plane slip cleavage (described more fully later) which transects the older schistosity (Figure 10). It is believed that these folds are related to the doming of the metasediments caused by the emplacement of plutons in the area. As indicated in the previous section the plutons are late kinematic intrusions which followed the major folding in the area. This second stage doming has been discussed by many writers in eastern Vermont (e.g. Dennis, 1956; Bean, 1953; Lyons, 1955; and others). Second stage structural features appear to be more pronounced in the vicinity of the Willoughby arch and other dome-like features. The second stage folds, depending on their position to the axial planes of the older folds, exhibit both normal drag folds and reverse drag folds. The reverse drag folds are common along the flanks of the Averill granite and the Nulhegan quartz monzonite.

Planar Elements

Bedding: Bedding can be recognized in most of the metasedimentary rocks in the quadrangle and, in many cases, it appears to have been accentuated rather than obscured by the metamorphism. In general, it is difficult to recognize bedding only in the more pelitic rock types. Commonly the metasediments are weathered more deeply along bedding planes in which case small depressions define the bedding. Iron oxide stains coat bedding planes in a few localities.

The various kinds of bedding present in the Gile Mountain Formation have been described in the section on *Stratigraphy*.

Schistosity and slaty cleavage: Schistosity refers to the ability of schists to split or cleave into thin layers or flakes. It is a secondary

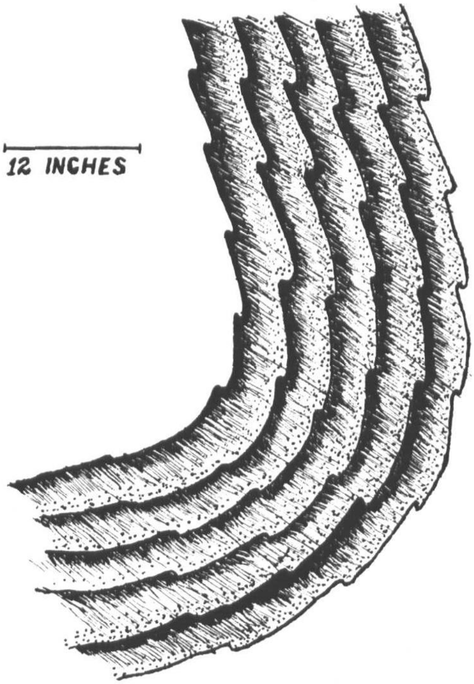


Figure 10. Sketch showing the relationship between cleavage, graded bedding, and minor folds in the graywacke sequence. The cleavage and folds are second generation structural features.

structure produced by the pronounced parallelism of platy mineral grains, generally micas, in the schists. A similar foliation which occurs in slates of other rocks insufficiently recrystallized to form schist is called slaty cleavage (Billings, 1954, p. 336). Schistosity is well developed in the phyllitic schists throughout the Averill quadrangle. As would be expected, the phyllites and slates generally are characterized by slaty cleavage. However, in the vicinity of the Nulhegan pluton, the phyllites and slates are coarser grained due to a greater degree of recrystallization. In such cases, the slaty cleavage of these rocks borders on schistosity as defined above. The foliation of the hornblende schist is rather poorly defined because of the needle-like nature of hornblende, the main constituent. Some of the quartzites in the area exhibit a schistose appearance to a minor degree.

Two generations of schistosity are recognized in the area. The first generation, presumed to be an axial plane cleavage of the older folds, is well developed parallel to bedding planes in the southern portion of the quadrangle. The second generation is difficult to distinguish from the older variety. It is the result of the extreme development of slip cleavage. White (1949) established the genetic relationships between slip cleavage and secondary schistosity in eastern Vermont by pointing out the gradation between the two in the vicinity of the Woodsville area. Although fairly common in the region as a whole, second generation schistosity is rare in the Averill quadrangle, probably because the deformation has not been sufficiently intense in this area. Secondary schistosity may be suspected, although not definitely identified, where there is a complete absence of microfolds or crinkles in the foliation planes.

Slip cleavage: Slip cleavage or shear cleavage as defined by Mead (1940) has developed in this area through the deformation of previously existing foliation planes. White (1949) studied the development of slip cleavage in east-central Vermont. The initial step in the development of slip cleavage is the production of small micro folds on earlier formed schistosity. As the micro folds increase in amplitude, the micaceous minerals become oriented along the limbs of the folds. With continued deformation, all of the micaceous minerals become oriented in the new direction and a second generation schistosity is developed. In this area, the slip cleavage is parallel to the axial planes of the second generation minor folds, and like the minor folds is considered to be related to the doming of the metasediments, a late phase of the Acadian orogeny.

Joints: Two pronounced joint sets, one striking approximately northeast, the other approximately northwest, predominate over joint sets of other orientations in the metasediments. Possibly these joints are conjugate shear joints since the orientation of each set is at an angle of roughly 45° to the regional trend of the fold axes. The mafic dikes of the area generally are oriented parallel to some recognizable joint set, but no single joint set seems to be favored. Most of the pegmatites and aplites in the Averill granite are oriented parallel to a joint set which follows a N 20°E trend.

Faults: Only two faults were found in the area although it is suspected that many more are present. One of these occurs on the western flank of Averill Mountain. At this locality, a down-dropped block of metasediments has been preserved within the pluton. Slickensides are common along the fault plane in the Averill granite and a small gouge zone was observed at one locality. The second fault cuts the eastern flank of

Monadnock Mountain and separates the quartz syenite of this pluton from the surrounding metasediments. A deep steepsided ravine follows this fault.

Many small gouge zones were found on Monadnock Mountain, the two most prominent occurring at the entrance to Norton's Mine, which is on the eastern slope of the mountain at an elevation of 1500 feet. A trail which ends at this locality branches southward from the trail to the fire tower. Here the fault zones are approximately eight feet thick and contain a core of highly shattered and leached quartz syenite. Sulfide minerals (pyrite, and to a lesser degree sphalerite and galena) are common in the shattered and leached zone. Each of the fault zones is bounded on both sides by thick (10–18 inches) bands of intensely leached light red-brown to buff sandy fault gouge. Hydrous iron oxide is the only cement observed in the gouge zone in surface outcrops. Due to the ease with which the fault zones are weathered, it is impossible to trace them for more than one hundred feet in either direction.

Linear patterns on aerial photographs, abrupt changes in topography, and displacement of outcrop and topographic patterns suggest the presence of faults which were not found during the field studies. Since no concrete evidence could be obtained to support the existence of these hypothetical "faults," they are not shown on the structure map of the area. The linear patterns have been compiled in Figure 11.

Linear Elements

Fold axes of minor folds: It is possible in many cases to observe and measure the axes of minor folds. Most of these axes are parallel to the axes of major folds in the area. In the northern half of the quadrangle, fold axes of minor folds are consistently oriented N 15–20°E and plunge 10° and 30° (average about 20°) northeast. In the central portions of the quadrangle, the axes of the minor folds are oriented more nearly north-south and shallow plunges in both directions are noted. In the southern portions of the quadrangle, the fold axes maintain a south-east to south strike and plunge steeply (45°–65°) to the south. Except in the vicinity of plutons where the regional structure has been modified, the minor folds fairly consistently follow the pattern of the regional folds.

