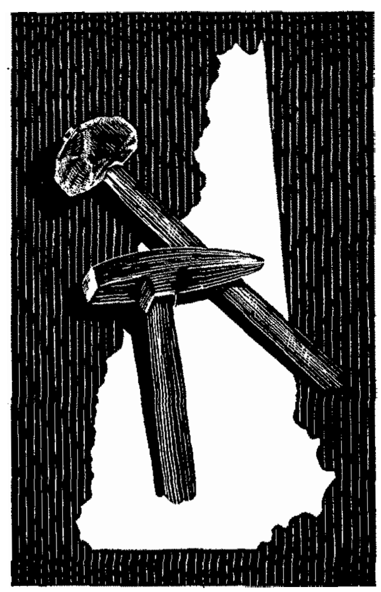
The Geology of the DIXVILLE QUADRANGLE NEW HAMPSHIRE

BULLETIN NO. 1

By Norman L. Hatch, Jr.



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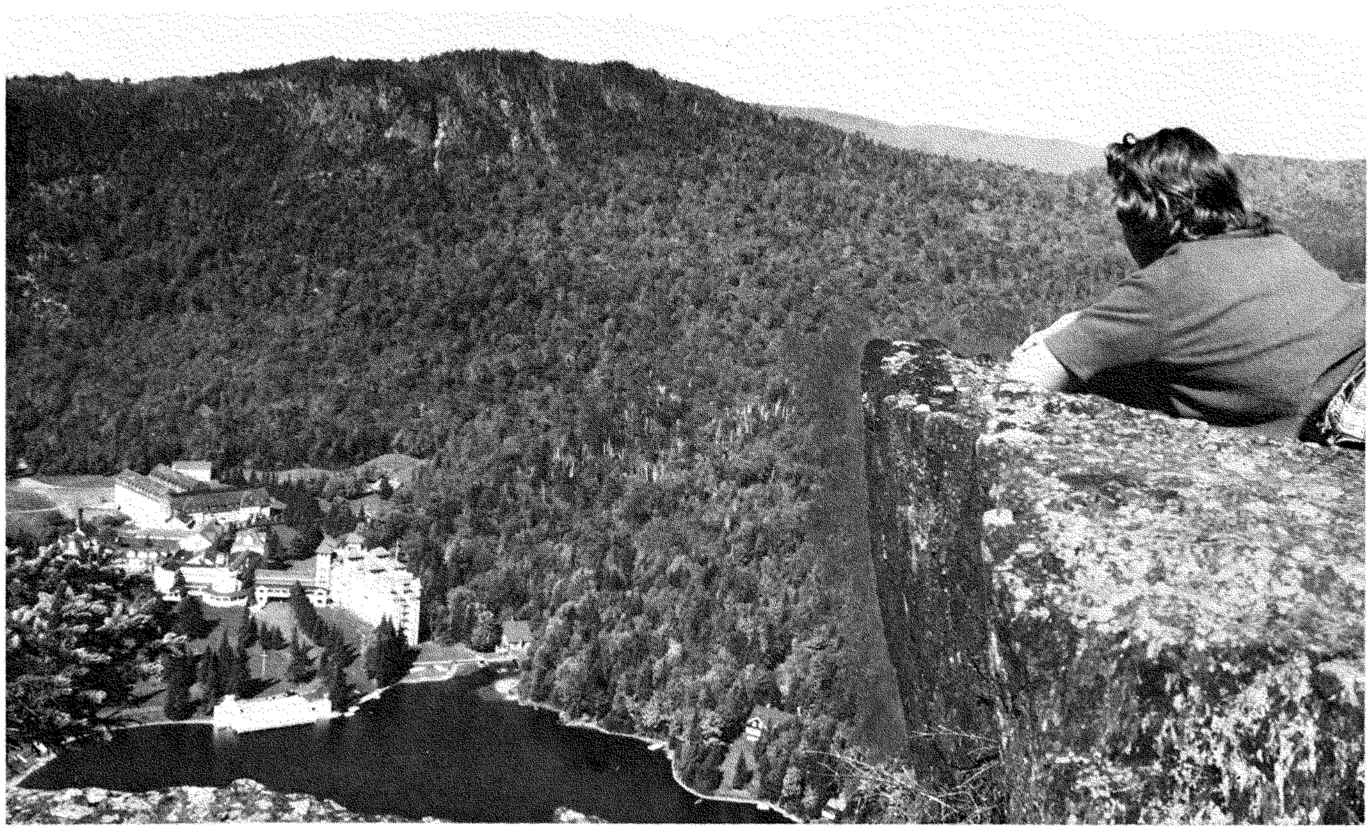

Photograph by Don Sieburg

Frontispiece. Dixville Notch area. Lake Gloriette, The Balsams Hotel, and Abeniki Mountain seen from Table Rock.

ACKNOWLEDGEMENTS

Acknowledgement is given to Dr. Marland P. Billings of Harvard University, Professor T. Ralph Meyers of the University of New Hampshire and Professor John B. Lyons of Dartmouth College for their critical review of the manuscript for publication. Appreciation is also extended to Alice Cosgrove and Donald Jacobs, Graphic Arts Section, Department of Resources and Economic Development for the drafting of the maps and illustrations and the preparation of the manuscript for publication. Coordination of the entire publication was carried on under the direction of Jonathan B. Pollard, Jr. of the Department's planning staff.

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ABSTRACT

The Dixville quadrangle in northern New Hampshire is underlain by metamorphosed Ordovician and Devonian sedimentary and volcanic rocks and by Devonian and Triassic intrusive rocks. The stratified rocks, which have a total thickness of about 23,000 feet, are divided into five units: the Albee, Dixville, Kidderville, Waits River, and Gile Mountain formations.

The Ordovician Albee formation contains light-gray mica schists, staurolite schists, sillimanite schists, and micaceous quartzites. Staurolite, garnet, and biotite megacrysts characterize these rocks. The Ordovician Dixville formation is composed primarily of dark-gray and black, sulfidic phyllites and schists interbedded with gray and white quartzites. Two lenses of amphibolite near the top of the formation are mapped separately.

The name "Kidderville formation" is proposed here for the first time for the sequence of rocks that unconformably overlie the Ordovician formations in the Dixville quadrangle. On the basis of a correlation with the Seboomook and Frontenac formations of Quebec, the Kidderville formation is assigned to the Lower Devonian. Two members are mapped: The eastern or felsic volcanic member is composed of light- and dark-gray, non-sulfidic schists and quartzites and metamorphosed felsic volcanic rocks. The western or mafic volcanic member is composed primarily of sulfidic schists and quartzites, greenstones, and amphibolites. The Devonian Waits River formation, which comprises dark-gray phyllites, gray mica schists, mica quartz schists, micaceous quartzites, calcareous schists, and quartzose marbles, is distinguished from the overlying Devonian Gile Mountain formation only by the presence of calcareous rocks.

The stratified rocks have been intruded by a variety of plutonic rocks. The Kidderville formation is cut by irregular dikes and sills of sheared granite of Middle Devonian (?) age. The New Hampshire magma series is represented in the quadrangle by sills of metamorphosed diabase in the Gile Mountain and Waits River formations, and by two stocks of muscovite-biotite-quartz monzonite in the south and southeast parts of the area. The youngest rocks in the area are the intrusives of the Triassic White Mountain magma series: the diorite, syenite, and biotite granite in the southwest corner of the quadrangle, the two stocks of leucogranite on Owlhead Mountain and the West Branch of Simms Stream, and numerous post-metamorphic dikes. Extensive glacial and alluvial deposits are mapped in the west-central and southeast parts of the area.

The major structural features of the quadrangle are six major folds and the unconformity between the Ordovician and Devonian formations.

The Ordovician rocks were folded prior to the deposition of the Kidderville formation. Evidence was found for two later stages of folding. During the first of these, the major folds in the Devonian rocks and possibly some of the folds in the Ordovician rocks were formed. During the last stage of folding, abundant minor folds were formed in the rocks of the Waits River and Gile Mountain formations, but no evidence of this deformation was seen in the eastern half of the quadrangle. The bedding-plane schistosity that is well developed in all of the formations represents the axial plane cleavage of the earlier stages of folding. The slip cleavage that is present in the rocks of the Waits River and Gile Mountain formations transects the schistosity and is thought to represent the axial plane cleavage of the folds of the final deformation.

The rocks of the quadrangle show a wide range of metamorphic zones. The north edge of the quadrangle lies in the biotite zone. The grade of metamorphism increases to the sillimanite zone in much of the south and southeast parts of the area. Although andalusite and sillimanite are common in the higher metamorphic zones, no kyanite was seen in the area.

Regional relations suggest that the Kidderville formation is the correlative of the Seboomook formation and the Frontenac volcanics of the Quebec sequence to the northeast. If correct, this correlation indicates that not only the Kidderville formation, but also the Waits River and Gile Mountain formations are Lower Devonian or younger.

INTRODUCTION

Location

The Dixville quadrangle, occupying 205 square miles in northern New Hampshire, lies between 44°45′ and 45° north latitude and between 71° 15′ and 71°30′ west longitude (Fig. 1). The area is entirely within Coos County, New Hampshire, except for a quarter of a square mile of Vermont along the west edge of the quadrangle.

Physiography and Culture

The Dixville quadrangle is a hilly to mountainous area within the New England physiographic province. The northwest quarter of the area consists of partially wooded, gently rolling hills with a relief of 1000 feet. The rest of the area is wooded, has mountainous topography with steep slopes, and has an average relief of about 2000 feet. The total relief in the quadrangle, from the highest point on the top of Blue Mountain (3723 feet) to the lowest point on the Connecticut River (1000 feet) is 2723 feet.

The western three-quarters of the Dixville quadrangle is drained by the Connecticut River; the eastern quarter is drained by the Androscoggin. The major tributary of the Connecticut is the Mohawk River, which rises in Dixville Notch and drains the northwest quarter of the area. Less important tributaries are Simms Stream, Phillips Brook, and the drainage basin of Nash Bog Pond. Clear Stream, which rises in Dixville Notch, and the Diamond River, which rises in the Diamond Ponds, are the major tributaries draining east into the Androscoggin. Nathan Pond Brook and the drainage from Millsfield Pond are the other important east-draining tributaries.

The Pleistocene ice sheet covered all of the Dixville quadrangle. Glacial deposits and erratic boulders are common, and are found on the summits of the highest mountains. The north and northwest slopes of most hills are plastered with glacial debris, whereas the south and southeast slopes generally have only a thin mantle of surficial material. Glacial striae were noted in many places in the area; all but one place indicated a direction of ice movement within 5 degrees of S.45°E.

Erratic boulders, the largest of which are composed of the massive metadiabase that forms numerous sills in the Gile Mountain formation

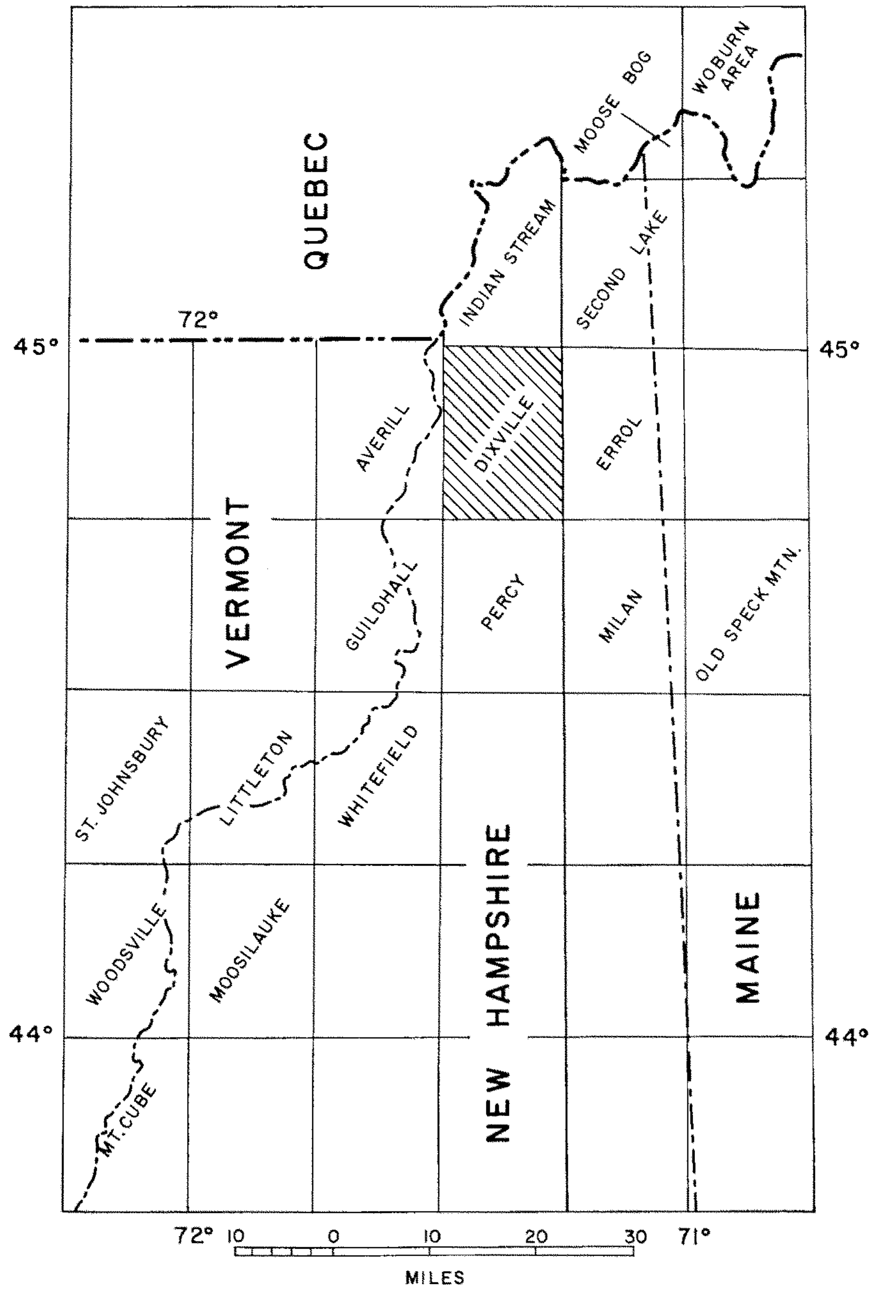


Figure I. Index map. Dixville quadrangle is ruled.

in the northwest part of the Dixville quadrangle, are plentiful. Blocks of this rock are present in the very southeast corner of the quadrangle, 12 miles from the nearest outcrop of the rock. Boulders of a granite, the nearest outcrops of which are 6 miles northwest of the Dixville quadrangle in Canada (Plate III), are common in the central and northwest parts of the area. The evidence from these boulders agrees with the evidence from the striae and indicates a southeasterly direction of ice movement.

Eskers are present along the larger river valleys. The dissected remains of one esker are very well exposed along the valley of the Mohawk River for about 3 miles west of the village of Kidderville.

Beds of blue-gray boulder clay up to 10 feet thick are present in many of the brook valleys.

Access to the Dixville quadrangle is generally fair. A good network of town and state roads covers the northwest third of the area. Access to the eastern and southern portions is much more restricted, but all points in the quadrangle may be reached from a drivable road. Work in the southern part of the area was facilitated by logging roads into Nash Bog and Phillips Ponds maintained by the Groveton and International Paper Companies. Similarly, roads recently built into Millsfield Pond and up the valley of the Diamond River by the Brown Company made access to the eastern part of the quadrangle easier. Most of the foot trails shown on the topographic map (Plate I) have been abandoned and no trace of many of them could be found.

The only major settlement is the village of Colebrook on the extreme west edge of the quadrangle. With a population of about 1200, it serves as the major shopping and farming center for most of northernmost New Hampshire. The small villages of Kidderville and Stewartstown Hollow are the only other settlements. The rest of the northwest third of the area is settled with scattered dairy and potato farms. The remaining southern and eastern portions of the quadrangle are forest covered and sparsely populated. Lumbering is the only industry, and most of the land is owned by paper companies.

Purpose of Study

The principal purpose of the present investigation of the Dixville quadrangle was to determine the stratigraphy and structure of the metamorphosed sedimentary and volcanic rocks. A second purpose was to relate that stratigraphy and structure to the geology of surrounding areas in New Hampshire, Vermont, Quebec, and Maine. The third purpose was to study the intrusive rocks and the metamorphism in the quadrangle.

Method of Study

The field work was carried out during the summers of 1958, 1959, and 1960. An additional week during the fall of 1960 was spent in the field. Traverses were made along the roads and the few trails at the beginning of the first field season. Subsequent traverses were concentrated along stream and brook beds and along ridges. Other areas that showed promise of outcrop were also covered, the concentration of work being determined by the complexity of the geology. Critical contacts were studied in detail.

Field data were plotted on one of two bases: the U. S. Geological Survey fifteen-minute series topographic map (scale 1:62,500) and U. S. Department of Agriculture aerial photographs (scale approximately 1:20,000). Wherever possible, the aerial photographs were used in preference to the map. To supplement the map and aerial photographs, an aneroid barometer and a Brunton compass were used for locating outcrops in the field.

Four hundred and eighty hand specimens were collected in the field. From these specimens approximately 300 thin sections were cut and studied. The modes listed in the tables on the following pages were estimated from these thin sections. X-ray diffraction studies were made on most of the samples listed in the tables of modes. This method proved particularly useful for the identification of minerals in fine-grained rocks and for the detection of small amounts of untwinned plagioclase in schists and quartzites.