Boudinage: Boudinage, although not common in this area, was observed in the southern portions of the quadrangle. In all cases, the boudins were composed either of milky quartz, or lime silicate rock. Generally, the long directions of individual boudins are oriented perpendicular to the fold axes, but in a few cases the long directions of the

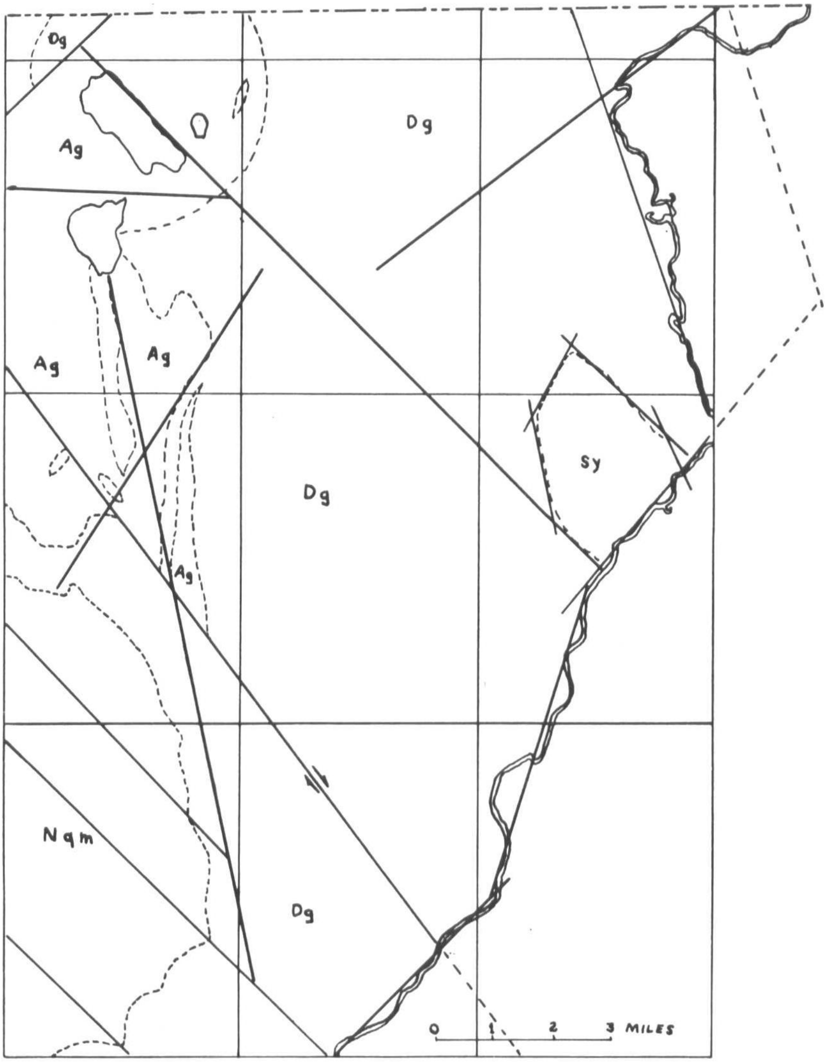


Figure 11. Linear patterns in the Averill quadrangle which possibly are controlled by faulting. Formation symbols as shown on Geologic Map (Plate 1).

boudins are parallel to the fold axes. It is not known whether two generations of boudinage are present.

Intersections of planar elements: Bedding and cleavage intersections in almost all cases are parallel to both the minor and major fold axes in the area. The intersections of an older foliation and slip cleavage also are common in the Averill quadrangle. Generally, this type of intersection is represented by a crinkle lineation of the older foliation surface. The strike of the crinkle lineation generally is parallel to the strike of the fold axes. In many cases, the plunge of this lineation is steeper than that of the axes of the earlier folds.

Mineral streaks: This type of lineation is not common in the rocks of the Averill quadrangle. The Halls Stream grits contain large feldspars which generally are elongated parallel to the strike of the fold axes. The preferred orientation of hornblende needles in the hornblende schist also gives rise to a lineation parallel to fold axes. This lineation is particularly well developed in the finer grained varieties of the schist.

Major Folds

The Averill quadrangle is bisected by the axis of an overturned syncline (hereafter referred to as the Averill syncline) which forms the major structural feature of the area (Plate 1). In the northern portion of the quadrangle, the axis of the syncline plunges approximately 20° northeast. The plunge of the fold gradually becomes less steep to the south until in the central portion of the area, the fold axis is horizontal. Continuing south, the plunge of the fold axis reverses and gradually steepens. At the southern edge of the quadrangle, the plunges are approximately 50° south. Thus the syncline is doubly plunging. This attitude explains a similar change in the plunges of the axes of the minor folds. The beds of the Averill syncline dip gently to the west on the eastern limb, become progressively steeper westward until they swing through the vertical and become overturned to the east. The western limb of the fold has steeply dipping beds close to the axis and the beds become more gently dipping westward. With the exception of the Brownington syncline (Doll, 1951) most folds in this region are overturned to the northwest.

The axis of the Averill syncline is markedly sinuous in plan view (Plate 1). A striking correlation can be noted between the configuration of the axis of the folds and the location of the plutons in the area. As was previously shown, the Nulhegan pluton has had an effect on the attitude of foliation in the vicinity of the eastern side of the pluton

(Figure 4). Since the foliation has been tilted, it is conceivable that the whole block bordering the eastern edge of the pluton was deformed during the emplacement of the pluton. This would change the attitude of the previously formed syncline as well. The other two plutons in the area do not appear to have had a pronounced effect on the sediments in their immediate vicinity but from the configuration of the axis of the syncline it may be suspected that they too had an effect on the regional structure probably by doming the sediments.

Regional Structural Relations

Due to the structural complexity of the Connecticut Valley-Gaspe synclinorium and the questionable stratigraphic succession of the Vermont sequence, structural relationships in this area are not all certain. Four possible interpretations of the structural and stratigraphic relationships in eastern Vermont have been reviewed by White (1959) and still another view has been proposed by Ern (1963) and Goodwin (1963). These various interpretations, illustrated by the schematic cross-sections in Figure 12 are as follows:

A. The "Vermont sequence" consists of two formations (Waits River and Gile Mountain) which are repeated by structural folding (Eric and Dennis, 1958).

B. The "Vermont sequence" consists of three formations (Barton River, Gile Mountain = Westmore, Waits River) in a synclinal structure which has been domed into a cleavage arch in the center (Murthy, 1957).

C. The "Vermont sequence" consists of two formations (Waits River and Gile Mountain) which are repeated by a reverse fault (White and Jahns, 1950).