Acknowledgments

The funds necessary to meet the summer field expenses came from two sources. Through all of the first and third field seasons, and through half of the second season, the writer was employed by the New Hampshire State Planning and Development Commission. During the first half of the second field season, funds were kindly made available from the Reginald and Louise Daly Fund of Harvard University. I would also like to thank the members of the New Hampshire State Planning and Development Commission for their interest and cooperation.

The writer was ably assisted in the field by David Nussman during the summer of 1958, by Edwin Brown during the summer of 1959, and by Charles Swift, Jr. for ten days during the summer of 1960.

Professor Marland P. Billings visited the area for five days during the summer of 1958, and again with Professor James B. Thompson, Jr. for one day each during the summers of 1959 and 1960.

The thin sections for this study were generously provided by the Department of Mineralogy and Petrography of Harvard University.

I wish to express my appreciation to the International Paper Company for permission to use their private road into Phillips Pond, and to both the International Paper Company and the Groveton Paper Company for permission to camp on their land. To the residents of the area, and in particular to Mr. and Mrs. Eldon Corbett and Mr. and Mrs. Leonard Gould, Jr. who provided the writer and his family with a base camp for the three summers, I wish to express my thanks.

Appreciation is due to Professors Billings and Thompson for critical reviews of the manuscript. Many of the ideas set forth in this paper arose from, or were encouraged by, many hours of discussion with the following persons: Professors Billings and Thompson, Dr. John C. Green, Dr. Daniel J. Milton, Mr. Peter Robinson, Dr. Paul Myers, Jr., Dr. Wallace Cady, and Dr. Warren Johansson.

Previous Work

The first geologic work in the Dixville quadrangle was done in the 1870's by J. H. Huntington in preparation for Hitchcock's (1877) report on the geology of New Hampshire. Huntington considered the Coos group (Gile Mountain formation) and the Calciferous mica schist (Waits River formation) to be Silurian or Devonian, but he mapped all of the rocks east of the Coos group as Huronian.

The next geologic mapping in the Dixville quadrangle was done by M. P. Billings in 1951. This work was of a reconnaissance nature in preparation for the geologic map of New Hampshire published in 1955. On this map, which was based largely on Huntington's work for the Dixville quadrangle, the Gile Mountain and Waits River formations are tentatively assigned to the Middle Ordovician (?). The Devonian Kidderville formation is shown as Middle Ordovician (?) Orfordville, and the Dixville and Albee formations are mapped together as Albee formation.

Recent mapping in northernmost New Hampshire was started by R. W. Chapman (1935, 1948) in the Percy quadrangle (Fig. 1). In his study Chapman was primarily concerned with the intrusive rocks. Green (1960) mapped the Errol quadrangle between 1955 and 1957. Paul Myers, Jr. (1960) completed mapping the Vermont portion of the Averill quadrangle in 1959, and Warren Johansson completed work in the Vermont portion of the Guildhall quadrangle in the same year. Daniel Milton has recently mapped the Old Speck Mountain quadrangle and the northern third of the Milan quadrangle. John Green is currently mapping the Second Lake and Moose Bog quadrangles.

Recent mapping on the Quebec side of the international boundary was started by McGerrigle (1935). Still more recently R. A. Marleau (1957, 1958, 1959) has done detailed mapping immediately north of the boundary.

LITHOLOGY AND STRATIGRAPHY

General Statement

Most of the northern and central portions of the Dixville quadrangle are underlain by metamorphosed sedimentary and volcanic rocks. Plutonic rocks belonging to two different plutonic series are present throughout the southern third of the quadrangle. The rocks along the north edge of the quadrangle are in the biotite zone of metamorphism. The grade of metamorphism increases to the southeast; much of the south and southeast parts of the quadrangle is in the sillimanite zone.

The metamorphosed sedimentary and volcanic rocks are divided into five major stratigraphic units: the Albee, Dixville, Kidderville, Waits River, and Gile Mountain formations (Fig. 2). The Albee and Dixville formations, which underlie most of the southeastern third of the quadrangle, are assigned to the Ordovician. The Albee formation comprises light-gray mica schists, staurolite schists, sillimanite schists, and micaceous quartzites. The Dixville formation is composed of gray and black phyllites and quartzites and two lenses of amphibolite. The Kidderville, Waits River, and Gile Mountain formations, which underlie the northwestern two-thirds of the quadrangle, are assigned to the Devonian. The Kidderville formation contains light-and dark-gray slates, phyllites, and schists, as well as greenstones, amphibolites, and quartz-feldspar schists and gneisses of volcanic origin. Phyllites, schists, quartzites, and marbles compose the Waits River and Gile Mountain formations. In addition, the Gile Mountain formation contains mappable lenses of greenschist.

The metamorphosed sedimentary and volcanic rocks are cut by eight types of intrusive rocks: Irregular sills and dikes of sheared granite are present in the Kidderville formation. Sills of metadiabase in the Gile Mountain and Waits River formations and two stocks of quartz monzonite are assigned to the New Hampshire magma series. A diorite, syenite, biotite granite, leucogranite, and post-metamorphic dikes are assigned to the White Mountain magma series.

The location, description, and thickness of these lithologic units are discussed on the following pages. Although a brief discussion of the age and correlation accompanies each unit, the subject of correlations is treated more comprehensively in a separate section at the end of this report.

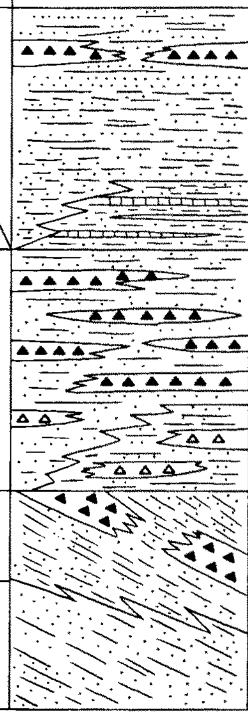
SYSTEM	FORMATION	COLUMNAR SECTION	THICKNESS IN FEET	LITHOLOGY
LOWER DEVONIAN	GILE MOUNTAIN		8000	Dark-gray and black, crinkly phyllite, gray mica schist, gray and brown mica-quartz schist, gray ankeritic schist, and micaceous quartzite. Volcanics are schistose to massive, green chlorite-epidote-albite schists and epidote amphibolites.
	WAITS RIVER		0–1500	Dark-gray phyllite, gray mica schist, mica-quartz schist, micaceous quartzite, calcareous schist, and quartzose limestone.
	KIDDERVILLE		4500	Mafic volcanic member: Quartz-feldspar-biotite-chlorite schist and gneiss and dark-green amphibolite interbedded with gray, sulfidic phyllite and quartzite and a few beds of non-sulfidic schist.
			1500	Felsic volcanic member: Gray-brown, sub-porphyritic rhyodacites and dacites interbedded with light-gray and black, non-sulfidic phyllites and quartzose schists.
MIDDLE ORDOVICIAN	DIXVILLE		4500	Gray to black, shiny, crinkly, sulfidic phyllites and schists thinly interbedded with gray and white quartzites. Minor light gray-brown feldspathic quartzite and conglomerate. Lenses of massive to poorly foliated, dark-green amphibolite.
	ALBEE		2000 to 3000	Light-gray mica schists, mica-quartz schists, staurolite schists, sillimanite schists, and micaceous quartzites.

Figure 2. Columnar section for the Dixville quadrangle.

Albee Formation

GENERAL STATEMENT

The oldest rocks in the Dixville quadrangle are the mica schists, staurolite schists, sillimanite schists, and micaceous quartzites of the Albee formation. These rocks underlie an area about 3 miles wide and 5 miles long that extends from the west slopes of Dixville Peak south and southwest to Nelson Brook and to Moran Brook. The southwestern continuation of this belt is indicated by smaller patches in Columbia Brook, in Nash Stream, on West Peak, and in Silver Brook.

LITHOLOGY

Ninety percent of the rocks of the Albee formation in the Dixville quadrangle are gray to light-gray mica schists, staurolite schists, with and without garnet, sillimanite schists, and micaceous quartzites. The rest of the rocks, all of volcanic origin, are quartz-feldspar-mica schists, amphibolites, and chlorite-biotite schists. Most of the formation lies in the staurolite and sillimanite zones of metamorphism.

The predominant rock is a light-gray, moderately foliated staurolite or staurolite-garnet schist (Table 1, Nos. 147, 148, 345, 362). Biotite forms round megacrysts 1 mm in diameter. Some of the staurolite crystals, many of which are twinned, are 1 inch in length. In contrast, few of the garnets are larger than 1 or 2 mm in diameter. Although chlorite is present in most specimens, much of it appears to have altered from biotite.

The next most common rock in the staurolite and garnet zones is a light-gray mica schist that differs from the staurolite schists chiefly in the smaller percentage of staurolite and garnet (Table 1, Nos. 126, 354). All gradations between staurolite schists and mica schists are present. Beds of micaceous quartzite 1 to 2 inches thick are interbedded with the staurolite and mica schists in many outcrops. Individual schist beds generally range in thickness from 3 to 10 inches. Fair to poor graded bedding is present in eight places in the formation (Fig. 4).

Fibrous sillimanite, although rarely visible in hand specimen, is common southwest of Dixville Peak (Table 1, Nos. 359, 365, 195). Coarsely crystalline sillimanite was seen in only one thin section. Staurolite is present immediately within the sillimanite isograd, but most of the sillimanite schists are simple sillimanite-biotite-muscovite quartz rocks. Chlorite and andalusite are both present locally, but no garnet was seen in any of the sillimanite schists.

X-ray diffraction studies show the presence of small amounts of

TABLE 1

REPRESENTATIVE ESTIMATED MODES OF METAMORPHOSED SEDIMENTARY ROCKS OF THE ALBEE FORMATION.

	Garnet zone	Staurolite zone							Sillimanite zone		
Sample No.	126	127	146	147	148	345	362	354	359	365	195
Quartz	50	90	75	53	32	35	33	50	38	36	60
Plagioclase*	8	1	4	2	3	5	5	16	2	5	
Muscovite	25	tr	5	27	20	30	20	15	35	40	7
Chlorite	8	3	6	tr	3	2		6	2	5	5
Biotite	8	4	7	8	23	20	8	8	10	10	20
Garnet	0.5	2	tr	4		3	5	2			
Staurolite		tr	1	5	18	4	12	2	3		
Sillimanite									5	3	5
Andalusite							15		4	tr	
Ore	0.5	tr	2	1	1	1	2	1	1	1	3
Apatite	tr	tr	tr		tr			tr			tr
Tourmaline	tr	tr	tr	tr	tr		tr	tr	tr	tr	
Zircon	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr

*The composition of the plagioclase is not listed because the mineral was detected only by X-ray methods in most samples. Wherever determined, it is oligoclase.

Description and location of samples listed in Table 1.

No.	Description and location
126	Light-gray mica schist; 1960 feet elevation in the East Branch of Simms Stream.
127	Light-gray-brown micaceous quartzite; 1960 feet elevation in the East Branch of Simms Stream.
146	Weakly schistose mica-quartz schist; 1755 feet elevation in Simms Stream.
147	Gray staurolite-garnet schist; 1820 feet elevation in Simms Stream.
148	Coarse, gray staurolite schist; 1940 feet elevation in Simms Stream.
345	Light-gray staurolite-garnet schist; 3000 feet elevation on the slope N.80°W. from Dixville Peak.
362	White, coarse-grained staurolite-garnet schist; 2180 feet elevation in Annis Brook.
354	Light-gray mica schist; 2680 feet elevation in the West Branch of Clear Stream.
359	Splintery sillimanite-staurolite schist; 2720 feet elevation in Rocky Brook.
365	Contorted sillimanite schist; 0.5 mile NNE of the north end of Nash Bog Pond.
195	Contorted, light-gray sillimanite schist; 2720 feet elevation in Nelson Brook.

plagioclase in most samples of schist and quartzite from the Albee formation. Because this plagioclase is not twinned and because it has refractive indices very close to the indices of quartz, it was seen in only a few of the thin sections. X-ray and some optical data both indicate that the plagioclase is oligoclase. The amounts listed in Table 1 are estimated from diffractometer charts. Because reliable estimation of composition from diffractometer charts is difficult and time consuming, no attempt is made to list compositions in Table 1.

Table 2

REPRESENTATIVE ESTIMATED MODES OF METAMORPHOSED VOLCANIC AND DIKE ROCKS IN THE ALBEE FORMATION.

Sample No.	145	356	270	361	337
Quartz	8		5		40
		74		74	
Plagioclase	58		61		40
Actinolite					15
Hornblende	30		30	10	
Garnet				5	4
Sphene	tr		3		1
Epidote					tr
Muscovite		tr			tr
Biotite	3	10	1	10	
Ore	1	1	tr	1	
Apatite	tr	tr		tr	
Chlorite		15			
Zircon		tr			
% An in plagioclase	40	20	30	30	60

Description and location of samples listed in Table 2.

No.	Description and location
145	Fine-grained, dark-gray, dense amphibolite; 1750 feet elevation in Simms Stream.
356	Greenish-gray biotite-chlorite schist; 2480 feet elevation in the West Branch of Clear Stream.
270	Medium-grained, dark-green amphibolite; 2830 feet elevation in the valley immediately north of Gadwah Notch.
361	Massive, gray, fine-grained garnet amphibolite; 2370 feet elevation in Annis Brook.
337	Gray quartz-feldspar-garnet-actinolite granulite; 2140 feet elevation on the slope 1.35 miles east of Bungy.

Volcanic rocks, although not abundant, are present throughout the Albee formation (Table 2). They are not, however, sufficiently concentrated in any part of the formation to be mapped separately. These rocks may be described briefly under the following groups: 1) fine-grained, dense, dark-gray amphibolite sills and dikes 4 to 6 feet thick (Table 2, No. 145), 2) bedded, dark-greenish-gray, medium-grained biotite-chlorite schist found north of Nash Bog Pond and east of Kelsey Notch (Table 2, No. 356), 3) medium-grained, dark-green amphibolite similar to the amphibolites in the Dixville formation (Table 2, No. 270), 4) light-gray-brown, chalky-weathering, poorly foliated quartz-feldspar-mica schist, 5) massive, fine-grained, gray garnet amphibolite (Table 2, No. 361).

One other rock, found throughout the formation in small lenses and thin discontinuous beds, is a light-gray, medium-grained quartz-plagioclase-garnet-amphibole granulite. The plagioclase is calcic andesine or labradorite, and the amphibole, which occurs as large poikilitic sheaves, is actinolite. In addition to the minerals listed above, traces of sphene, muscovite, and possibly epidote are present in the rock. Green (1960, p. 70) describes a similar rock in the Albee formation in the Errol quadrangle. He notes that an analysis for total MnO of one of his samples gave MnO = 0.85 percent. The origin of this rock is problematical.

THICKNESS

Only the top of the Albee formation is exposed in the Dixville quadrangle. The rocks described above are thought to form a distinctive unit about 2000 to 3000 feet thick at the top of the formation. The evidence for this figure comes in part from the Errol quadrangle in which rocks similar to those described above form a belt half a mile wide at the top of the Albee formation (John Green, personal communication). The thickness of the whole Albee formation is estimated to be 10,000 feet in the Errol quadrangle (Green, 1960). Billings (1956) gives a figure of 5000 feet for the thickness of the formation based on mapping further south.

AGE AND CORRELATION

The Albee formation has been traced (Eric and Dennis, 1958; Warren Johansson, personal communication; Chapman, 1948; Billings, 1956) continuously from the type area at Albee Hill (Billings, 1937) to the south edge of the Dixville quadrangle (Plate III).

The Albee formation is assigned to the Middle Ordovician largely on the basis of a correlation with the Moretown formation of Vermont. At the international boundary, the Moretown formation strikes into the Beauceville formation (Cady, 1960) which includes the Magog slate (Cooke, 1950). At Castle Brook, Magog, the Magog slate has produced an excellent fauna of graptolites. This fauna has been studied by Ruedemann (1947, p. 68–70) and others and has been assigned a Trenton age.

The nearest Ordovician fossils to the northeast are at Somerset Junction, about 5 miles southwest of Moosehead Lake (Boucot, 1953). The fossils occur in tuffs of the Kennebec formation on the southeast limb of the Moose River syncline (Plate III), and have been assigned to the Middle Ordovician (Boucot, 1953, p. 9). Detailed mapping in the intervening areas is needed before the rocks at Somerset Junction can be traced to northern New Hampshire.

Dixville Formation

GENERAL STATEMENT

Green (1960, p. 72) proposed the name Dixville formation for the sequence of phyllites, schists, quartzites, and amphibolites that overlies the Albee formation in the township of Dixville.

In the Dixville quadrangle, the formation underlies an area that extends from Blue Ridge southward to the south slopes of Dixville Peak. It is also found in a narrow strip along the east edge of the area, two small areas in the southeast corner of the quadrangle, a small xenolith north of Millsfield Pond, and on Keyser Mountain.

The main body of the formation consists primarily of dark-gray phyllites and quartzites. The amphibolites, which contain very little interbedded metasedimentary material, occur in two large lenses that lie near the top of the formation.

METAMORPHOSED SEDIMENTARY ROCKS

The metamorphosed sedimentary rocks of the Dixville formation in the Dixville quadrangle are gray to black sulfidic phyllites and schists interbedded with gray to white quartzites. Beds, where observable, are generally 1 to 2 inches thick. In other lithologically more homogeneous outcrops, only the omnipresent schistosity can be seen. These pelitic schists and quartzites compose at least 99 per cent of the metamorphosed sedimentary rocks of the formation. Metaconglomerate, a quartzose limestone, and a quartz-garnet-amphibole rock are the only other rocks.

Although the Dixville formation has a relatively small outcrop area, it shows a wide range of metamorphic zones. On the west slopes of Blue Ridge, the rocks are in the biotite zone. The grade of metamorphism increases southward to the east side of Dixville Peak, where the rocks lie in the sillimanite zone. Andalusite is present in the schists in the general vicinity of the quartz monzonite.

In the biotite zone, the metasedimentary rocks of the Dixville formation are light-gray to black phyllites interbedded with quartzites (Table 3, Nos. 300, 172). Typically, the rock is a dark-gray to black, rusty phyllite with a pronounced cleavage. Under the microscope, these rocks are seen to be composed largely of fine grained quartz, muscovite, and chlorite. Scattered, fine-grained graphite clouds all but the lighter colored specimens. Pyrite or pyrrhotite is generally present, and oxidation of sulfides is responsible for the rusty coating on most outcrops. Biotite porphyroblasts about 0.1 mm in diameter are common. Small, euhedral, graphite-clouded garnets are abundant in a few thin beds and lenses. Because all the evidence points to their being spessartitic, and because the garnet isograd drawn on the geologic map represents the appearance of a relatively pure almandite, these garnetiferous rocks are mapped in the biotite zone. A few beds of light-gray, non-graphitic, non-sulfidic phyllite are interbedded with the more typical rocks of the formation (Table 3, No. 181).

Almandite is present in most of the pelitic rocks south of Mud Pond Ridge. These rocks are gray to dark-gray phyllites and fine-grained schists composed largely of muscovite, quartz, chlorite, biotite, and almandite.

Within the staurolite zone, chlorite is less abundant, staurolite is present, and some of the rocks are lighter in color. Texturally, the rocks are schists in that the individual muscovite flakes are easily visible to the naked eye. This coarsening of grain size is doubtless partially responsible for the lighter color of the rock. Thin section study shows that these rocks contain less graphite than do the lower grade rocks. Furthermore, the graphite is concentrated in large clots and in clouds of small flakes in crystals of staurolite, andalusite, and garnet.

Although sillimanite is rarely seen in hand specimens, its presence is indicated by the lighter color and the coarser, faintly gneissic texture of the rocks which contain it. This lighter color in the higher metamorphic zones is largely responsible for the difficulties encountered in mapping the contact between the Dixville and the Albee formations.

Andalusite is common in the pelitic rocks in the staurolite and sillimanite zones near the quartz monzonite.

Plagioclase was seen in only three thin sections of metamorphosed sedimentary rocks of the Dixville formation. In these thin sections the relief indicated an oligoclase. Most of the plagioclase listed in Table 3 was detected only by X-ray diffraction.

In order to determine whether or not the black phyllites of the Dixville formation owe their color to finely divided carbon, a powder of specimen No. 157 (Table 3) was treated with acids (chemical work by Jun Ito, Department of Mineralogy and Petrography, Harvard University). First the powder was boiled for 5 minutes in 1:1 HCl to dissolve pyrrhotite. This process did not change the color of the sample. Boiling for 5 minutes in 1:1 HNO_3 also failed to change the color. Treatment with dilute solution of equal parts of HNO_3 and HF isolated a black amorphous material identified as carbon that amounted to over 1 percent of the sample.

Interbedded with the phyllites and schists of the Dixville formation are light-gray and gray quartzites and micaceous quartzites. Some of the purer quartzites are nearly white (Table 3, No. 172).

TABLE 3

REPRESENTATIVE ESTIMATED MODES OF METAMORPHOSED SEDIMENTARY ROCKS OF THE DIXVILLE FORMATION.

	Biotite zone					Garnet zone		Staurolite zone						Sillimanite zone					
Sample No.	300	181	172	182	169	157	306	59	72	74	134	335	336	349	351	331	325	248	475
Quartz	45	69	95	43	82	50	32	55	57	77	33	46	50	40	50	46	49	59	78
Plagioclase[1]	8			3		5	8				5	2	tr	2	10		5	2	7
Muscovite	15	tr	5	tr		31	40	25	25	10	35	12	27	25	27	29	3	15	8
Chlorite	20	25	tr	3			3	5	3	3	4	1	2	3	tr	2	1		
Biotite	5	4		1		5	10	2	10	9	3	20	12	25	8	12	20	10	6
Garnet	3[2]				10	1	5					3							
Staurolite									3		5	15	8	tr	tr		1	1	
Sillimanite											1			3	2	8	20	3	
Andalusite								8			10							8	
Actinolite					8														
Calcite				50															
Ore[3]	2[4]	2	tr	tr		6[4]	2	3	1	1	2	1	1	2	2	2	1	2	tr
Graphite	2					2	tr				2								
Zircon			tr				tr		tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr
Apatite			tr				tr	tr	tr	tr	tr			tr		tr	tr		tr
Tourmaline		tr	tr				tr		1			tr	tr	tr	1	1	tr	tr	1

[1]The composition of the plagioclase is not determined because the mineral was detected only by X-ray methods.
[2]Garnet is spessartitic.
[3]Undifferentiated except where noted.
[4]Pyrite.

Description and location of samples listed in Table 3.

No.	Description and location
300	Black, biotite-garnet phyllite; 0.2 mile south of X 1745 in the Diamond River.
181	Greenish-gray phyllite; 1718 feet elevation in the Diamond River.
172	Gray-white, sugary quartzite; 1930 feet elevation in the brook on the north side of Cave Mtn.
182	Gray quartzose limestone; 2300 feet elevation on the west side of Blue Ridge, ¾ mile northeast of X 1745 in the Diamond River.
169	Banded quartz-garnet-actinolite granulite; 2380 feet elevation on the northwest end of Nathan Pond Ridge.
157	Black, pyritiferous phyllite; in the notch at the northeast end of Abeniki Mtn.
306	Gray biotite-garnet phyllite; 2320 feet elevation, 0.2 mile south of Lake Gloriette.
59	Dark-gray, contorted andalusite phyllite; on the highway, 0.1 mile northwest of The Flume.
72	Gray-brown staurolite schist; 1.5 miles east of The Flume.
74	Light-tan, conglomeratic mica-quartz schist; 1¼ miles east of X 1444 on the east edge of the quadrangle.

No.	Description and location
134	Silvery-gray, crinkly andalusite phyllite; 1630 feet elevation in Cascade Brook.
335	Splintery, gray staurolite-garnet schist; 1920 feet elevation in Cascade Brook.
336	Gray staurolite-garnet schist; 1920 feet elevation in Cascade Brook.
349	Crinkly, gray sillimanite schist; 0.1 mile north of the northwest corner of Millsfield township.
351	Gray mica schist; 3100 feet elevation on the SSW ridge of Dixville Peak.
331	Contorted, graphitic sillimanite schist; summit 3081 northeast of Dixville Peak.
325	Gray sillimanite schist; 1600 feet elevation, 0.3 mile west of 1400 feet elevation in Clear Stream.
248	Gray andalusite-sillimanite phyllite; 2650 feet elevation on the northwest side of the ridge southwest of The Bog.
475	Gray mica-quartz schist; 2600 feet elevation on the northwest end of the ridge southwest of The Bog.

A small patch of the metasedimentary rocks that overlie the amphibolites of the Dixville formation is exposed on the easternmost edge of the quadrangle 1 mile north of the Millsfield-Dixville town line. Interbedded with the more typical rocks of the Dixville formation are light-gray and gray-brown feldspathic quartzites and staurolite schists. The weathered surface of one outcrop shows a bed about 40 feet thick that contains many lenses of conglomerate. The pebbles average 1 to 2 inches in length and are elongated parallel to the schistosity. Both the pebbles and the matrix are a light-brown, feldspathic quartz-mica schist. Although the pebbles stand out well on a weathered surface, they are almost impossible to distinguish from the matrix on a fresh face.

One small outcrop of quartzose marble, about 20 feet in diameter, was found at 2300 feet elevation on the west slope of Blue Ridge three quarters of a mile northeast of the mouth of Keyser Brook. Near the junction of Keyser Brook and the Diamond River, a large outcrop of conglomerate in the Dixville formation has recently been exposed by logging operations. This rock differs from the conglomerate described above in being dark gray and in having a finer grain size in both the pebbles and matrix. Some of the pebbles, the largest of which are only 6 inches long, are angular and some are intensely brecciated.

The rocks of the Albee formation are distinguished in the field from the rocks of the Dixville formation by the following features. The rocks of the Albee formation are light gray; most of the rocks of the Dixville formation are dark gray or black. Texturally, the rocks of the Albee formation are less schistose and coarser grained than are the phyllites of the Dixville formation. The biotite in the schists of the Albee formation occurs as round megacrysts 0.5 to 1.0 mm in diameter that are evenly distributed through the rock; the biotite in the phyllites and schists of the Dixville formation occurs as ragged clots and flakes that are irregularly distributed through the rock. Most outcrops of the Dixville formation have a coating of limonite formed by the weathering of sulfide minerals. Neither the sulfides nor the limonite are present in most outcrops of the Albee formation.

Many of these differences, however, have been minimized in areas of high grade metamorphism. In the higher metamorphic grades, sulfides have apparently been introduced into the rocks of both the Albee and the Dixville formations. Furthermore, the rocks of the Dixville formation have become light gray and texturally coarsened. Interbedding of black phyllites and light-gray schists along the contact is evidence that the boundary between the two formations is gradational. The zig-zag nature of the contact shown on the geologic map (Plate I) is thus due not only to folding of the contact, but also to the gradational character of the boundary.

METAMORPHOSED VOLCANIC ROCKS

Metamorphosed volcanic rocks in the Dixville formation are present in four areas in the quadrangle. The largest is along the east edge of the quadrangle in the townships of Dixville and Millsfield. A second area is in the vicinity of Lakes Abeniki and Gloriette. Two smaller patches crop out on the east side of Mt. Metalak and on the southeast ridge of Dixville Peak. These four areas are interpreted as belonging to two large lenses at approximately the same stratigraphic position.

The dominant rock of these lenses is a medium-grained, dark-green amphibolite. Although some specimens are massive, most are poorly- to well-foliated. The presence locally of thin lenses or beds of felsic material suggests a pyroclastic origin for some of the material. Some outcrops show pillow structure, which indicates that the rocks are metamorphosed flows. In other outcrops, the rock is massive and structureless, and some of this material may represent metamorphosed sills. With the exception of very minor amounts of felsic volcanic material and of a few thin beds of phyllite, the rocks of these lenses are all amphibolites.

The grain size of the amphibolites is fairly constant. Individual hornblende needles average 2 to 3 mm, and only in a few cases are they as much as 10 mm long. The mineralogy of these rocks is simple (Table 4). Hornblende and plagioclase are the two most prominant minerals. Quartz, epidote, chlorite, and biotite are present in some specimens. Magnetite, sphene, and apatite are the only common accessories.

THICKNESS

No accurate estimate of the thickness of the Dixville formation can be made in the Dixville quadrangle. The thickness of the meta-sedimentary rocks below the amphibolites has been estimated by Green (1960) to be about 2000 feet. Due to the complications caused by folding and igneous intrusion, no better estimate than this can be given here. The amphibolites on Mt. Metalak have an outcrop width of about 2500 feet. Because the dips in this area are steep and because the amphibolites, relative to the surrounding schists, are a competent rock, the true thickness of the amphibolites is probably close to this figure, or about 2000 feet. Only about 500 feet of metasedimentary rocks above the amphibolites are exposed in the Dixville quadrangle. In conclusion, the total thickness of the Dixville formation in the Dixville quadrangle is about 4500 feet.

Table 4

REPRESENTATIVE ESTIMATED MODES OF METAMORPHOSED VOLCANIC ROCKS IN THE DIXVILLE FORMATION.

	Biotite zone	Garnet zone	Staurolite zone		Sillimanite zone	
Sample No.	403	42	61	75	139	310
Quartz	5	26			21	
Plagioclase	30	40	66	45	50	58
Hornblende	59	30	30	49	25	40
Biotite	3			3		
Epidote		2		tr		
Ore	3	2	2	3	1	
Sphene			2	tr	3	2
Apatite			tr	tr	tr	tr
% An in plagioclase	20	30	22	38	20	55

Description and location of samples listed in Table 4.

No.	Description and location
403	Medium-grained, green, pillowed, massive amphibolite; 0.9 mile southeast of Mud Pond.
42	Medium-grained, green, foliated amphibolite; southwest end of Abeniki Mountain.
61	Medium-grained, dark-green, poorly foliated amphibolite; 0.4 mile north of the Millsfield-Dixville town line in Clear Stream.
75	Medium-grained, dark-green, massive amphibolite; 1.4 miles east of The Flume.
139	Medium-grained, green, massive, light amphibolite; 2000 feet elevation in the brook on the east side of Dixville Peak.
310	Coarse-grained, dark-green, poorly foliated amphibolite with coarse, felty hornblende; 2150 feet elevation on the ESE ridge of Dixville Peak.

AGE AND CORRELATION

The Dixville formation overlies the Albee formation with a gradational contact. On the basis of lithologic similarities and stratigraphic position, the Dixville formation is correlated with the Ammonoosuc and Partridge formations of the Littleton-Moosilauke area (Billings, 1937) and is assigned to the Middle Ordovician (Cady, 1960, p. 554.)

Kidderville Formation

GENERAL STATEMENT

Metamorphosed sedimentary and volcanic rocks of the Kidderville formation underlie a belt that extends in a northeasterly direction across the Dixville quadrangle. The formation name, proposed here for the first time, is taken from the village of Kidderville located in the middle of this belt. Good exposures of rocks of this formation may be seen both east and west of the village along the Mohawk River.

Rocks of the formation are exposed in a belt that extends from the West Branch of Simms Stream to the northeast corner of the quadrangle. At its northeast end, this belt is about 3½ miles wide; it narrows southwestward to less than a mile at the point where the biotite granite cuts it off. Because similar rocks are not present at this stratigraphic position in the Guildhall quadrangle (Fig. 1) (Warren Johansson, personal communication), the Kidderville formation must pinch out rapidly to the southwest.

The formation comprises a variety of rocks of both sedimentary and volcanic origin. Within the limits of the Dixville quadrangle, it can be divided into two members that are distinguished by their different proportions of the various rocks. The eastern or felsic volcanic member is present only along the northern half of the belt. The western or mafic volcanic member extends the full length of the belt.

FELSIC VOLCANIC MEMBER

The felsic volcanic member of the Kidderville formation underlies a belt 1½ to 2 miles wide that extends from the Mohawk River to the northeast corner of the quadrangle. This member includes a variety of metamorphosed sedimentary and volcanic rocks.

In the field, this member is distinguished from the underlying Dixville formation by the first appearance, going west, of abundant felsic volcanics and of predominantly non-sulfidic sediments. The contact with the western member of the Kidderville formation is gradational and is drawn where the metavolcanic rocks change from predominantly felsic to predominantly mafic. Furthermore, the meta-sediments of the mafic volcanic member are mostly sulfidic and form a smaller percentage of the member than do the non-sulfidic metasediments of the felsic volcanic member.

The felsic volcanics of the eastern member are gray to gray-brown and fine grained; most specimens are slightly porphyritic. Outcrops of these felsites weather chalky or light gray, and the plagioclase megacrysts, which are 1 to 2 mm in diameter, weather white against the gray matrix. On a fresh face, the rock is uniformly gray or gray-brown, and the feldspar megacrysts stand out only as flashing cleavage faces. Most specimens are massive, although the rock in some outcrops has a faintly schistose texture.

Mineralogically, most of these rocks are rhyodacites and dacites (Table 5). Quartz, plagioclase, fine-grained muscovite, and, in some specimens, potassic feldspar are the dominant minerals. The muscovite is fine grained and is probably secondary; it is found in both the plagioclase and the potassic feldspar. Biotite is present in most samples, although much of it is altered, at least in part, to chlorite. The chlorite noted in Table 5 is a distinctly separate phase from that in the altered biotite; it has extremely low birefringence, forms much larger flakes and clots, and is pale green, rather than olive drab, in thin section. Small amounts of both calcite and dolomite are seen in many of these rocks.

Throughout most of the member, the small amount of interbedded mafic volcanic material is in the form of chlorite schists and chlorite-epidote-hornblende schists. At the south end of the member, metamorphism has converted these rocks to amphibolites.

The metasediments of the felsic volcanic member of the Kidderville formation include both sulfidic and non-sulfidic types (Table 6). Phyllites and micaceous quartzites are the commonest rocks (Table 6, Nos. 408, 413, 63, 381, 390, 322, 45, 245). Pure quartzites are relatively rare. Northeast of Nathan Pond, most of the rocks are dark gray or black. Southwest of Nathan Pond, however, many of the non-sulfidic rocks are light gray. In Moose Brook, beds of otherwise similar light-gray and black non-sulfidic schists are interbedded (Table 6, Nos. 45 and 245). South of Old Ramsay Camp, sulfidic rocks, common throughout the western member, are rare in the eastern member.

The foliation is only fair to poor in most of the non-sulfidic metasedimentary rocks of the eastern member of the formation. Even the slaty phyllites in the biotite zone have only a fair fissility. This condition is caused by the relatively high quartz content of the rocks. In contrast, the sulfidic rocks are more micaceous and thus are more schistose. In addition, the sulfidic rocks are structurally less competent and show much more contortion and minor folding than do the surrounding non-sulfidic rocks.