D. The "Vermont sequence" consists of four formations in a homoclinal sequence (Barton River, Gile Mountain, Waits River, Westmore) (mentioned in White, 1959). (This appears unlikely since, according to Goodwin (1963), the Gile Mountain Formation and the Westmore Formation are equivalent.)

E. The "Vermont sequence" consists of two formations (Gile Mountain and Waits River) repeated in a large recumbent anticline or nappe (Goodwin, 1963; Ern, 1963).

None of the above interpretations appears to offer a panacea to all of the stratigraphic and structural problems in the area.

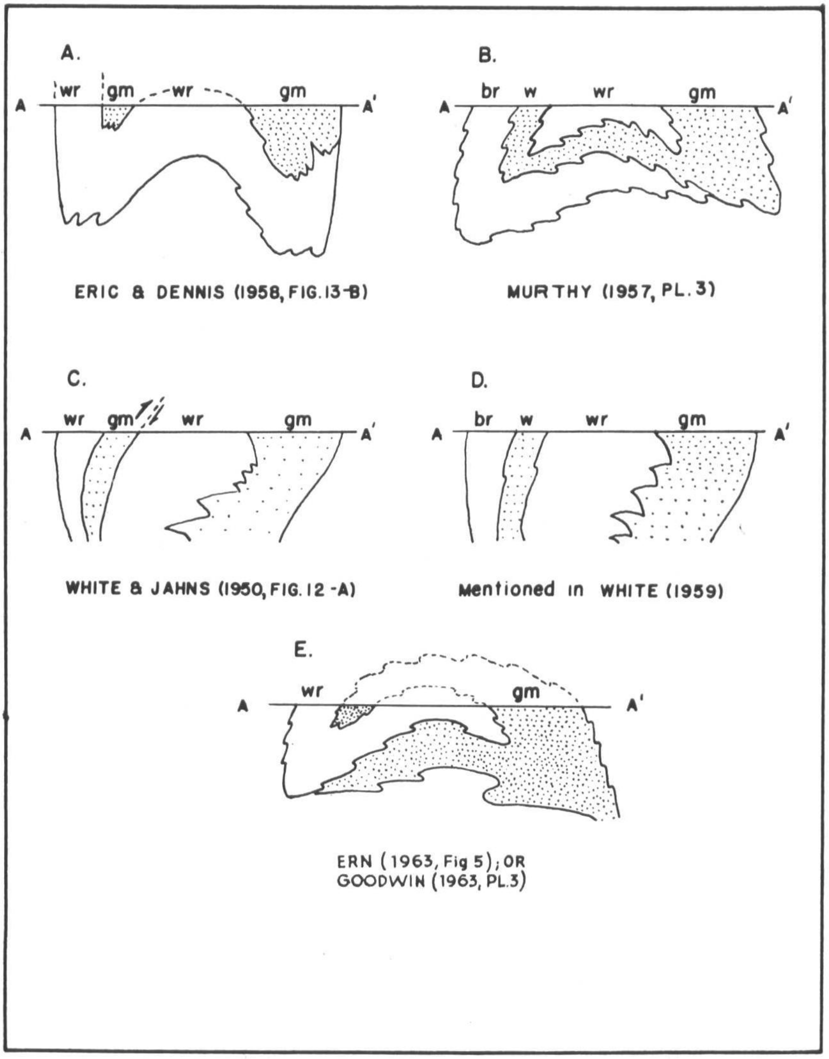


Figure 12. Various interpretations of structure and stratigraphy in eastern Vermont. (*Location of section A-A′ shown in Figure 2.*)

Structural features of the Averill quadrangle fit any of the above interpretations as only the Gile Mountain Formation is involved in this area and any structures within the formation can be considered as minor folds which are related to the major structural pattern of the region.

METAMORPHISM

Four metamorphic zones are recognized in the quadrangle (Figure 13). These zones cannot be precisely delineated, partly because of poor outcrops and partly because of variations in bulk chemical composition of the metasediments.

Rocks of the Averill quadrangle represent metamorphic grades from the chlorite zone of the greenschist facies to the sillimanite zone of the almandine, amphibolite facies. The classification of metamorphic facies used in this report is that presented by Fyfe, Turner, and Verhoogen (1958). Igneous intrusion in the area has complicated the metamorphic pattern by superimposing the effects of thermal metamorphism on the regional metamorphism. Consequently, isograds parallel the structural pattern in some places and transect the structure in others.

Chlorite Zone

Chlorite is nearly universally present in the metasediments of the quadrangle regardless of metamorphic grade. Apparently its presence at some localities is a result of regional metamorphism and at others a result of "retrograde" metamorphism. In this report the chlorite zone of the greenschist facies is considered to occur only in the extreme northeastern portion of the quadrangle. The lack of other metamorphic minerals rather than the presence of chlorite appears to be most characteristic of this zone.

Chayes (1955) discussed the reaction by which biotite and quartz are transferred to potash feldspar and chlorite in granites. The process which Chayes believed caused this reaction was one in which dilute hydrothermal solutions penetrated the rocks along minute shear fractures and other openings and reacted with those biotite grains which were in their path. The biotite grains so affected are altered to chlorite and potash feldspar. Biotite grains not in the pathways of the solutions remain unscathed. The replacement of biotite by chlorite is common in the Averill area, although potash feldspar is present in the rocks only in trace quantities. The fine-grained nature of the matrix of the schists and phyllites, however, would make it easy to overlook small grains of