In the northeast corner of the quadrangle, the dark-gray and black phyllites and quartzites of the felsic volcanic member of the Kidderville formation are composed essentially of quartz, plagioclase, chlorite, fine-grained muscovite, and graphite (Table 6, No. 408). A few beds of

Table 5

REPRESENTATIVE ESTIMATED MODES OF METAMORPHOSED VOLCANIC ROCKS IN THE FELSIC VOLCANIC MEMBER OF THE KIDDERVILLE FORMATION.

Sample No.	262	414	406	420	68	140	65	180	393	163	247
Quartz	35	10	38	15	15	10	}	10	20	20	} 68
Plagioclase	20	27		68	66	79	} 85	66	51	49	}
K feldspar	40				5		}	10		20	
Biotite	2	tr	1	4	12	5		8	3	10	2
Chlorite		30	4	10		3			1		
Muscovite	1	2	25	2	1	2	10	5	25	1	
Calcite		30					5				
Dolomite			30								
Hornblende											30
Ore	1	1	2	1	1	1	tr	1		tr	
Epidote	1									tr	
Zircon	tr				tr				tr		
Apatite			tr	tr	tr	tr		tr		tr	tr
Sphene										tr	
% An in plagioclase	5	20		5	5	5	?	15	3?	5	?

Description and location of samples listed in Table 5

No.	Description and location
262	Light-brown rhyolite with pink and green feldspar megacrysts; 2200 feet elevation in the headwaters of Crystal Brook.
414	Greenish-gray, medium-grained chlorite-calcite schist; 2040 feet elevation on the ridge between Gulf and Alder Brooks.
406	Sub-porphyritic, massive, light-gray-brown muscovite-dolomite-quartz rock; 1880 feet elevation in Tracey Brook.
420	Light-gray, porphyritic dacite; 2820 feet elevation on the north side of Tumble Dick Mtn.
68	Gray, slightly porphyritic, massive rhyodacite; at the north end of Nathan Pond.
140	Gray, faintly schistose, porphyritic dacite; 2040 feet elevation in Sugar Hill Brook.
65	Light-brown, porphyritic felsite; 2000 feet elevation in the Diamond River.
180	Light gray-brown, schistose, porphyritic rhyodacite; 2080 feet elevation on the east end of Diamond Ridge.
393	Light gray-brown, biotite-spotted, muscovitic dacite; 2700 feet elevation on the southeast ridge of Sugar Hill.
163	Dark-gray, medium-grained, sub-porphyritic rhyodacite; 1700 feet elevation in the brook 1¼ miles WSW of Lake Gloriette.
247	Massive, dark gray-green amphibolite; 1610 feet elevation in Moose Brook.

black phyllite in Tracey Brook contain an estimated 10 percent of sulfides. Biotite is visible microscopically south of Bateman Brook. South of Old Ramsay Camp, however, it forms shiny, round, black megacrysts easily visible in hand specimen. South of Moose Pond, garnet is abundant as euhedral grains about 0.1 to 0.5 mm in diameter.

Many beds of a light-gray schist very rich in feldspar crop out along the road southwest of Moose Pond (Table 6, No. 244). Except for the high feldspar content, this rock closely resembles, both in texture and in mineralogy, the light-gray, quartzose schists described above. It probably was formed by the rapid erosion of a source area underlain in part by igneous rocks.

A second interesting rock found in the felsic volcanic member is the magnetite schist that crops out along the road about half a mile south of Moose Pond (Table 6, No. 44). This rock, which occurs in beds 5 to 10 feet thick, interbedded with the more common schists and volcanics, is a fine-grained, gray schist or phyllite studded with perfect octahedra of magnetite 1 mm in diameter. The remaining minerals of this rock are the same as the minerals of the more typical schists of the member.

In the northeast corner of the quadrangle, a few beds of gray, schistose grit are exposed (Table 6, No. 423). Pebbles 2 to 4 mm in diameter of quartz, feldspar, and slate, as well as pebbles of interlocked quartz and feldspar grains were identified in this rock. In contrast to the other schists and quartzose schists throughout the quadrangle, the plagioclase in these rocks is twinned. These beds may possibly represent a crystal tuff that may or may not be intermixed with detrital material.

MAFIC VOLCANIC MEMBER

The western or mafic volcanic member of the Kidderville formation also includes a variety of metamorphosed sedimentary and volcanic rocks. Because the western edge of the Kidderville formation is underlain entirely by greenstones, the contact with the sediments of the overlying Gile Mountain formation is easily mapped.

Metamorphosed sedimentary rocks compose about 40 percent of this member (Table 7). Most of these rocks are gray to light-gray, rusty, sulfidic phyllites, schists, and quartzites. Interbedded with them are a few beds of non-sulfidic, light-gray, quartzose schist similar to the schists of the eastern member (Table 7, Nos. 116, 120). Unlike the sulfidic rocks of the felsic volcanic member and of the Dixville formation, the sulfidic rocks of the mafic volcanic member of the Kidderville formation contain very little graphite.

Most outcrops of the metasediments, and some outcrops of the meta-

TABLE 6

REPRESENTATIVE ESTIMATED MODES OF METAMORPHOSED SEDIMENTARY ROCKS OF THE FELSIC VOLCANIC MEMBER OF THE KIDDERVILLE FORMATION.

	Biotite zone									Garnet zone			
Sample No.	408	413	63	66	381	390	392	322	423	45	244	245	44
Quartz	94	60	88	58	40	40	42	35	68	66	60	60	56
Plagioclase[1]		2			10	5	7	3	15	5	22	5	8
Muscovite	5	25	8	25	40	44	40	30	1	20	2	20	25
Chlorite	tr	5	1		3	2	4	23	5	5	1	2	3
Biotite			3	5	4	7	5	5	5	3	10	10	2
Garnet								2[2]		1	3	1	3
Calcite			tr	10			1	2					
Ore[3]	1	3	tr	1	2	1	1	tr	1	tr		1	
Apatite						tr	tr		tr		tr	tr	tr
Tourmaline						1	tr			tr	2		
Zircon							tr		tr	tr		tr	
Magnetite													3
Graphite	tr	5		1	1				tr			1	
Epidote											tr		
Slate pebbles									5				

[1]The composition of the plagioclase is not listed because the mineral was dete cted only by X-ray methods.
[2]Spessartitic garnet
[3]Undifferentiated

Description and location of samples listed in Table 6

No.	Description and location
408	Fine-grained, gray, crinkly micaceous quartzite; 1970 feet elevation in Tracey Brook.
413	Dark-gray phyllite; 2220 feet elevation in Horn Brook.
63	Fine-grained, light-gray micaceous quartzite; 2160 feet elevation in the Diamond River.
66	Gray, calcareous phyllite; 1760 feet elevation in the Diamond River.
381	Fine-grained, gray mica schist; 1970 feet elevation in Horn Brook.
390	Fine-grained, gray mica schist; 0.2 mile north of the top of Van Dyck Mtn.
392	Gray mica schist; 0.5 mile ESE of the top of Sugar Hill.
322	Dense, gray mica schist; ¼ mile northwest of Mud Pond.
423	Mottled, gray schistose grit; 1980 feet elevation in the brook between Black Bluff and Tumble Dick Mtn.
45	Light-gray mica-quartz schist; at the southwest end of Moose Pond.
244	Light-gray plagioclase-garnet-mica schist; on the road 0.5 mile southwest of Moose Pond.
245	Dark-gray, biotite-spotted mica schist; 2000 feet elevation in Moose Brook.
44	Light-gray, crinkly mica schist with octahedral magnetite megacrysts; on the road, 0.6 mile south of Moose Pond.

volcanics, appear to be strongly sheared. This impression is partly caused by the thick coating of limonite that extends deep into the outcrops along slickensided planes. Thin sections of specimens from these outcrops show that most of the quartz is strongly strained, and that most of the biotite is partially altered to chlorite. In contrast, nearby outcrops of unsheared, unrusted rocks show much less straining of quartz, and much less alteration of biotite. Although no evidence exists for large-scale faulting, many small faults or shears may have at one time formed in these rocks. These shears may then have served as channelways for the introduction or redistribution of sulfides. Alternatively, beds rich in sulfides may have acted as planes of weakness during the shearing.

The mineralogy of the metasediments of the mafic volcanic member is indicated by the estimated modes listed in Table 7. Quartz, muscovite, chlorite, and biotite are the dominant minerals. Although garnet is present in a few specimens, its occurrence in tiny euhedral crystals and its absence from the pelitic schists of surrounding outcrops suggest that the garnet in most of these specimens is somewhat spessartitic.

In contrast to the felsites of the eastern member, most of the volcanic rocks of the western member of the formation are mafic or intermediate in composition (Table 8). Approximately the western third of the belt is underlain chiefly by greenstones and amphibolites. These rocks are light-green, poorly to moderately foliated chlorite-epidote-albite schists and chlorite-epidote-albite-actinolite schists. Schistosity is the only structure visible in most outcrops. In the vicinity of the Diamond Ponds, knots of epidote up to 2 inches in diameter are common in these rocks.

The rest of the western member of the formation comprises a variety of metamorphosed volcanic rocks interbedded with the phyllites and quartzites described above. Massive, gray-brown rhyodacitic and dacitic metamorphosed volcanic rocks, so common in the eastern member, are rare in the western member. In contrast, the few beds of felsic volcanics are schistose biotite-quartz-feldspar rocks (Table 8, Nos. 114, 149, 291, 425). Intermediate, or andesitic, material is common, and all gradations between meta-andesites and meta-dacites are found. Quartz-feldspar-chlorite-biotite schists and gneisses are the most abundant rocks. On South Ridge, outcrops of a greenschist are riddled with wedge-shaped holes half an inch across and one-sixteenth of an inch thick (Table 8, No. 174). These holes were formed by the weathering of wedge-shaped calcite crystals.

The remaining rocks of this western member are fine- and medium-grained amphibolites. Southeast of a line between Harvey Swell School and Sugar Hill, the metamorphosed basaltic and andesitic rocks are amphibolites (Table 8, Nos. 275, 373, 282). Northwest of this line they

TABLE 7

REPRESENTATIVE ESTIMATED MODES OF METAMORPHOSED SEDIMENTARY ROCKS OF THE MAFIC VOLCANIC MEMBER OF THE KIDDERVILLE FORMATION.

	Biotite zone									Garnet zone
Sample No.	40	110	116	120	279	281	427	434	436	5
Quartz	47	75	32	57	43 (Quartz and Plagioclase)	93	55 (Quartz and Plagioclase)	40 (Quartz and Plagioclase)	76 (Quartz and Plagioclase)	64
Plagioclase[1]		8	5	5						
Muscovite	40	tr	20	20	40		25	40	10	
Chlorite	1	1	35	10		tr	8	8	3	25
Biotite	10	10	5	7	15	7	6	10	10	1
Garnet			1[2]				4[2]			10
Carbonate		2								
Ore	2	3	2	1	2	tr	1	1	1	tr
Tourmaline	tr			tr	tr		1	1	tr	
Zircon	tr	tr	tr	tr	tr	tr	tr		tr	tr
Apatite			tr	tr	tr	tr	tr		tr	
Sphene		tr		tr						
Epidote		1								

[1]The composition of the plagioclase is not listed because the mineral was detected only by X-ray methods in most samples.
[2]Spessartitic garnet

Description and location of samples listed in Table 7.

No.	Description and location
40	Light-gray, biotite-spotted phyllite; 0.5 mile east of X 1414 on the highway east of Kidderville.
110	Purple-gray, massive, micaceous quartzite; Mohawk River at the Kidderville Dam.
116	Light greenish-gray mica schist; Mohawk River, 0.2 mile west of X 1414.
120	Gray mica schist; Mohawk River, 0.2 mile west of X 1414.
279	Light-gray mica schist; 0.6 mile west of Bungy.
281	Light-gray biotitic quartzite; 0.6 mile west of Bungy.
427	Gray spessartite-mica schist; 0.5 mile south of hill 2213, 3 miles NNE of Kidderville.
434	Gray, crinkled biotite phyllite; 0.5 mile east of Kidderville.
436	Gray, fine-grained mica-quartz schist; 1.5 miles east of Upper Kidderville.
5	Dark-green garnet-chlorite-quartz schist with quartz-garnet pods 1 inch in diameter; 1460 feet elevation in the Mohawk River.

are chlorite schists. The amphibole in the amphibolites is an actinolitic hornblende. In general, the amphibole becomes more hornblendic as the grade of metamorphism increases to the south. Quartz, albite or oligoclase, biotite, epidote, and an ore mineral compose most of the rest of these amphibolites.

TABLE 8

REPRESENTATIVE ESTIMATED MODES OF METAMORPHOSED VOLCANIC ROCKS OF THE MAFIC VOLCANIC MEMBER OF THE KIDDERVILLE FORMATION.

<table>
<tr><th>Sample No.</th><th>264</th><th>174</th><th>15</th><th>16</th><th>47</th><th>275</th><th>373</th><th>114</th><th>149</th><th>291</th><th>425</th><th>282</th></tr>
<tr><td>Quartz</td><td>10</td><td>5</td><td rowspan="2">30</td><td rowspan="2">37</td><td></td><td>10</td><td>5</td><td>30</td><td>33</td><td>24</td><td>20</td><td>15</td></tr>
<tr><td>Plagioclase</td><td>44</td><td>36</td><td>30</td><td>61</td><td>62</td><td>65</td><td>60</td><td>60</td><td>57</td><td>56</td></tr>
<tr><td>Chlorite</td><td>10</td><td>37</td><td>25</td><td>17</td><td>5</td><td></td><td>2</td><td>2</td><td>2</td><td>7</td><td>7</td><td></td></tr>
<tr><td>Biotite</td><td></td><td></td><td></td><td>1</td><td></td><td>10</td><td>tr</td><td>3</td><td>5</td><td>7</td><td>15</td><td>7</td></tr>
<tr><td>Actinolite</td><td>20</td><td></td><td>10</td><td>10</td><td>35</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Hornblende</td><td></td><td></td><td></td><td></td><td></td><td>15</td><td>25</td><td></td><td></td><td></td><td></td><td>20</td></tr>
<tr><td>Epidote</td><td>15</td><td>2</td><td>30</td><td>27</td><td>30</td><td>2</td><td>5</td><td>tr</td><td>tr</td><td></td><td></td><td>tr</td></tr>
<tr><td>Calcite</td><td></td><td>15</td><td>4</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Ore</td><td>1</td><td></td><td>1</td><td>1</td><td>tr</td><td>2</td><td>1</td><td>tr</td><td>tr</td><td>2</td><td>1</td><td>1</td></tr>
<tr><td>Sphene</td><td>tr</td><td>4</td><td></td><td></td><td>tr</td><td></td><td></td><td>tr</td><td></td><td></td><td>tr</td><td>1</td></tr>
<tr><td>Zircon</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>tr</td><td>tr</td><td>tr</td><td></td></tr>
<tr><td>Leucoxene</td><td></td><td></td><td></td><td>7</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Apatite</td><td></td><td></td><td></td><td></td><td></td><td>tr</td><td>tr</td><td>tr</td><td>tr</td><td>tr</td><td>tr</td><td>tr</td></tr>
<tr><td>Talc</td><td></td><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Plag. is:</td><td>Ab[1]</td><td>Ab</td><td>Ab</td><td>Ab</td><td>Ol[2]</td><td>Ol</td><td>Ab</td><td>Ol</td><td>Ab</td><td>Ol</td><td>Ab</td><td>Ol</td></tr>
</table>

[1]Albite
[2]Oligoclase

Description and location of samples listed in Table 8

No.	Description and location
264	Fine-grained, green chlorite-actinolite-epidote schist; ½ mile northwest of the north end of Diamond Pond.
174	Light-green chlorite schist with wedge-shaped calcite megacrysts; 2240 feet elevation on the west side of South Ridge.
15	Fine-grained, green chlorite-epidote-actinolite schist; on the road, ¼ mile northeast of Little Diamond Pond.
16	Medium-grained, gray-green albite-actinolite-chlorite-epidote granulite; on the road, ½ mile east of the northwest end of Little Diamond Pond.
47	Light-green, medium-grained epidote amphibolite; 1580 feet elevation in the East Branch of Hix Brook.
275	Fine-grained, dense, dark-green amphibolite; ⅔ mile west of Bungy.
373	Medium-grained, dense, dark-green amphibolite; 1400 feet elevation in Hix Brook.
114	Light-gray, faintly schistose, porphyritic dacite; Mohawk River, ½ mile east of Kidderville.
149	Medium-grained, gray, biotitic dacite; 1440 feet elevation in Roaring Brook.
291	Faintly banded chlorite-biotite dacite; 2050 feet elevation on the ridge between Uran Brook and the West Branch of Simms Stream.
425	Banded biotite-chlorite-plagioclase schist; 1 mile east of Harvey Swell School.
282	Medium-grained, dark-green amphibolite; ⅔ mile west of Bungy.

THICKNESS

The outcrop width of the Kidderville formation ranges from $3\frac{1}{2}$ miles in the northeast to less than a mile in the southwest corner of the quadrangle. The formation apparently pinches out completely a few miles to the southwest. The bedding dips between 70 and 90 degrees. The rocks of the formation are considerably folded. This is suggested by the anticline of rocks of the Dixville formation on Keyser Mountain. Only a rough estimate of the thickness can be made on this basis, however, since neither the true regional dip nor the amount of thickening by isoclinal folding are known. The outcrop width of the felsic volcanic member on the west side of Keyser Mountain is only 2000 feet, which suggests a thickness for this member of about 1500 feet. Just north of the Diamond Ponds, the outcrop width of the mafic volcanic member is 5000 feet. This width indicates that the mafic volcanic member, which is nearly vertical in this area, is 4000 to 5000 feet thick. The maximum total thickness for the formation is thus estimated to be about 6000 feet.