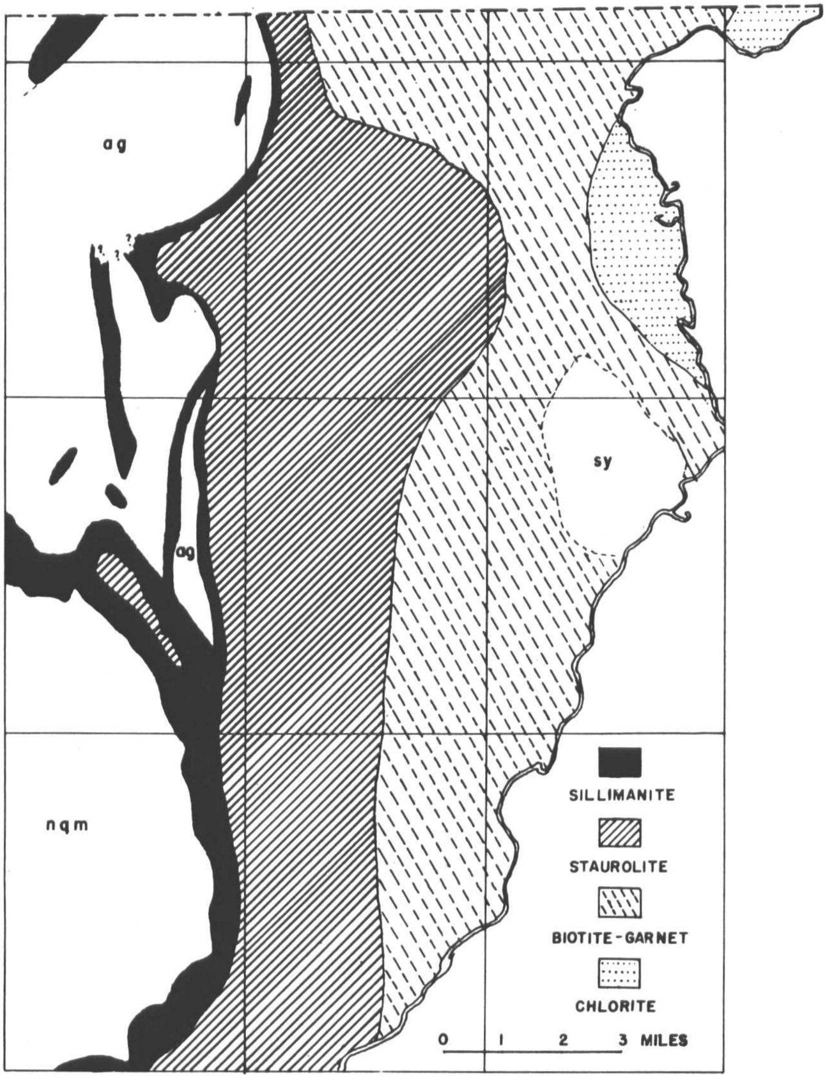


Figure 13. Map showing approximate metamorphic zones in the Averill quadrangle. Formation symbols as shown on Geologic Map (Plate 1).

orthoclase produced by the above reaction. It is herein suggested that a mechanism such as that proposed by Chayes is responsible for the presence of chlorite in the metamorphic rocks of the area which occur in zones of higher metamorphic grade than the normal chlorite zone of regional metamorphism. This would be a process of retrograde metamorphism.

Chlorite produced by regional metamorphism is distinguished from that formed by the replacement of biotite by the fact that it is not closely associated with biotite. It is on this basis that the chlorite zone of this report was mapped.

Chlorite is also present as the alteration product of hornblende in the hornblende schists, amphibolites, and igneous rocks.

Biotite-Garnet Zone

The biotite and garnet zones, which also are characteristic of the greenschist facies, are indistinguishable in this area and so are placed together into one metamorphic zone, the biotite-garnet zone. This zone covers most of the eastern portion of the quadrangle. Large porphyroblasts of biotite occur in the light gray phyllitic rocks and almandine garnet is scattered throughout the zone. No distinct garnetiferous and nongarnetiferous zones could be drawn. However, the more pelitic beds are richer in garnet than the phyllites. The incidence of garnet increases to the west as does the metamorphic grade.

Staurolite Zone

The staurolite zone is characterized by the presence of staurolite and a mineral assemblage which otherwise is the same as that of the biotite-garnet zone. The staurolite zone is representative of the staurolite-quartz subfacies of the almandine, amphibolite facies. In general, the staurolite occurs as large euhedral crystals, many of which are the characteristic cruciform penetration twins. The random arrangement of the staurolite crystals indicates that they were probably post deformational.

Sillimanite Zone

In the immediate vicinity of the Averill and Nulhegan plutons, sillimanite is a common constituent of the metasedimentary rocks. The mineral assemblage of quartz-sillimanite-almandine places this rock in the sillimanite-almandine subfacies of the almandine, amphibolite facies. Sillimanite needles replace muscovite and biotite at almost any locality close to the contact of the two plutons. No sillimanite was observed in megascopic examinations.

Crystals of andalusite were observed at two localities close to the contact of the Nulhegan quartz monzonite and at a small outcrop in the north-central portion of the quadrangle far from any pluton. These areas are too small to be included in the metamorphic map.

Time of Metamorphism

Porphyroblasts of staurolite and less commonly biotite exhibit an orientation which does not appear to be related to structural features in the area. This is interpreted to indicate that, at least the higher metamorphic zones of the Averill quadrangle must have been developed during the period of igneous intrusion which followed the regional deformation. Of course, recrystallization and the development of porphyroblasts must have accompanied a period of deformation as intense as that in evidence in eastern Vermont, but the higher metamorphic zones as they are seen today appear to be too closely related to the outlines of the plutons in the area to be developed by purely regional deformation. Contacts of the Averill granite and the metasediments and inclusions within the Averill granite, resemble the metasediments far removed from the pluton. This suggests that the metamorphic zones had their major development prior to the intrusion of the Averill granite, probably during the intrusion of the Nulhegan quartz monzonite. The Nulhegan quartz monzonite is believed to belong to the New Hampshire magma series (Upper Devonian?) as defined by Billings (1956).

GEOLOGIC HISTORY

The geologic history of the rocks now exposed in the Averill quadrangle began with the deposition of Siluro-Devonian sediments into a geosyncline in which subsidence had just been renewed. Renewed subsidence is indicated by the presence of a widespread unconformity (Hall, 1959; Billings, 1956; and others) separating the Siluro-Devonian rocks in eastern Vermont from the underlying Ordovician rocks. The Gile Mountain Formation must have been deposited as a thick sequence of dark pelitic sediments interbedded with silty and fine-grained sands, thin, impure limestones and marly clays. All of the sediments were relatively impure. Subsidence of the geosyncline developed to such an extent by Lower Devonian times that turbidity currents were generated along the slope of the geosyncline giving rise to the graded graywacke deposits of the quadrangle. Vulcanism occurred sporadically in the geosynclinal belt. The vulcanism is reflected by the presence of the Standing Pond amphibolite, roughly at the Waits River-Gile Mountain contact, and the Halls Stream grits which were deposited at a later date and are believed to be reworked pyroclastic deposits. The Halls Stream grits were deposited within a sequence of dark gray muds and silty sand layers which slowly gave way to more sandy deposits indicating a slight increase in the rate of subsidence.

The above assemblage of impure poorly sorted clastic sediments interbedded with volcanics has been described as representative of the eugeosynclinal environment (Kay, 1951). During the Acadian orogeny, the sediments were intensely folded with a general overturning of the folds to the northwest. An axial plane cleavage developed in the folded rocks. This cleavage appears as a bedding plane schistosity in most areas due to the isoclinal nature of many of the early folds. Late in the Acadian orogeny the Nulhegan quartz monzonite was intruded. The intrusion gave rise to doming of the previously folded sediments and the development of a second generation of folds. An axial plane slip cleavage also was developed at this time. The Averill granite and the Monadnock complex were intruded later, at the end of the Acadian orogeny. The Averill granite is probably older than the Monadnock complex although age relations are not certain. Finally, the mafic dikes of the area were emplaced.

The last geologic event which had a pronounced effect on the area was Pleistocene glaciation, which modified the topography to a large degree. Lineations in the area indicate that the ice moved across the quadrangle in an approximately S 30°E direction. Products of the glaciation include kame terraces, outwash gravels, roches moutonnées, glacial striae and grooves, and large erratics.