AGE AND CORRELATION

Southwest of the Dixville quadrangle, the Meetinghouse slate is the only formation between the Ordovician rocks and the Gile Mountain formation. No volcanic rocks have been reported in the Meetinghouse slate.

To the northeast, however, rocks comparable to and continuous with the Kidderville formation have been mapped. John Green (written communication, 1961) has tentatively traced these rocks through the Second Lake and Moose Bog quadrangles to the Quebec border (Plate III). At the border, they apparently strike into rocks of the Seboomook and Frontenac formations (Marleau, 1959). The felsic volcanic member of the Kidderville formation thus correlates with the Seboomook formation, and the mafic volcanic member correlates with the volcanics in the overlying Frontenac formation.

The Seboomook is fossiliferous and has been assigned to the Lower Devonian (Arthur Boucot, personal communication). The overlying Frontenac formation must therefore be Lower Devonian or younger. The Kidderville formation is thus assigned to the Lower Devonian.

Waits River Formation

GENERAL STATEMENT

The phyllites, schists, quartzites, and marbles of the Waits River formation crop out in a belt that trends north-northeast in the northwest part of the Dixville quadrangle. This belt is about 2½ miles wide at the Mohawk River and narrows northward to about 1¼ miles at the north edge of the quadrangle. Reconnaissance work by the writer in the Indian Stream quadrangle suggests that this body of Waits River formation terminates on the north side of Ben Young Hill, about 2 miles north of the 45th parallel (Plate III). The map pattern of the south end of this body is obscured by extensive drift cover, but the absence of calcareous rocks on and west of Carlton Hill indicates that it must narrow very rapidly south of the Mohawk River.

Two outcrops with marble beds are present in and immediately northeast of the Mohawk River at the contact between the Gile Mountain and Kidderville formations. These outcrops, which are indicated on Plate I, represent a thin eastern edge of the Waits River formation (Plate I, sections A-A′ and B-B′). The Waits River formation thus forms a wedge, which thins eastward, between the Kidderville and Gile Mountain formations. The two outcrops in question must be a small tongue on the east edge of this wedge.

LITHOLOGY

The contacts of the Waits River formation with the Gile Mountain formation to the east and west were mapped on the basis of the presence or absence of beds of quartzose marble and calcareous schist. With few exceptions, calcareous beds are absent from the rocks mapped as Gile Mountain formation. No amphibolite horizon comparable to the Standing Pond of east central Vermont is found in the Dixville quadrangle at the contact between the Waits River and Gile Mountain formations.

The rocks of the formation are gray quartzose marbles, calcareous schists, micaceous quartzites, mica-quartz schists, mica schists, and phyllites. The calcareous rocks compose between 5 and 15 percent of the formation, although they may form as much as 50 percent of some outcrops. Vein quartz is abundant in the formation and may form as much as 20 percent of some exposures. Individual beds range in thickness from less than 1 inch to 2 feet. The quartzose marbles and calcareous schists form the thicker beds; the phyllites and quartzites form the thinner beds.

All of the rocks are light to dark gray where fresh, but some beds of calcareous schist are rusty-brown on the surface because of the weathering of an iron-bearing carbonate.

Quartz, carbonate, muscovite, and chlorite are the most abundant minerals in these rocks. Some of the quartzose marbles contain as much as 80 percent of carbonate. X-ray diffractometry shows the presence of both calcite and dolomite in all the samples studied. Relative peak heights indicate that either carbonate may predominate over the other. The iron which causes the rusty weathering is presumed to be in the dolomite rather than in the calcite. The most abundant impurity in the

TABLE 9

REPRESENTATIVE ESTIMATED MODES OF THE WAITS RIVER FORMATION.

Sample No.	19	20	21	23	82	93	201	241
Quartz	42	55	27	23	8	33	15	74
Plagioclase[1]	5	6	3		2	5	5	10
Muscovite	25	11	3	5	4	2	2	
Carbonate		20	62	70	82	60	77	5
Chlorite	17	5			1			5
Biotite	7	tr	tr					5
Graphite	3	1	3	2	2		1	tr
Ore[2]	1	2	2		1	tr		1
Hematite	tr							
Apatite	tr	tr						
Zircon	tr							tr
Tourmaline	tr						tr	
Calcite/Dolomite + Calcite estimated from X-ray charts		10	60	70	25	50	65	100

[1]The composition of the plagioclase is not listed because it was detected only by X-ray methods in most samples.
[2]Undifferentiated ore minerals

Description and location of samples listed in Table 9

No.	Description and location
19	Gray, contorted phyllite; on highway, ½ mile northwest of Lombard Pond.
20	Gray, calcareous mica-quartz schist; on highway, ¼ mile southwest of Beaver Brook Falls.
21	Gray quartzose marble; Beaver Brook Falls.
23	Gray quartzose marble; 0.3 mile east of South Hill School.
82	Gray quartzose marble; 0.3 mile SSW of the top of Stevens Hill.
93	Gray quartzose marble; 0.8 mile SSW of Stewartstown Hollow.
201	Gray quartzose marble; junction of Gulch and Bishop Brooks.
241	Gray quartz-mica schist; Mohawk River, 0.2 mile southwest of Factory School.

marbles is quartz, with lesser amounts of fine-grained muscovite, chlorite, plagioclase, graphite, and minor accessories (Table 9, Nos. 21, 23, 82, 93, 201).

The calcareous schists and the quartzose marbles contain the same minerals, but their proportions are different. Carbonate makes up less than 50 percent of the calcareous schists. Quartz and mica are correspondingly more abundant than in the quartzose marbles. In some of the calcareous schists a few shreds of biotite are present. Calc-silicate minerals, such as diopside, tremolite, and grossularite, are not present in the Waits River formation.

The phyllites, schists, and quartzites of the Waits River formation are identical to the rocks so named in the Gile Mountain formation described below.

THICKNESS

The rocks of the Waits River formation are complexly and tightly folded. Because the rocks are relatively incompetent, considerable flowage has taken place, particularly in the calcareous beds. Furthermore, because the main belt of the formation forms the core of an anticline, its base is only exposed where the thin edge of the formation crops out to the east. The maximum thickness of the formation exposed in the Dixville quadrangle is estimated to be about 1000 to 1500 feet.

The chief difference between the Gile Mountain and Waits River formations lies in the presence of calcareous rocks in the Waits River formation. Therefore, the apparent eastward thinning of the formation to a feather edge may be the result of a combination of thinning and of facies change whereby fewer and fewer calcareous rocks are present in the section to the east.

In the Hanover quadrangle where the formation is better exposed, Lyons (1955) gives the thickness of the formation as 4000 feet. White and Billings (1951) suggest a thickness of about 10,000 feet for the formation in the Woodsville quadrangle.

AGE AND CORRELATION

The Waits River formation in the Dixville quadrangle is almost 25 miles from the nearest exposures of the main body of the formation in Vermont. The lithologic similarity to the rocks of the Waits River formation in Vermont, and the stratigraphic position below the Gile Mountain formation suggest the correlation.

Another interpretation is, however, entirely possible. White and

Billings (1951), Dennis (1956), Murthy (1957), and Lyons (1955) all describe lenses with abundant calcareous material within the Gile Mountain formation. Therefore, one could argue that the calcareous rocks in the Dixville quadrangle are a lens, or facies, within the Gile Mountain formation.

A second point that should be noted is that different authors have used different criteria to distinguish the Gile Mountain formation from the Waits River formation. Dennis (1956) and Hall (1959) both map outcrops with 25 percent or less of marble as Gile Mountain formation. Most other authors have apparently mapped as Waits River formation any rocks containing a few percent of marble or calcareous schist. This latter policy is the one which was followed in the Dixville quadrangle. Because of the relatively low percentage, about 10 percent, of calcareous rocks in the Waits River formation in the Dixville quadrangle, these rocks could, by the criteria of Dennis and Hall, be mapped as Gile Mountain formation.

In conclusion, the calcareous rocks of the Dixville quadrangle may be interpreted as either Waits River formation or a lens in the Gile Mountain formation. The name Waits River formation is used in this report largely to emphasize the differences between these rocks and the rocks of the Gile Mountain formation.

Cady (1960) gives the age of both the Waits River and Gile Mountain formations as Siluro-Devonian. If, however, the correlation of the Kidderville formation (p. 27) is correct, the Waits River formation is Lower Devonian or younger. The formation is thus assigned to the Devonian.

Gile Mountain Formation

GENERAL STATEMENT

Rocks of the Gile Mountain formation are known over a large area in eastern Vermont and western New Hampshire. These rocks underlie much of the northwest half of the Dixville quadrangle. They crop out in two belts which extend from Simms Stream to the north edge of the quadrangle.

At least 90 percent of the formation is composed of metamorphosed clastic sediments. Four long, narrow lenses of greenstone, shown separately on the geologic map, comprise the remaining few percent. Because the grade of metamorphism is relatively constant throughout the formation, the rocks are similar in appearance and mineralogy.

METAMORPHOSED SEDIMENTARY ROCKS

The metamorphosed sedimentary rocks of the Gile Mountain formation in the Dixville quadrangle are phyllites, mica schists, quartz-mica schists, and micaceous quartzites. These rocks range from brown through light and dark gray to black.

The contact between these metasedimentary rocks and the greenschists of the underlying Kidderville formation is sharp. This contact can be seen on the road across Cilley Hill and again about a quarter of a mile to the northeast. At both of these localities, careful measurements of the contact and of the foliation in the rocks on either side all agree within 3 degrees. The contacts between the Gile Mountain formation and the Waits River formation are gradational.

Although some local variations were noted in the sedimentary rocks of the Gile Mountain formation, no one type is sharp or distinctive enough, or geographically sufficiently isolated, to be mapped separately. Their approximate distribution is discussed below with the lithologic descriptions. Estimated modes of samples of the various rock types are listed in Table 10.

Brown schist

Rocks of the Gile Mountain formation within half a mile of the contact with the Kidderville formation have a distinctive brownish cast (Table 10, Nos. 12a, 34). The rocks of this belt are mica schists and quartz-mica schists; only a few scattered beds of gray phyllite are present. Except for their color, these rocks are generally similar to the gray mica schists and quartz-mica schists to the west. The brown color is apparently caused by the relatively high percentage of biotite.

Black phyllite and gray schist

Throughout the rest of the area underlain by metasedimentary rocks of the Gile Mountain formation, the outcrops show one of three rock types or rock associations. The first, and probably the most common, is the association of black phyllite and gray schist. Outcrops of these rocks contain abundant veins, pods, and rods of milky quartz. Some outcrops have little or none of the gray mica schist, but outcrops with abundant vein quartz and no phyllite are rare. Rocks of this association are always highly contorted, as is shown by the folding of the quartz veins, the bedding, and the schistosity. This contortion is so extreme in many outcrops that to measure a significant trend of bedding or schistosity, even

TABLE 10

REPRESENTATIVE ESTIMATED MODES OF METAMORPHOSED SEDIMENTARY ROCKS OF THE GILE MOUNTAIN FORMATION.

Sample No.	8	9	383	12a	25	29	30	34	288	50	92	94
Quartz	54	25	74	65	69	70	78	75	62	71	80	60
Plagioclase	15	40	10	20	20	20	10	8	5	10	10	31
Muscovite	15	20	10	2	2		2	1	15	8	5	2
Chlorite	6	10	5	3	8	7	4	2	5	4	1	5
Biotite				10		3	5	13	12	5	3	1
Carbonate	3											
Ore[1]	2		1	tr	1	tr	1	1	1	1	1	1
Sphene	tr				tr		tr	tr			tr	
Tourmaline	tr		tr	tr				tr	tr	tr	tr	
Apatite	tr			tr		tr	tr	tr		tr	tr	
Limonite	5											
Graphite		5	tr		tr		tr		tr	1		
Epidote						tr				tr		
Zircon			tr	tr			tr		tr	tr		tr
% An in plagioclase[2]	5	5	5	5	5	5	5	5	5	5	5	20

[1]Undifferentiated ore minerals
[2]Estimated from relief in thin section and from X-ray diffractometer charts

Description and location of samples listed in Table 10

No.	Description and location
8	Gray, ankeritic mica-quartz schist; BM 2316 on the west side of Mudget Mtn.
9	Shiny, crinkly, black, feldspathic phyllite; 0.1 mile south of BM 2316 on the west side of Mudget Mtn.
383	Gray quartz-mica schist; 1150 feet elevation on the northwest end of Collins Hill.
12a	Fine-grained, brown quartz-mica schist; on the road ¾ mile east of Bear Rock School.
25	Fine-grained, light-gray, laminated quartz-mica schist; on the road on the north side of Lovering Mtn.
29	Light gray-brown, foliated, feldspathic quartzite; on the road 1 mile northeast of the East Colebrook Church.
30	Gray-brown, fine-grained quartz-mica schist; on the road 1 mile northeast of the East Colebrook Church.
34	Fine-grained, brown quartz-mica schist; in the hollow between 1702 and 1768 on Marshall Hill.
288	Fine-grained, gray mica-quartz schist; on the hill ¾ mile southwest of Cleveland School.
50	Gray quartz-mica schist; on the road 0.6 mile south of Piper Hill School.
92	Medium-grained, light-gray micaceous quartzite; 1940 feet elevation on the trail on the west side of Piper Hill.
94	Light-gray, schistose, micaceous quartzite; 1300 feet elevation in the brook west of Stewartstown Hollow School.

though both structures may be present, is impossible. The quartz veins, generally 1 to 2 inches thick, are mostly conformable with the schistosity of the surrounding schists and phyllites, although they cut across both schistosity and bedding for short distances. The phyllites are dark gray or black, shiny, and complexly crinkled. The schists of this association are light- to dark-gray, fine-grained mica schists and quartz-mica schists. In some outcrops, all gradations are present between black phyllites and gray mica schists. The distribution of this association is irregular. It underlies most of the area between the Waits River formation and Dearth Hill. It also makes up about 35 percent of the rocks between the Waits River formation and the brown schist.

Ankeritic schist

In the remaining 65 percent of the area between the Waits River formation and the brown schist the rock is a gray, fine-grained quartz-mica schist characterized by numerous, round pits, 1 mm in diameter, filled with limonite (Table 10, No. 8). Although a moderately good schistosity is present in all outcrops, bedding is visible in only a few. Some outcrops with exposures 25 to 30 feet across the strike of the schistosity show no bedding. In other outcrops, however, a few phyllitic beds demonstrate that the bedding is parallel to the schistosity. Quartz veins are rare in this rock type.

When fresh material was obtained from an outcrop that showed limonite-filled pits on the surface, the unweathered rock was found to contain a few percent of carbonate (Table 10, No. 8). Since rust-pitted specimens contain no carbonate, it is concluded that the pits are caused by the weathering of an iron-bearing dolomite or ankerite and not of a sulfide mineral. The color and spotty occurrence of the rust in these rocks is in marked contrast to the coatings of red-brown limonite formed on the schists of the Dixville formation as a result of the weathering of iron sulfides.

Graded quartz-mica schist

A well-bedded, graded-bedded quartz-mica schist is exposed three quarters of a mile northeast of Read School and on the west side of Dearth Hill in the northwest corner of the quadrangle (Plate I, Fig. 3). This rock also crops out in the area west and southwest of Dearth Hill in the adjoining Averill quadrangle (Fig. 3). Excellent exposures of this rock may be seen on U. S. Route 3, about 1½ miles south of the village of West Stewartstown in the Averill quadrangle. Myers (1960) has mapped this rock as a separate member of the Gile Mountain formation and shows it as a northeast-trending belt about a mile wide where it

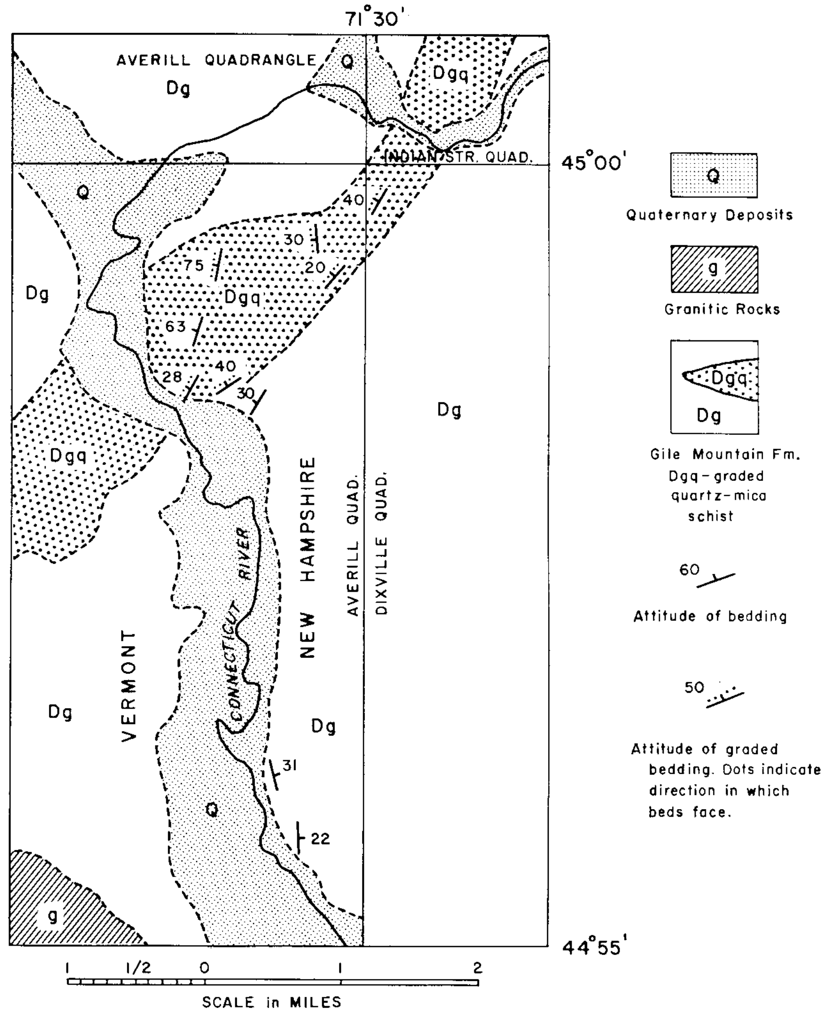


Figure 3. Geologic map of the northeast corner of the Averill quadrangle and adjoining parts of the Indian Stream and Dixville quadrangles. Vermont geology from Myers (1960).

crosses the Connecticut River. This belt continues across the west side of Dearth Hill and into the very southwest corner of the Indian Stream quadrangle (Fig. 3), beyond which it has not been traced. If continuous along strike to the northeast, this rock should prove an invaluable marker bed for working out the structure of the Indian Stream quadrangle. The beds of graded quartz-mica schist northeast of Read School could not be traced beyond the few outcrops in that area.

These rocks are gray to dark-gray, fine- to medium-grained micaceous quartzites, quartz-mica schists, and phyllites. Individual beds, which range in thickness from a few inches to 2 feet, may grade from light-gray micaceous quartzite, through quartz-mica schist, to dark-gray phyllite. Quartz veins are generally restricted to those outcrops in which the beds are thin, and in which black phyllite is relatively abundant.

Calcareous rocks

Minor amounts of calcareous rocks are present in the Gile Mountain formation. The contact between the Waits River and Gile Mountain formations is gradational. Although this contact was mapped by the appearance, approaching the Waits River formation, of beds of impure limestone, some thin beds of calcareous schist are mapped with the Gile Mountain formation. These calcareous schists are identical to the calcareous schists of the Waits River formation and serve to prove the gradational nature of the contact between the two formations.

GREENSTONE AND AMPHIBOLITE

Outcrops of greenschist are present in a narrow zone in the eastern belt of the Gile Mountain formation between Simms Stream and Deadwater Stream. This rock forms four long narrow lenses 500 to 1000 feet wide and 1½ to 4 miles long. These lenses are composed of greenish-gray to green, massive to moderately schistose greenstones and amphibolites. Slight compositional differences indicate original bedding in a few places, but in most outcrops bedding cannot be seen. Mafic volcanic material that is both compositionally and structurally homogeneous probably represents metamorphosed flows. A suggestion of a former ophitic texture in a few thin sections also leads to the same conclusion.

The mineralogy of these rocks is simple, partly because of their comcompositional homogeneity and partly because of their narrow range of metamorphic grade (Table 11). Albite, quartz, chlorite, and epidote are the abundant minerals. Most specimens contain small amounts of calcite and an amphibole. In all cases, this amphibole is dark-green and pleochroic in thin section and has a birefringence suggestive of a hornblendic rather than an actinolitic amphibole. In conclusion, the mineralogy and texture of these rocks suggest that the original rocks were flows of andesite and basalt.

THICKNESS

The thickness of the Gile Mountain formation in the Dixville quadrangle can only be estimated approximately. The stratigraphically highest rocks of the formation are exposed along the axis of a syncline that extends from Hedgehog Hill to the west side of Marshall Hill. The base of the formation is exposed along the east and west contacts of the Waits River formation and along the west contact of the Kidderville formation. The distance between the east contact of the Waits River formation and the axis of the syncline mentioned above ranges between three quarters of a mile and 3 miles. The larger distance at the north edge of the map is a result of the northward plunge of the formations. If the average easterly dip of the beds is assumed to be 30 degrees, the thickness of the Gile

TABLE 11

REPRESENTATIVE ESTIMATED MODES OF THE GREENSTONES AND AMPHIBOLITES IN THE GILE MOUNTAIN FORMATION.

Sample No.	262a	33	35	48	100	176
Quartz	14	10	20		15	20
Plagioclase	50	55	42	64	40	46
Calcite	10	6	5		2	15
Dolomite		4				
Chlorite	20	2	15	20		3
Biotite		10	tr	3		8
Hornblende		7	1	1	35	3
Epidote	1	5	15	10	5	4
Ore	2	1	2	2	3	1
Apatite		tr	tr		tr	tr
Muscovite	3					
% An in plagioclase	5	5	5	5	15	5

Description and location of samples listed in Table 11.

No.	Description and location
262a	Light-green, medium-grained chlorite-plagioclase schist; 0.9 mile southwest of the top of Hedgehog Hill.
33	Greenish-gray, calcareous biotite-plagioclase schist; 1/3 mile west of the East Colebrook Church.
35	Massive, medium-grained greenstone; 0.65 mile northwest of the East Columbia Church.
48	Medium-grained, light-green chlorite schist; 2/3 mile northeast of the East Colebrook Church.
100	Banded, medium-grained amphibolite; junction of Read Brook and the Mohawk River.
176	Greenish-gray biotite-plagioclase-calcite-quartz schist; 0.5 mile west of the East Colebrook Church.

Mountain formation at the north edge of the quadrangle is 8000 feet.

The lenses of greenschist are 500 to 1000 feet wide in outcrop. When allowance is made for the dip of the bedding, these lenses are estimated to make up about 500 feet of the total thickness of the formation.

AGE AND CORRELATION

The western belt of the Gile Mountain formation in the Dixville quadrangle is continuous with the Gile Mountain formation mapped in the Averill quadrangle (Myers, 1960). In the present paper, the age of the formation is given as Devonian for the following reasons: 1) The Gile Mountain formation conformably overlies the Kidderville formation, which is tentatively correlated with the fossiliferous Devonian Seboomook formation. 2) It is probably continuous with part of the Frontenac and Compton formations of Quebec which overlie the Seboomook formation (Marleau, 1959) (Plate III).

The greenschists in the Gile Mountain formation in the Dixville quadrangle are in approximately the same stratigraphic position, immediately above the graded quartz-mica schist, as are the amphibolites mapped by Myers (1960) in the Averill quadrangle. These greenschists are also correlated with the greenstones in the Frontenac formation in Quebec (Marleau, 1957, 1959).

Intrusive Rocks

GENERAL STATEMENT

The metamorphosed sedimentary and volcanic rocks of the Dixville quadrangle are cut by intrusive rocks assigned to eight units. Only six of these units, however, are in large enough bodies to show on the geologic map (Plate I). The two oldest units have been metamorphosed. They are the unmapped irregular sills and dikes of granite that intrude the Kidderville formation, and the metadiabase sills that are present in the Waits River and Gile Mountain formations.

The metadiabase, and the quartz monzonite that underlies much of the southeastern part of the quadrangle, are the only representatives of the New Hampshire magma series (Billings, 1934). The White Mountain magma series is represented in the Dixville quadrangle by the five remaining types; the diorite, syenite, and biotite granite that hold up the mountains in the southwest corner of the area, the stocks of leucogranite west of Uran Brook and on Owlhead Mountain, and numerous unmapped post-metamorphic dikes. These intrusive rocks are discussed below in chronologic order from oldest to youngest. Representative modes are listed in Tables 12 and 13.

SHEARED GRANITE

Many small irregularly shaped bodies of sheared granite are present throughout the western part of the Kidderville formation. Good examples of this rock can be seen along the road south of Little Diamond Pond. The contacts of this granite with the surrounding schists and volcanics are predominantly cross-cutting and highly irregular in plan. Nowhere does this rock form bodies large enough to map on the present scale.

The rocks described under the heading of sheared granite vary in mineralogy and texture. The two most common rocks are a slightly pinkish, poorly foliated biotite granite or granite-gneiss, and a schistose, chloritic, sphene-rich granite. Some specimens of the biotite granite-gneiss are sufficiently porphyritic to be called augen gneiss. One specimen of the gneiss contains an estimated 3 percent of sphene (Table 12, No. 277).

The schistose, chloritic granites, when viewed on a plane parallel to the schistosity, resemble many of the specimens of schistose felsic volcanics. On a weathered surface or in a plane oblique to the schistosity, however, crystals of potassic feldspar 4 and 5 mm in diameter set in a finer grained matrix of granular quartz and plagioclase indicate the granitic origin of the rock.

In these rocks the feldspars are sericitized, much of the biotite is altered to chlorite, and the texture is cataclastic. This texture, the alteration of the constituent minerals, and the fact that the micas in the rock appear to have been smeared out show that the granite has undergone the deformation of the surrounding rocks.

Whether all of the rocks included in this type are genetically related is impossible to determine. They are deformed and altered granitic rocks that have been intruded into the western part of the Kidderville formation. Their age is probably Middle or Upper Devonian because they intrude Devonian rocks that were metamorphosed in the late Devonian.

TABLE 12

ESTIMATED MODES OF INTRUSIVE ROCKS.

	Sheared granite				Metadiabase				Quartz monzonite					
Sample No.	17	150	277	280	11	27	168	177	7	76	429	250	252	371
Quartz	8	15	30	35	5	5			25	20	35	20	22	25
Plagioclase	20	15	22	16	47	46	69	47	35	30	30	35	30	35
K-Feldspar	66	63	30	35					33	40	23	41	40	32
Biotite		4	10	6	3	tr	8	3	4	5	6	3	5	5
Chlorite	5	1			3	2	12	5						
Muscovite									3	5	5	tr	2	2
Hornblende					25	35		25						
Epidote	tr	tr	3		12	3	tr	10	tr	tr	1		1	tr
Sericite		2		7										
Ore	1	tr	1	1	tr	tr	2			tr	tr	1	tr	1
Sphene	tr		3		} 3		} 1	} 10						
Leucoxene						9								
Zircon		tr		tr					tr		tr	tr	tr	tr
Calcite					1		7		tr		tr			
Apatite	tr	tr	1	tr	1	tr	1	tr		tr	tr	tr	tr	tr
Rutile											tr			
% An in plagioclase	7	5	20	15	5	5	3	5	20	Ol*	22	Ol	Ol	10

*Oligoclase

Description and location of samples listed in Table 12.

No.	Description and location
17	Pale greenish-gray, faintly schistose granite; 0.1 mile west of BM 2199 on the road west from Diamond Pond.
150	Light-gray, porphyritic biotite granite-gneiss; 1555 feet elevation in Roaring Brook.
277	Gray, foliated biotite granite-gneiss; 0.5 mile west of Bungy.
280	Faintly gneissic, pink biotite granite; 0.5 mile west of Bungy.
11	Medium-grained, massive, gray-green epidote amphibolite; BM 1713 by Bear Rock School.
27	Medium-grained, massive, gray-green amphibolite; 0.2 mile south of BM 1713 by Bear Rock School.
168	Medium-grained, massive, gray biotite-chlorite-calcite-plagioclase granulite; X 1842 on the west side of Kidder Hill.
177	Gray-green, medium-grained epidote amphibolite; 1 mile south of Hedgehog Hill.
7	Light-gray, medium-grained biotite-muscovite-quartz monzonite; 0.1 mile west of The Flume.
76	Fine-grained, light-gray biotite-muscovite-quartz monzonite; 0.4 mile southeast of X 1444 on highway.
429	Medium-grained, light-gray biotite-muscovite-quartz monzonite; road-cut 100 yards west of The Flume.
250	Medium-grained, pink, sub-porphyritic biotite-quartz monzonite; 0.5 mile north of Cranberry Bog Pond.
252	Pinkish-gray, medium-grained, sub-porphyritic biotite-quartz monzonite; 0.5 mile east of Cranberry Bog Pond.
371	Gray, medium-grained biotite-quartz monzonite; 1.2 miles east of the north end of Nash Bog Pond.

NEW HAMPSHIRE MAGMA SERIES

General statement

In the Dixville quadrangle the New Hampshire magma series is represented by sills of metadiabase and by two stocks of quartz monzonite.

Metadiabase

Sills of metamorphosed diabase are common in the eastern belt of the Gile Mountain formation between the Mohawk River and the north edge of the quadrangle. One sill of metadiabase is present in the Waits River formation between Kidder and Lang Hills. Similar sills are common in the southeast corner of the Indian Stream quadrangle; Green (written communication, 1961) has mapped them in the northwest part of the Second Lake quadrangle. Easily accessible exposures of this rock may be seen at the Bear Rock School in the Dixville quadrangle.

These sills are generally 20 to 500 feet thick, and some are as much as 3 miles long. The sills are all parallel to the foliation of the surrounding schists and were never seen to cross-cut their host rocks.

The rock composing these sills is a medium-grained, massive, gray-green epidote amphibolite (Table 12, Nos. 11, 27, 177). Because the rock is so massive, especially in contrast to the surrounding schists, it crops out well and tends to form long, narrow, rounded ridges. Many of the sills shown on the map (Pl. I) were first suspected from their topographic expression. Some of the outcrops seen in the field were connected with the aid of aerial photographs. The one small sill in the Waits River formation stands out sharply as a long, narrow ridge.

Mineralogically, these rocks are composed primarily of sodic plagioclase, actinolitic hornblende, epidote, chlorite, and biotite. The rock composing the sill in the Waits River formation (Table 12, No. 168) is unusual because it contains no amphibole. Its texture in thin section, however, makes the igneous origin of this rock unquestionable. Many specimens, especially from the northern part of the area, retain a diabasic texture. The percentage of dark minerals ranges between about 25 and 40.

The sills intrude the Lower Devonian Gile Mountain formation, and have been metamorphosed during the Upper Devonian. The rock of the sills closely resembles the Moulton diorite (Billings, 1937; Eric and Dennis, 1958; Hall, 1959) which is assigned (Billings, 1937, 1956) to the New Hampshire magma series. Because of this resemblance and because of its Devonian age, the metadiabase is assigned to the New Hampshire magma series, the age of which is discussed below under the quartz monzonite.

Quartz monzonite

Quartz monzonite underlies much of the southeast quarter of the quadrangle. This rock forms two stocks that may merge under the surficial deposits east of Phillips Pond (Plate I). The smaller of the two stocks underlies the Nash Bog Pond area. It extends in a tongue north to Simms Stream and east to Phillips Pond. The larger stock is highly irregular in plan; it holds up Cave Mountain and Mt. Kelsey, and underlies the valleys of Clear Stream and the West Branch of Clear Stream. The Nash Bog Pond stock is a continuation of the Long Mountain granite in the Percy quadrangle (Chapman, 1948). The larger stock is continuous with the quartz monzonite mapped by Green (1960) in the Errol quadrangle.

At The Flume and in the valley of Flume Brook, the contact with the metamorphic rocks is sharp. In other places, such as along the east and south sides of Dixville Peak, a zone up to half a mile wide is present along the contact in which large sills and dikes of quartz monzonite are abundant. In general, where the field evidence suggests a steeply dipping contact, the contact is sharp; where the evidence indicates a relatively flat contact, abundant sills and dikes are present. Along much of its contact, the quartz monzonite is roughly conformable with the foliation of the surrounding schists. In many areas, such as on the south side of Dixville Peak, the schistosity wraps around the quartz monzonite. Locally, however, the quartz monzonite is sharply cross-cutting.

The rock in these stocks varies somewhat in texture and in the relative proportions of the constituent minerals. Excellent exposures in fresh road-cuts may be found along the highway at the east end of Dixville Notch. There the rock is a medium-grained, light-gray, equigranular muscovite-biotite-quartz monzonite (Table 12, Nos. 7, 429). The rock is similar on Cave Mountain, in the valley of Clear Stream, and in the area north of Millsfield Pond. This rock also crops out in the lower parts of Wells, Kelley, and Watkinson Brooks, immediately west of Nash Bog Pond, and in Pike Brook and Nash Stream.

The average grain size of this rock is 2 to 4 mm. The proportions of potassic feldspar and plagioclase vary from sample to sample, and either feldspar may predominate. Most of the potassic feldspar shows the grid twinning of microcline, and some grains are microscopically slightly perthitic. Some quartz grains are strained—the only evidence of deformation in the rock. Muscovite and biotite are approximately equally abundant.

The second phase of the quartz monzonite is a porphyritic, gray, medium-grained biotite-quartz monzonite with traces of muscovite. This rock is present on Mount Kelsey, and makes up the tongue that extends north from Cranberry Bog Pond. It also crops out east of Nash Bog Pond (Table 12, Nos. 250, 252, 371). It differs from the equigranular phase chiefly in the porphyritic character of the potassic feldspar crystals, and in the smaller percent of muscovite. Muscovite generally cannot be seen megascopically, although traces of it are present in every thin section studied. Most hand specimens appear slightly porphyritic. The phenocrysts of potassic feldspar are 5 to 8 mm long and are set in a matrix of quartz and plagioclase grains 2 to 4 mm in diameter. Much of the potassic feldspar shows grid twinning, and some grains are perthitic. In all the specimens, the plagioclase is badly sericitized. The zoning of many plagioclase grains is accentuated by the more intense sericitization of the inner zones.