ECONOMIC GEOLOGY

The Averill quadrangle contains an abundance of granitic rocks which could be used both as building and ornamental stone. Only one small quarry is present in the area, however. This quarry, which is not in operation at the present time, is in the Nulhegan quartz monzonite. It supplied the building stone for the foundations of the bridges which span the Nulhegan River in the southwestern corner of the quadrangle. As far as is known by the writer, this is the only locality where granitic rocks have been exploited in the quadrangle.

Large deposits of sand and gravel are scattered throughout the area. Terraces on both sides of the Connecticut River are formed of Pleistocene and Recent alluvium, covering a size range from coarse gravels to clay. The depression underlain by the Nulhegan quartz monzonite is filled with sand and gravel.

Shear zones on the Monadnock pluton contain galena, chalcopyrite, sphalerite, and pyrite. No localities were found where these minerals were present in quantities sufficient to make an economic deposit.

BIBLIOGRAPHY

ADAMS, C. B., 1845, First annual report on the geology of Vermont: Burlington, 99 p.

ADAMS, F. D., 1913, The Monteregian Hills: Internat. Geol. Cong. XII, Canada, Guide Book No. 3, p. 29–80.

ANDERSON, E. M., 1936, The dynamics of the formation of cone sheets, ring dikes, and cauldron subsidences: Royal Soc. Edinburgh Yearbook, v. 56, pt. 2, p. 128–157

BAIN, G. W., 1931, Flowage folding: Amer. Jour. Sci., v. 22, p. 503–530.

BALK, R., Structural behavior of igneous rocks: Geol. Soc. America, Mem. 5, 177 p.

BEAN, R. J., 1953, Relation of gravity anomalies to the geology of central Vermont and New Hampshire: Geol. Soc. America Bull., v. 64, p. 509–538.

BILLINGS, M. P., 1937, Regional metamorphism of the Littleton-Moosilauke area, New Hampshire: Geol. Soc. America Bull., v. 48, p. 463–566.

—— 1945, Mechanics of igneous intrusion in New Hampshire: Amer. Jour. Sci., v. 243-A, p. 40–68.

—— 1954, Structural geology: Prentice-Hall, Inc., Englewood Cliffs, N.J., 513 p.

—— 1955, Geologic Map of New Hampshire: U.S. Geol. Survey.

—— 1956, The geology of New Hampshire, part II: Bedrock Geology: New Hampshire State Planning and Development Commission, Concord, New Hampshire, 203 p.

BOUCOT, A. J., 1953, Fossils in metamorphic rocks: Geol. Soc. America Bull., v. 64, p. 997–998.

—— 1953, Lower Devonian rocks of westcentral Maine: Unpublished Ph.D. thesis, Harvard University, 135 p.

BOWEN, N. L., TUTTLE, O. F., 1958, Origin of granite in light of experimental studies: Geol. Soc. America, Mem. 74, 154 p.

BUDDINGTON, A. F., 1959, Granite emplacement with special reference to North America: Geol. Soc. America Bull., v. 70, p. 671–748.

CADY, W. M., 1956, Gedrock geology of the Montpelier quadrangle, Vermont: U. S. Geol. Survey, Geol. quad. Map GQ-79.

CANADA, DEPT. OF MINES AND TECH. SURVEYS, 1954, Geophysical papers No. 152, 169, 170 and 175, Aeromagnetic Maps.

CHAPMAN, R. W., 1935, The Percy ring dike complex: Amer. Jour. Sci., v. 30, p. 401–431.

—— 1954, Emplacement of the alkaline stock, Mount Monadnock, Vermont: Geol. Soc. America Bull., v. 65, p. 97–114.

CHAPMAN, R. W., AND CHAPMAN, C. A., 1940, Cauldron subsidence at Ascutney Mt., Vermont: Geol. Soc. America Bull., v. 51, p. 191–212.

CHAPMAN, R. W., and WILLIAMS, C. R., 1935, Evolution of the White Mountain magma series: American Mineral., v. 20, p. 502–530.

CHAYES, F., 1949, A simple point counter for thin section analysis: American Mineral., v. 34, p. 1–11.

—— 1950, On a distinction between late magmatic and post-magmatic replacement reactions: Amer. Jour. Sci., v. 248, p. 22–36.

—— 1952, The finer grained calc alkaline granites of New England: Jour. Geol., v. 60, p. 207–254.

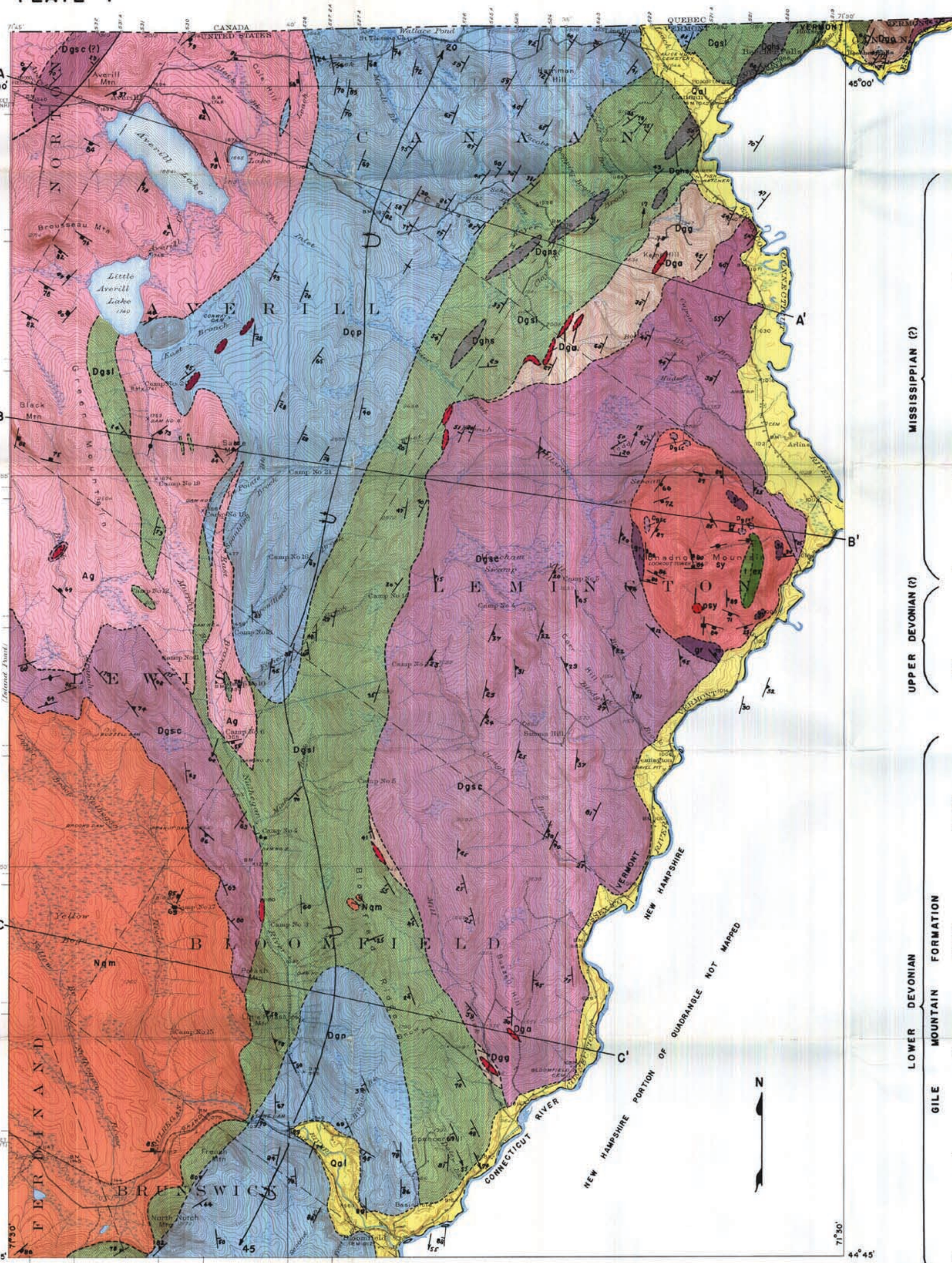
—— 1955, Potash feldspar a by-product of the biotite-chlorite transformation: Jour. Geol., v. 63, p. 75–82.