A finer grained phase of the quartz monzonite is present near Clear Stream in the area north and northwest of BM 1390 (Table 12, No. 76). This rock has roughly equal amounts of biotite and muscovite. Although a few larger phenocrysts of potassic feldspar are present, the rock is predominantly equigranular. Individual quartz and feldspar crystals are generally 0.5 to 1 mm in diameter. The structural and genetic relationship of this finer grained phase to the rest of the body is not known.

Although the equigranular and the porphyritic phases are markedly different in their extremes, they grade into one another, and mapping contacts between them is both difficult and arbitrary. Furthermore, when rough contacts are drawn, they are complicated and indefinite and mask any possible structural significance of the differences. For this reason, the two phases are mapped together on Plate I.

Small dikes of pegmatite are common throughout the quartz monzonite. The pegmatites, in addition to quartz and feldspars, generally contain muscovite; a few contain small pink garnets. No large or mineralogically complex pegmatites were seen in the quadrangle.

The quartz monzonite is considered part of the New Hampshire magma series (Billings, 1934) on the basis of lithology, the structural relations to the surrounding schists, and the overall similarity to the Concord and Bickford granites (Billings, 1956; Williams and Billings, 1938).

The geologic evidence (Billings, 1956; Lyons et al., 1957) indicates that the age of the New Hampshire magma series is post-Lower Devonian and probably Middle Devonian.

WHITE MOUNTAIN MAGMA SERIES

General statement

The five remaining types of intrusive rocks in the Dixville quadrangle belong to the White Mountain magma series (Billings, 1934). These types are the diorite, syenite, and granite in the southwest corner of the quadrangle, the leucogranite, and the post-metamorphic dikes. Despite the relief of the mountains in the southwest corner of the quadrangle, outcrops are poor, even on the steep slopes and the high summits. For this reason, the contacts between the diorite, the syenite, and the granite are known only roughly.

Hornblende-biotite diorite

The north end of the mountains in the southwest corner of the quadrangle is held up by a hornblende-biotite diorite (Table 13, Nos. 232, 234, 235). This rock crops out over an area of about 2 square miles. The best exposures, although not very accessible, are in Cree Notch one-quarter of a mile west of the northwest corner of the body in the Dixville quadrangle.

In hand specimen, this rock is a light-gray to gray, fine- to medium-grained, massive diorite. Some specimens contain needles of biotite or hornblende up to 1 cm long set in a matrix of plagioclase, biotite, and hornblende crystals averaging only 1 mm in length. Both hornblende and biotite are present in every specimen studied; either one may predominate. The plagioclase, which is a calcic oligoclase, is generally strongly zoned and sericitized. Most specimens contain minor amounts of quartz.

Almost every outcrop of the diorite is complexly cut by irregular dikes and stringers of biotite granite. Billings (1928) describes a similar diorite from the North Conway quadrangle which he says (p. 102) "has been remarkably shattered and impregnated by the biotite granite." Modell (1936, p. 1899–1900) describes the Endicott diorite in the Belknap Mountains as being brecciated and intruded by Conway granite. Based on these and other descriptions and the mineralogical similarity, a correlation with the diorite of the North Conway and Belknap areas seems reasonable.

Syenite

The very southwest corner of the Dixville quadrangle is underlain by a medium- to coarse-grained syenite that is a continuation of the body on Sugarloaf Mountain mapped by Chapman (1948) in the Percy quadrangle (Table 13, Nos. 227, 370). The contact between the syenite and the biotite granite to the north is gradational over at least part of its length. Where fresh, the syenite is blue gray; weathered exposures are light gray or white. Individual feldspar crystals average almost 1 cm in length throughout most of the outcrop area. Locally, the grain size of the rock is only 3 or 4 mm. The predominant dark mineral is a black hornblende.

TABLE 13

ESTIMATED MODES OF INTRUSIVE ROCKS OF THE WHITE MOUNTAIN MAGMA SERIES

	Hbd.-biot. Diorite			Syenite		Biotite granite				Leucogranite					Dike Rocks	
Sample No.	232	234	235	227	370	185	213	267	384[2]	141	198	199	249	292	62	101
Quartz	3	4	3	5	2	25	15	15	20	15	25	13	25	20		
Plagioclase	77	74	80	20		10		8			5		tr	8	76	20
K-Feldspar[1]				63	87	56	79	68	75	83	69	85	75	72		
Biotite	4	10	15	1		8	2	6	5	1	tr	1	tr	tr		
Hornblende	15	10	2	10	10		2	2	tr							
Augite															5	12
Olivine															15	3
Serpentine															2	10
Ore	1	1.5		1	1	1	2	1		1	1	1	tr	tr	2	1
Sphene		tr						tr								
Zircon			tr	tr	tr	tr	tr	tr								
Fluorite				tr												
Apatite	tr	0.5	tr	tr	tr	tr	tr	tr								
Rutile							tr									
Fine-grained matrix																54
% An in plagioclase	28	25	25	Ol[3]		Ol		Ol			Ol			Ol	47	65

[1]Predominantly microperthite [2]Estimated from hand specimen [3]Oligoclase

Description and location of samples listed in Table 13

No.	Description and location
232	Fine-grained, dense, gray hornblende-biotite diorite; 2100 feet elevation on the ridge ENE from hill 3176.
234	Light gray-brown, porphyritic hornblende-biotite diorite; 2800 feet elevation on the ridge east of hill 3176.
235	Light gray-brown, porphyritic biotite-hornblende diorite; 2050 feet elevation, 1.1 miles NNW of hill 3176.
227	Coarse-grained, light-pink hornblende syenite; 2850 feet elevation in the brook west of Castle Mtn.
370	Medium-grained, light-brown hornblende syenite; 2200 feet elevation in Silver Brook.
185	Medium-grained, light-brown biotite granite; 2000 feet elevation in the brook 1½ miles northeast of Blue Mtn.
213	Medium-grained, light-brown biotite-hornblende granite; 3100 feet elevation on the ridge northeast of Gore Mtn.
267	Pink, medium-grained biotite-hornblende granite; 3040 feet elevation in the brook immediately south of Cone Brook.
384	Coarse-grained, pink biotite granite; 0.2 mile southwest of the summit of Gore Mountain.
141	Light-pink, sub-porphyritic leucogranite; 2400 feet elevation on the east ridge of Owlhead Mtn.
198	Light-pink, medium-grained leucogranite; 2500 feet elevation on the northwest side of the southwest ridge of Owlhead Mtn.
199	Light-pink, medium-grained leucogranite with conspicuous round, gray quartz grains; 0.2 mile northwest of the summit of Owlhead Mtn.
249	Light-pink, sub-porphyritic, medium-grained leucogranite; 2300 feet elevation on the south side of Owlhead Mtn.
292	Light-pink, sub-porphyritic leucogranite with conspicuous round, gray quartz grains; on top of the ridge 0.2 mile east of 1860 feet elevation in the West Branch of Simms Stream.
62	Dense, black, fine-grained, sub-porphyritic dike rock; 2000 feet elevation, 0.25 mile east of Flume Brook.
101	Dense, black, fine-grained dike rock with phenocrysts of olivine 1 to 2 mm in diameter; junction of the Mohawk River and Read Brook.

Under the microscope, the feldspar is seen to be mostly microperthite; only minor amounts of separate plagioclase are present. Most specimens contain between 1 and 10 percent of quartz. Small amounts of biotite are also present generally, although a strongly pleochroic, dark-green hornblende predominates. Zircon is present in the syenite in amounts approaching 0.5 percent in some specimens. A trace of fluorite was noted in one specimen (Table 13, No. 227). No evidence was found in the area for the age of the syenite relative to either the biotite granite or the hornblende-biotite diorite. Modell (1936) describes a syenite similar to the Sugarloaf syenite that intruded a diorite comparable to the diorite described above. At Red Hill (Quinn, 1937), a fine-grained biotite granite comparable to the biotite granite described below cuts a syenite similar to the Sugarloaf syenite.

Biotite granite

The third, and most widespread representative of the White Mountain magma series in the Dixville quadrangle is the biotite granite. This rock holds up the highest mountains in the quadrangle. Exposures are generally poor, but the rock crops out well on and near the summits of Gore and Notch Mountains. Even where good exposures are plentiful, however, fresh material for petrographic study is difficult to find. For this reason, the samples (Nos. 185, 213, 267, and 384) listed in Table 13 may not be truly representative of the rock.

On Blue Mountain and on the slopes to the north and east, the rock is a medium-grained (averaging 3 to 4 mm), tan to pink, biotite or biotite-hornblende granite. The feldspar is largely microperthitic, although most samples show small amounts of a separate plagioclase phase. In thin section, the quartz grains appear slightly rounded, and many are badly fractured. In some specimens of this granite there are inclusions about 1 inch across of a fine-grained (0.5 mm) granite of the same color and mineralogy as the enclosing rock.

On Gore and Notch Mountains and in both forks of Gore Brook, the rock is a coarse-grained (8 to 10 mm) biotite granite (Table 13, No. 384). In hand specimen this rock is seen to be composed of rectangular, pink, feldspar crystals showing carlsbad twins, gray, sub-rounded, granulated quartz grains, and of somewhat smaller (4±mm) black, shiny biotite plates. Traces of hornblende are present in some specimens. A sample of this rock sufficiently fresh to warrant thin section study could not be obtained. In texture and in grain size, this rock closely resembles the hornblende syenite to the south and apparently grades into it. The similarity of this rock to the Conway granite (Billings, 1956) makes a correlation reasonable.

Leucogranite

A circular stock of leucogranite about 1¾ miles in diameter is exposed in the southeast corner of the Dixville quadrangle. This stock holds up Owlhead Mountain. A smaller stock of the same leucogranite intrudes the southwest end of the Kidderville formation in the West Branch of Simms Stream.

In outcrop and in hand specimen this rock is a pink or light brown, locally porphyritic granite with smoky, gray, rounded quartz grains and traces of a dark mineral (Table 13, Nos. 141, 198, 199, 249, 292). The microscopic mineralogy of this rock is extremely simple. Microperthite and quartz constitute at least 90 percent of every specimen. The only other mineral to make up more than 1 percent of any sample is the plagioclase that is present in only about half of the specimens. Traces of chloritized biotite and an ore mineral constitute a maximum of 2 percent of the rock. No other minerals are present.

The texture of the leucogranite in thin section is generally porphyritic. Tabular crystals of microperthite 5 or 6 mm long and slightly smaller crystals of quartz are set in a fine-grained (0.1 mm or less) groundmass of the same minerals. This groundmass constitutes between 5 and 50 percent of the rock. In some specimens with a high percentage of groundmass, the rock appears sufficiently brecciated to suggest that these round stocks are the plugs of ancient volcanoes. Although no volcanic rocks belonging to the White Mountain magma series are presently exposed in the Dixville quadrangle, it is possible that they were deposited in the area and were subsequently removed by erosion.

The leucogranite is thought to belong to the White Mountain magma series for the following reasons: 1) The rock is unfoliated. 2) It occurs in rounded stocks which cross-cut the foliation in the surrounding rocks. 3) The stocks appear to be unrelated to the regional metamorphism. 4) The feldspars in the rock are largely in the form of microperthite. 5) There is no muscovite in the rock. Immediately north of The Bog a dike of leucogranite cuts the quartz monzonite. No direct evidence was found for the age of the leucogranite in relation to any of the rocks of the White Mountain magma series described above.

Post-metamorphic dikes

All of the rocks of the Dixville quadrangle, both metamorphic and intrusive, are cut by mafic dike rocks. Most of these are dark gray or black, dense, fine-grained, and porphyritic (Table 13, Nos. 62, 101). Although gray or black where fresh, many dikes weather to a reddish-brown. The dikes have been intruded along fractures that are unrelated to the foliation in the surrounding rocks. None of the dikes are conformable with the foliation of the host rocks; none have been deformed. Most of the dikes are 4 to 6 feet wide; some can be traced as much as 50 yards along strike. About fifty were seen throughout the quadrangle; no one area shows a concentration significantly higher than does any other area.

These dike rocks are composed primarily of crystals of calcic plagioclase, augite, and serpentinized olivine set in a fine-grained matrix. Some dikes contain phenocrysts of black augite up to 1 inch in diameter. In other dikes, olivine grains one-quarter of an inch across are the most common phenocrysts. Although serpentinization of olivine is common, the plagioclase and augite in these dikes are generally fresh.

Age of the White Mountain magma series

Radioactive methods give ages averaging about 185 million years for rocks of the White Mountain magma series (Tilton et al., 1957). According to Holmes (1959) this age places the magma series in the Upper Triassic.

STRUCTURAL GEOLOGY

General Statement

Large- and small-scale northeast-trending folds dominate the structure of the Dixville quadrangle. Throughout the quadrangle the strikes of bedding, schistosity, axial planes of folds, and cleavage are generally within 20 degrees of N.20°E.

The structural pattern is complicated by more than one stage of deformation. For this reason, minor structures such as lineations and drag folds are not necessarily reliable guides to the larger structures. Primary sedimentary structures that indicate the direction of younger beds are rare in the quadrangle. Nineteen outcrops showing graded bedding and one showing pillow structure were seen in the field, and are plotted in Figure 4. The interpretation of the structure presented in this paper is based primarily on three factors: the map pattern of the formations, the 20 outcrops showing primary structures (Fig. 4), and the regional correlations. The minor structures will be considered later. Their attitude and distribution were mostly explained after the gross structure was worked out because they were found an unreliable guide to the major structures. Large intrusive bodies belonging to two periods of igneous activity and a major unconformity further complicate the structure of the quadrangle.

Major Structures

The major structural features in the quadrangle are six large folds and a major unconformity. The six folds are, from east to west, the Rice Mountain syncline, the Baldhead Mountain anticlinorium, the Abeniki Mountain syncline, the Keyser Mountain anticline, the East Colebrook syncline, and the Beaver Brook anticline. The axial traces of these folds are shown in Figure 4. The major unconformity is the contact between the Middle Ordovician Albee and Dixville formations, and the Lower Devonian Kidderville formation.

UNCONFORMITY

The Middle Ordovician rocks of the southeast part of the area are separated from the Lower Devonian rocks of the northwest part of the area by a major unconformity. The angularity of this unconformity is indicated by the fact that the main body of the Dixville formation, the amphibolites in the Dixville formation, and the Albee formation all underlie the Kidderville formation.

Southwest of the Dixville quadrangle, a comparable unconformity between Ordovician and Silurian or Devonian rocks has been mapped for many miles (Plate III). At Monroe, New Hampshire, there is evidence for faulting along this contact and the name "Monroe fault" has been applied (Eric et al., 1941). Hall (1959) offers evidence that the Monroe fault in the St. Johnsbury quadrangle is a faulted unconformity. The continuity of the Monroe fault or unconformity is interrupted immediately southwest of the Dixville quadrangle by a large intrusive body. (Plate III). Thus, although the possibility of a fault cannot be disregarded, the contact in the Dixville quadrangle can most easily be explained by a simple angular unconformity.

RICE MOUNTAIN SYNCLINE

Green (1960) presents evidence for a syncline the axis of which trends north-south on the west side of Rice Mountain on the very west edge of the Errol quadrangle (Fig. 4). The west limb of this syncline is exposed in the southeast and east-central parts of the Dixville quadrangle. Graded bedding in the Dixville formation indicates younger beds to the east in this area (Fig. 4). One outcrop of schist and quartzite with graded bedding on the west side of Mt. Metalak in the very southeast corner of the quadrangle indicates younger beds to the west (Fig. 4). This outcrop, like many others that are seemingly incompatible with the major structure, must be on the short limb of a minor fold.

BALDHEAD MOUNTAIN ANTICLINORIUM

The map pattern of the Albee formation at the north end of its outcrop area strongly suggests that the formation forms the core of a north-plunging anticlinorium. Assuming that the zig-zag pattern of the contact between the Albee and Dixville formations northeast of Baldhead Mountain is primarily due to folding, the anticlinorium includes six minor anticlines and five minor synclines. Because these minor folds are not shown by the basal contact of the Kidderville formation, they must have been formed before the deposition of the Kidderville formation. The fact that these minor folds are not reflected by the contact of the amphibolite body around Lake Gloriette is difficult to explain.