CLARK, T. H., 1934, Structure and stratigraphy of Southern Quebec: Geol. Soc. America Bull., v. 45, p. 1–20.
CLOOS, E., 1946, Lineation: Geol. Soc. America, Mem. 18, 122 p.
COOKE, H. C., 1950, Geology of a southwestern part of the eastern townships of Quebec: Geol. Soc. Canada, Mem. 257, 137 p.
—— 1957, Coaticook-Malvina area, Quebec: Quebec Dept. of Mines, Geological Rept. No. 69, 37 p.
CURRIER, L. W., and JAHNS, R. H., 1941, Ordovician stratigraphy of central Vermont: Geol. Soc. America Bull., v. 52, p. 1487–1512.
DENNIS, J. G., 1956, The geology of the Lyndonville area, Vermont: Vt. Geol. Surv. Bull., no. 8, 98 p.
DOLL, C. G., 1943a, A Paleozoic revision in Vermont: Amer. Jour. Sci., v. 241, p. 57–64.
—— 1943b, A brachiopod from mica-schist, South Strafford, Vermont: Amer. Jour. Sci., v. 241, p. 676–679.
—— 1944, A preliminary report on the geology of the Strafford quadrangle, Vermont: Vt. State Geologist, 24th Bienniel Rept., p. 14–28.
—— 1951, Geology of the Memphremagog quadrangle and the southeastern portion of the Irasburg quadrangle, Vermont: Vt. Geol. Survey Bull., 3, 113 p.
ELLS, R. W., 1887. Report on the geology of a portion of the Eastern Townships: Geol. Surv. Canada for 1886, pt. K.
—— 1896, Report on a portion of the Province of Quebec: Geol. Surv. Canada, Ann. Rept. for 1894, v. 7, pt. J.
EMMONS, R. C. (Editor), 1953, Selected petrogenic relationships of plagioclase: Geol. Soc. America, Mem. 52, 142 p.
ERIC, J. H., and DENNIS, J. G., 1958, Geology of the Concord-Waterford area, Vermont: Vt. Geol. Surv. Bull. 11, 66 p.
ERIC, J. H., WHITE, W. S., and HADLEY, J. B., 1941, Monroe fault of New Hampshire and Vermont (Abstr.): Geol. Soc. America Bull., v. 52, p. 1900.
ERN, E. H., 1963, Bedrock geology of the Randolph quadrangle, Vermont: Vt. Geol. Surv. Bull. 21, 96 p.
ESKOLA, P., 1920, The mineral facies of rocks: Norsk. Geol. Tidsk., v. 6, p. 143–149.
—— 1945, The problem of mantled gneiss domes: Quat. Jour. Geol. Soc. London, v. 104, p. 461–476.
FENNEMAN, N. M., 1938, Physiography of eastern United States: McGraw-Hill Book Co., Inc., New York, 691 p.
FOYLES, E. J., 1930, Compressed mica resembling graptolites: Vt. State Geologist, Rept. 17, p. 252.
FYFE, W. S., TURNER, F. J., and VERHOOGEN, J., 1958, Metamorphic reactions and metamorphic facies: Geol. Soc. America, Mem. 73, 259 p.
GOODSPEED, G. E., 1940, Dilation and replacement dikes: Jour. of Geol., v. 48, p. 175–195.
GOODWIN, B. K., 1963, Geology of the Island Pond area, Vermont: Vt. Geol. Surv. Bull. 20, 111 p.
HALL, L. M., 1959, The geology of the St. Johnsbury quadrangle, Vermont and New Hampshire: Vt. Geol. Surv. Bull. 13, 105 p.
HATCH, N. L., 1963, The Geology of the Dixville Quadrangle, New Hampshire: N. H. Dept. of Resources and Economic Development, Bull. 1, 81 p.

Hitchcock, C. H., 1874, 1877, 1878, Geology of New Hampshire: Concord, N.H., 3 vols.
Hitchcock, E., 1861, Report on the geology of Vermont: Claremont, New Hampshire, 2 vols., 982 p.
Jacobs, E. C., 1950, The physical features of Vermont: Vt. State Development Comm., Montpelier, 169 p.
Johansson, W. I., 1963, Geology of the Lunenburg-Brunswick-Guildhall Area, Vermont: Vt. Geol. Surv. Bull. 22, 86 p.
Kay, G. M., 1951, North American geosynclines: Geol. Soc. America, Mem. 48, 143 p.
Kingsley, L., 1931, Cauldron subsidence of the Ossipee Mountains: Amer. Jour. Sci., 5th series, v. 22. p. 139–168.
Kuenen, Ph.H., and Migliorini, C. I., 1950, Turbidity currents as a cause of graded bedding: Jour. Geol., v. 58, p. 91–127.
Leith, C. K., 1905, Rock cleavage: U. S. Geol. Surv. Bull. 239, 211 p.
Logan, W. E., 1863, Geology of Canada: Geol. Surv. Canada.
Lord, C. S., 1935, Megantic sheet, west half, Frontenac County, Quebec: Geol. Surv. Canada, Map 279 A.
Lougee, R. J., 1953, A chronology of post glacial time in eastern North America: Sci. Monthly, v. 76, p. 259–276.
Lyons, J. B., 1955, Geology of the Hanover quadrangle, New Hampshire-Vermont: Geol. Soc. America Bull., v. 66, p. 105–145.
Marleau, R. A., 1958, Geology of the Woburn, East Megantic, and Armstrong areas Electoral districts of Frontenac and Beauce: Unpublished Ph.D. thesis, Laval University.
McGerrigle, H. W., 1935, Mount Megantic area, southwestern Quebec and its placer gold deposits: Que. Bur. of Mines, Ann. Report for 1934, pt. D, p. 63–104.
Mead, W. J., 1940, Folding, rock flowage, and foliate structures: Jour. Geol., v. 48, p. 1008–1021.
Murthy, V. R., 1957, Bed rock geology of the East Barre area, Vermont: Vt. Geol. Surv. Bull., 10, 121 p.
Prentice, J. E., 1960, Flow structures in sedimentary rocks: Jour. Geol., v. 68, p. 217–225.
Read, H. H., 1955, Granite series in mobile belts: Geol. Soc. America, Special Paper 62, p. 409–430.
Reynolds, D. L., 1956, Calderas and ring complexes: Verhandeligen van het Koninklijk Nederlandsch Geologisch-Mijnbouwkundig Genootschap, Geologish Serie, Deel XVI, Gedenkboek H. A. Brouwer, p. 355–379.
Richardson, C. H., 1902, The terranes of Orange County: Vt. State Geologist Rept., 5, p. 63–115.
—— 1906, The areal and economic geology of northeastern Vermont: Vt. State Geologist Rept., 5, p. 63–115.
Schroeder, R. A., 1920, A contribution to the geology of Essex County: Vt. State Geologist Rept., 12, p. 37–42.
Thompson, J. B., Jr., 1955, The thermodynamic basis for the mineral facies concept: Amer. Jour. Sci., v. 253, p. 65–103.
Turner, F. J., and Verhoogen, J., 1951, Igneous and metamorphic petrology: McGraw-Hill Book Co., Inc., New York, 602 p.

WHITE, W. S., 1949, Cleavage in east-central Vermont: Trans. Amer. Geophys, Union, v. 30, p. 587–594.
—— 1959, A revision of the lower Paleozoic stratigraphy in eastern Vermont: A discussion: Jour. Geol., v. 67, p. 577–582.
WHITE, W. S., and BILLINGS, M. P., 1951, Geology of the Woodsville quadrangle, Vermont-New Hampshire: Geol. Soc. America Bull., v. 62, p. 647–696.
WHITE, W. S., and JAHNS, R. H., 1950, Structure of central and east-central Vermont: Jour. Geol., v. 58, p. 179–220.
WILLIAMS, H., 1941, Calderas and their origin: Univ. of Calif. Pub., Bull. Dept. Geol. Sci., v. 25, no. 6, p. 239–346.
WILLIAMS, H., TURNER, F. J., and GILBERT, C. M., 1955, Petrography: W. H. Freeman and Co., San Francisco, 406 p.
WOLFF, J. E., 1929, Mount Monadnock, Vermont—a syenite hill: Jour. Geol., v. 37, p. 1–16.

PLATE I



GEOLOGY BY PAUL B. MYERS JR.
1957 - 1959

1 0 1 2 3 4 MILES
SCALE

LEGEND

Qal — QUATERNARY ALLUVIUM

IGNEOUS ROCKS

MISSISSIPPIAN (?)

sy — QUARTZ SYENITE
GREENISH GRAY TO PINK QUARTZ SYENITE WITH LOCAL GRANITIC SEGREGATIONS (gr).
(t) TRANSITION ZONE BETWEEN QUARTZ SYENITE AND ESSEXITE

psy — PORPHYRITIC SYENITE
GRAY SYENITE WITH PHENOCRYSTS OF FELDSPAR

ex — ESSEXITE
DARK GRAY, MEDIUM GRAINED ALKALINE GABBRO

Ag — AVERILL GRANITE
WHITE TO PINK, MEDIUM GRAINED, BIOTITE GRANITE

UPPER DEVONIAN (?)

Nqm — NULHEGAN QUARTZ MONZONITE
MEDIUM GRAINED, GRAY QUARTZ MONZONITE CLOSE TO GRANODIORITE IN COMPOSITION

METASEDIMENTARY ROCKS

LOWER DEVONIAN — GILE MOUNTAIN FORMATION

Dgp — PHYLLITE
PREDOMINANTLY LIGHT GRAY PHYLLITE INTERBEDDED WITH THIN BEDS OF DARK GRAY SCHIST, MINOR AMOUNTS OF IMPURE LIMESTONE, BLUE-GRAY QUARTZITE, AND LIME SILICATE ROCK.

Dghs / Dgsl — SLATE
DARK GRAY SLATE COMMONLY CONTAINING THIN BEDS OF GRAY SANDSTONE. THICK LENSES OF FELDSPATHIC GRITS (HALLS STREAM GRITS- Dghs) INTERBEDDED WITH THE SLATES. MINOR PHYLLITE PRESENT.

Dga — HORNBLENDE SCHIST
BLACK GARNETIFEROUS HORNBLENDE SCHIST WITH MINOR AMPHIBOLITE

Dgg — GRAYWACKE
THICK GRADED BEDS OF METAGRAYWACKE AND SUBGRAYWACKE WITH MINOR PHYLLITE

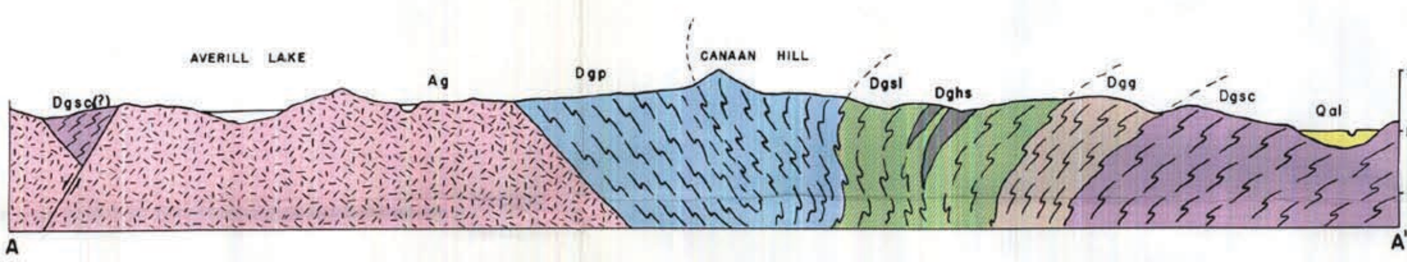
Dgsc — PHYLLITIC SCHIST
LIGHT GRAY PHYLLITIC QUARTZ-MICA SCHIST WITH MINOR SCHISTOSE QUARTZITE

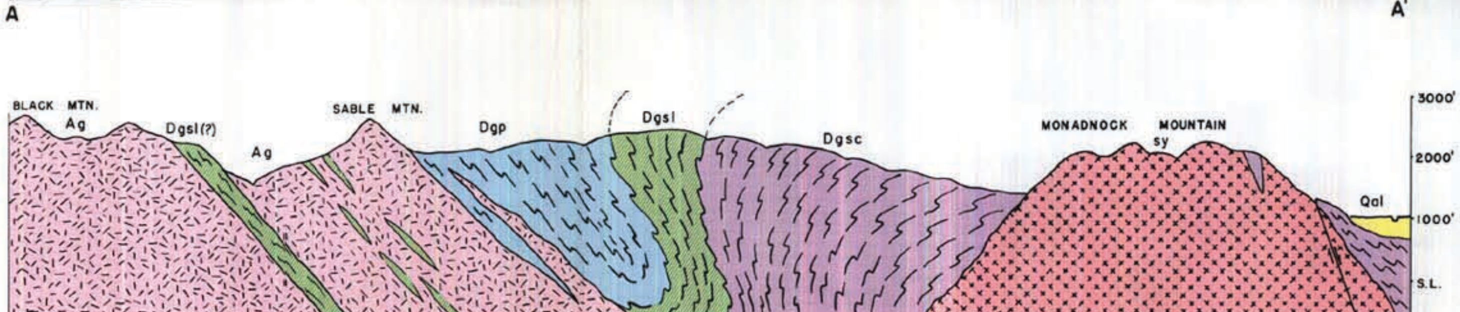
SYMBOLS

CONTACT, DASHED WHERE GRADATIONAL OR APPROXIMATE.
FAULT, DASHED WHERE APPROXIMATE.
STRIKE AND DIP OF BEDDING
STRIKE AND DIP OF FOLIATION OR CLEAVAGE
STRIKE AND DIP OF JOINTS.
BEARING AND PLUNGE OF AXES OF MINOR FOLDS.
BEARING AND PLUNGE OF OVERTURNED SYNCLINE (OVERTURNED TO NORTHWEST).
(?) INDICATES UNCERTAIN CORRELATION.

GEOLOGIC MAP OF THE AVERILL QUADRANGLE, VERMONT

VERMONT GEOLOGICAL SURVEY
Charles G. Doll, State Geologist
(Bulletin No. 27)





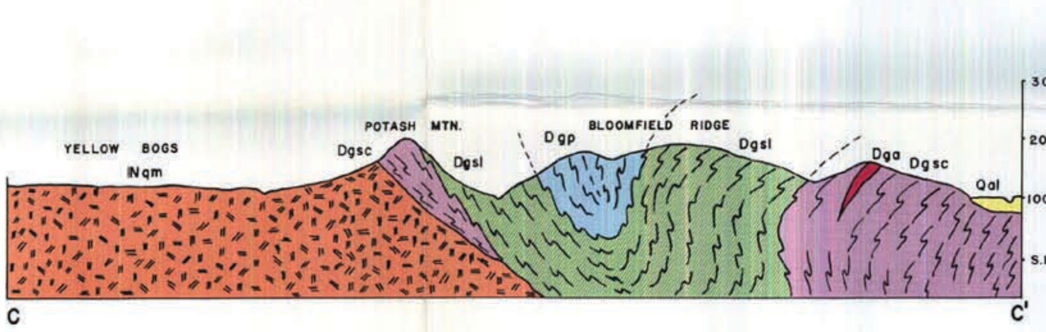
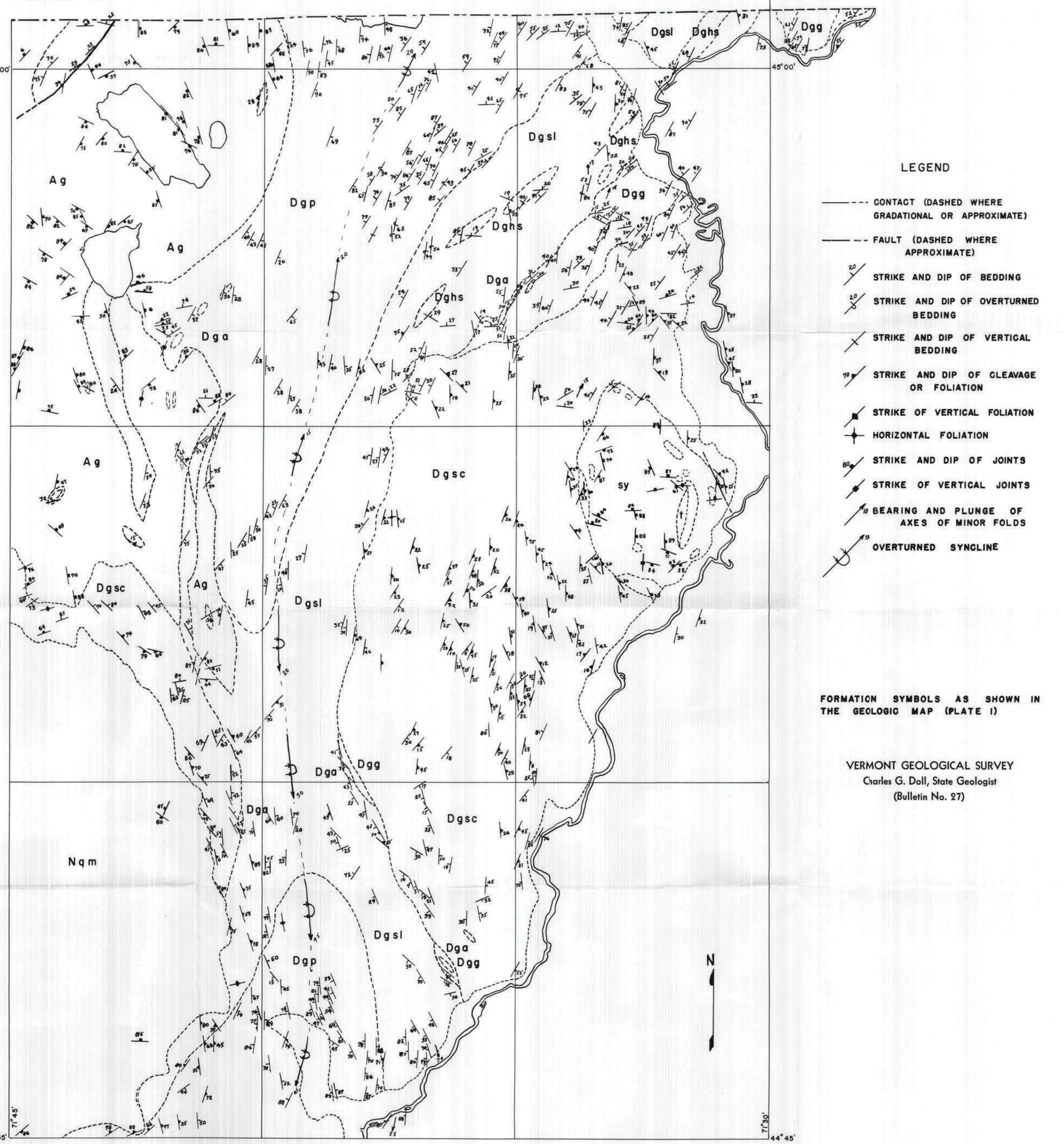


PLATE 2



VERMONT GEOLOGICAL SURVEY
Charles G. Doll, State Geologist
(Bulletin No. 27)

TECTONIC MAP OF THE AVERILL QUADRANGLE, VERMONT