Minor structures and the map pattern of the Albee formation show that the Baldhead Mountain anticlinorium plunges northeast. The lineations in the main body of the Albee and Dixville formations are

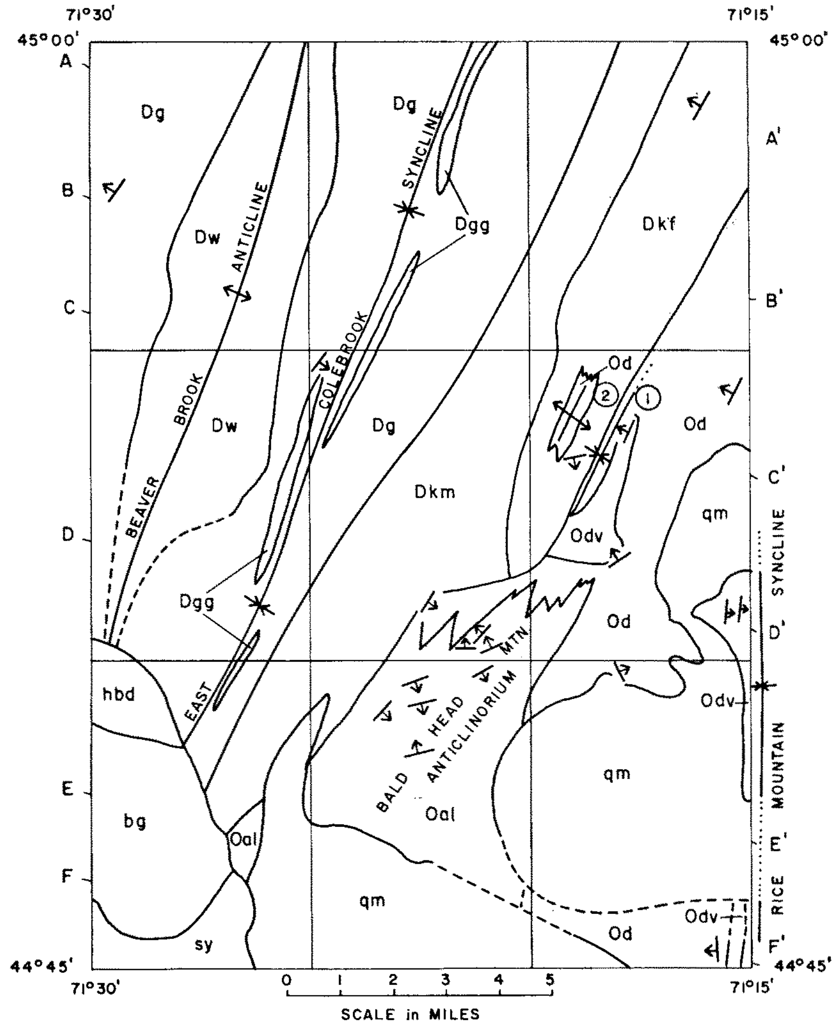


Figure 4. Simplified geologic map showing the location of topsense observations (arrow points in the direction of the younger beds) in relation to the axial traces of the major folds. Formation symbols are the same as on Plate I. (1) Abeniki Mountain syncline. (2) Keyser Mountain anticline

plotted in Figure 10. The pronounced northeast plunge is clear from this diagram and can be seen in the field in the cliffs of phyllite in Dixville Notch. Long slanting spires plunge into the north wall of the notch and form the steep ribbed slope of the south wall.

The absence of the Dixville formation from the west limb of the anticlinorium west and southwest of Baldhead Mountain is explained by pre-Kidderville erosion.

ABENIKI MOUNTAIN SYNCLINE

The east limb of a syncline, the west limb of which has been eroded off, is described by the amphibolite south and east of Abeniki Mountain. This amphibolite, which is present on the east limb of the fold, pinches out on Mud Pond Ridge. The axial trace of the syncline lies along the ridge of Abeniki Mountain, only a few hundred feet east of the contact between the Dixville and Kidderville formations. West-facing pillows at the north end of the body of amphibolite (Fig. 4) indicate the synclinal nature of the fold. The absence of a marker bed makes it impossible to trace the syncline north of Mud Pond Ridge. The relationship of the Abeniki Mountain syncline to the Baldhead Mountain anticlinorium is difficult to determine. It may correspond to one of the minor synclines in the anticlinorium, or it may be a structure west of the anticlinorium.

KEYSER MOUNTAIN ANTICLINE

On Keyser Mountain, the patch of rocks of the Dixville formation surrounded by rocks of the Kidderville formation indicates a doubly plunging anticline. This anticline is outlined by the contact between the Dixville and Kidderville formations. The bedding in the rocks of the Kidderville formation on the south end of Keyser Mountain wraps around parallel to the contact. Graded bedding in one outcrop on the southeast end of the mountain shows that the structure is an anticline. Because of the absence of marker beds in the Kidderville formation, this anticline cannot be traced beyond the immediate vicinity of Keyser Mountain.

EAST COLEBROOK SYNCLINE

Regional structural and stratigraphic evidence shows that the Kidderville formation underlies the Gile Mountain and Waits River formations. Therefore, the beds in the vicinity of the contact between the Kidderville and Gile Mountain formations must face west. Evidence presented below shows that the Waits River formation forms the core of an anticline, and that the beds on the east limb of this fold face east. A synclinal axis must therefore lie somewhere in the eastern belt of the Gile Mountain formation. Only one outcrop with graded bedding (Fig. 4) helps to locate this synclinal axis. The map pattern of the four lenses of greenschist in the Gile Mountain formation suggests two closely spaced belts that can be interpreted as two limbs of a fold. The axial trace of this fold would pass through the East Colebrook Church from which the fold derives its name.

The east limb of the East Colebrook syncline is made up of the Kidderville formation plus the easternmost part of the Gile Mountain formation. In contrast, the west limb of the syncline is formed of rocks of the Waits River and Gile Mountain formations. This apparent anomaly is explained by the eastward pinching of the Waits River formation (Plate I, sections A-A′ and B-B′ and Figure 16).

BEAVER BROOK ANTICLINE

The Waits River formation in the northwest corner of the quadrangle is flanked by rocks of the overlying Gile Mountain formation and thus forms the core of an anticline. Although this anticline appears on the map to be a relatively simple structure, it is greatly complicated in detail by minor folding. The bedding dips gently eastward all across the Waits River formation. On the west edge of the formation, however, the long limbs of the minor folds are nearly horizontal, and the short limbs dip steeply east (Plate I, section A-A′). An overall gentle westerly dip is the result. Good exposures of these minor folds may be seen at Beaver Brook Falls for which the anticline is named.

Large outcrops of thick-bedded, graded-bedded quartz-mica schist are present in the northeast corner of the Averill quadrangle and in the very northwest corner of the Dixville quadrangle (Fig. 3). These beds strike northeast, dip northwest, and face northwest. They give a clearer and more reliable indication of the northwest dips in this area than do the highly contorted beds on the west edge of the Waits River formation. Mapping in the northeast corner of the Averill quadrangle indicates that the tight folds at Beaver Brook Falls die out gradually in the direction of these graded beds.

Reconnaissance mapping by the writer in the Indian Stream quadrangle (Plate III) shows that the body of Waits River formation ends about 2 miles north of the 45th parallel, suggesting a north plunge at the north end of the body. The outcrop width of the Waits River formation narrows rapidly south of the Mohawk River. Although the south end of the formation is largely obscured by drift and intrusive rocks, the anticline probably plunges south in this area. Because most of the minor structures are unrelated to the major structures, the axis culmination must be located from the map pattern alone. On this basis, the culmination must lie immediately north of the Mohawk River.

Minor Structures

Minor structural features are common in the rocks of the Dixville quadrangle and are discussed under the following headings: schistosity, slip cleavage, minor folds, lineation, and joints.

SCHISTOSITY

Except for some of the micaceous quartzites and the quartzose limestones, the metamorphosed sedimentary rocks of the Dixville quadrangle possess a fair to excellent schistosity. In the Albee and Dixville formations, where individual schist beds are generally less than a foot thick, the schistosity is parallel, or nearly parallel, to the bedding on the limbs of folds, and intersects the bedding on the noses of folds. In the Kidderville formation, schistose rocks and minor folds are relatively rare. In general, where schistosity and bedding occur together, the two are parallel. In the Waits River and Gile Mountain formations, schistose rocks and minor folds are common. In these formations, the schistosity is parallel to the bedding on the noses as well as on the limbs of most folds.

Throughout most of the quadrangle, the schistosity strikes within 15 degrees of N.25°E. East of the East Colebrook syncline, the dip of the schistosity is generally steep to the east or vertical. Steep west dips are present locally, especially on the west limb of the Baldhead Mountain anticline. West of the East Colebrook syncline, the dip of the schistosity, and of the bedding to which it is parallel, is much less steep to the east. Most dips in this area fall within the range of 20 to 60 degrees to the east. In the extreme northwest corner of the quadrangle, on the northwest and west slopes of Dearth Hill, the schistosity strikes west and northwest and dips to the north and northwest.

SLIP CLEAVAGE

Throughout much of the Waits River and Gile Mountain formations, the schistosity described above is transected by a slip cleavage. This slip cleavage consists of a series of parallel planes, generally a quarter of an inch to 1 inch apart, along which the micaceous minerals have been reoriented so that their basal cleavage is parallel to the slip cleavage planes. This slip cleavage is generally associated with, and is the axial plane cleavage of, small folds the wavelength of which corresponds approximately to the spacing of the cleavage planes. In some outcrops, displacement of as much as a quarter of an inch has taken place along the slip cleavage planes.

The slip cleavage is particularly well developed in the phyllites and mica schists, and is rare or absent in the quartzose schists, calcareous schists, and ankeritic schists. For this reason, field data on the attitude of this cleavage are available only from restricted areas. Where the slip cleavage is common, however, it strikes roughly parallel to the bedding and schistosity and generally dips to the east at a steeper angle than does the schistosity (Figs. 5, 6, 7, 8, and 9, and Plate II). These diagrams also show the consistency of the attitude of the slip cleavage throughout the area.

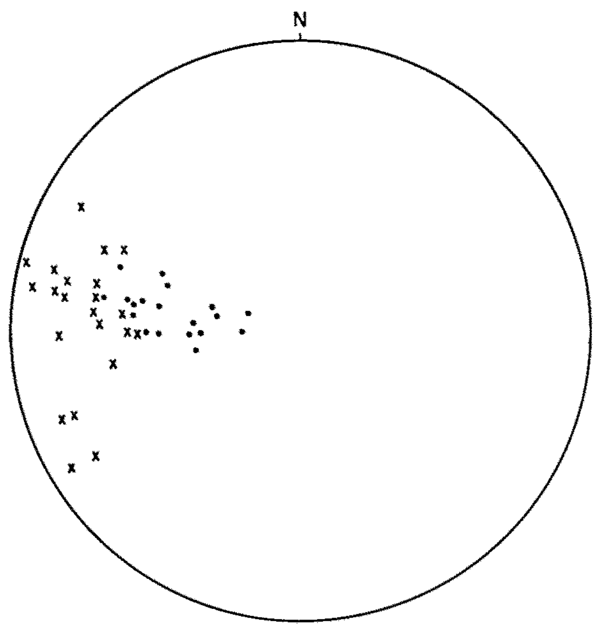


Figure 5. Poles of bedding and schistosity (•) and of slip cleavage and second deformation fold axial planes (x) in the Waits River formation in the vicinity of Bishop Brook.

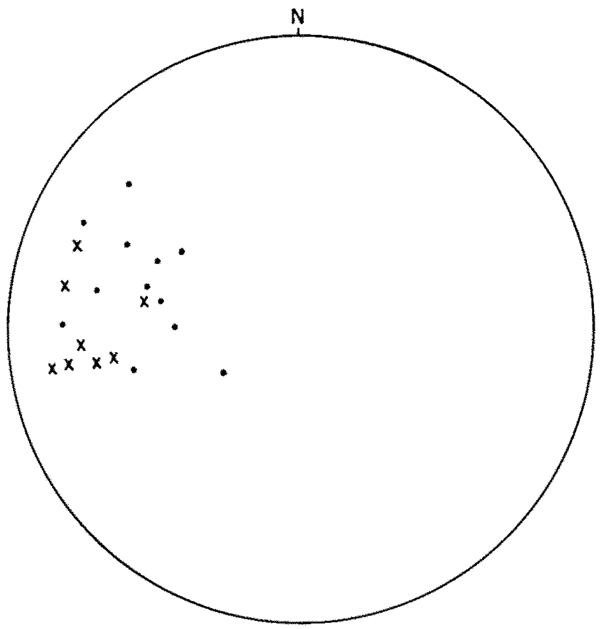


Figure 6. Poles of bedding and schistosity (•) and of slip cleavage and second deformation fold axial planes (x) in the Gile Mountain formation on the south end of Piper Hill.

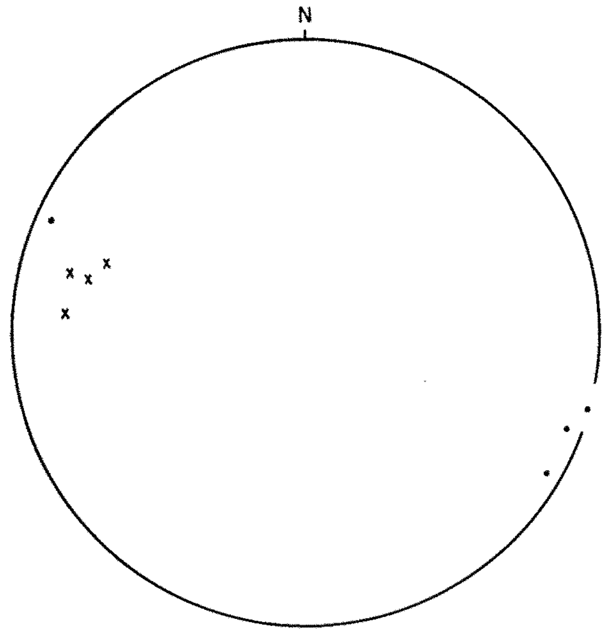


Figure 7. Poles of bedding and schistosity (•) and of slip cleavage and second deformation fold axial planes (x) in the Gile Mountain formation near the Mohawk School.

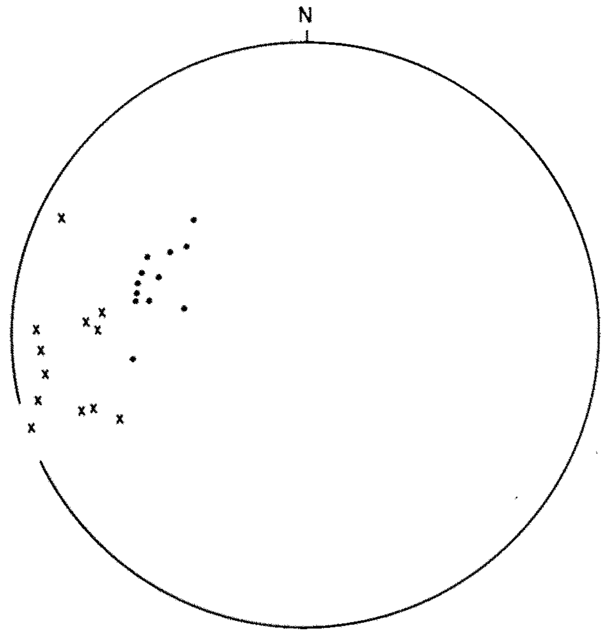


Figure 8. Poles of bedding and schistosity (•) and of slip cleavage and second deformation fold axial planes (x) in the Gile Mountain and Waits River formations along the east contact of the Waits River formation.

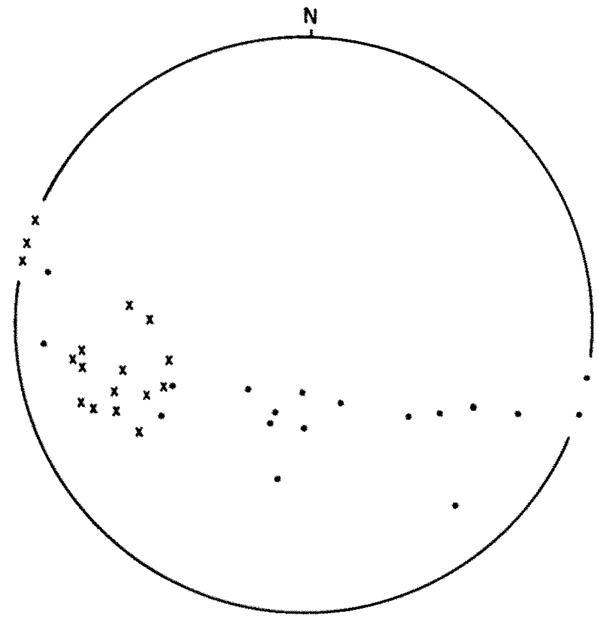


Figure 9. Poles of bedding and schistosity (•) and of slip cleavage and second deformation fold axial planes (x) in the Gile Mountain formation on Dearth Hill.

MINOR FOLDS

Minor folds are common in all of the metamorphic rocks of the quadrangle. Observed minor folds have wavelengths that range between less than an inch and 50 feet. Many have wavelengths of 5 to 10 feet and have drag folds on their limbs with wavelengths of 1 to 6 inches. The folds are generally nearly isoclinal.

Minor folds abound in the Waits River and Gile Mountain formations. Most of these folds deform the schistosity as well as the bedding, and their axial plane cleavage is the slip cleavage described above. In the Waits River formation, these folds are generally irregular because of the flowing of the calcareous beds. In Beaver Brook Falls, the excellent exposures make it possible to see much larger folds. These larger folds have wavelengths of about 30 or 40 feet and have long limbs and axial planes that dip very gently to the east. Although the noses of a few of the folds are exposed, the rocks are not sufficiently schistose to show whether or not the schistosity parallels the bedding on the noses. The axial planes of the folds dip very gently to the east, however, in contrast to the steeper eastward dips of the axial planes of the minor folds associated with the slip cleavage.

LINEATION

Many kinds of lineation are present in the Dixville quadrangle; axes of minor folds, crinkles, bedding-cleavage intersections, boudinage, parallel arrangement of prismatic mineral grains, and stretched pebbles. Of these, by far the most common are crinkles and the axes of minor folds.

Most crinkles are very small drag folds on the limbs of minor folds, and for this reason the plunges of crinkles and of axes of minor folds are generally the same in any given outcrop. Representative lineations are plotted on Plate II. A plot of the lineations in the Albee and Dixville formations (Fig. 10) shows a concentration of points that indicates a northeast plunge. A similar plot of the lineations in the Waits River and Gile Mountain formations (Fig. 11), however, shows a broad distribution of points across the east half of the diagram. If the lineations in the very northwest corner of the quadrangle, on the west side of Dearth Hill, are plotted separately (Fig. 12), a concentration of lineations plunging about 25 degrees N.15°E. is apparent.

JOINTS

Although joints are present in the rocks throughout the Dixville

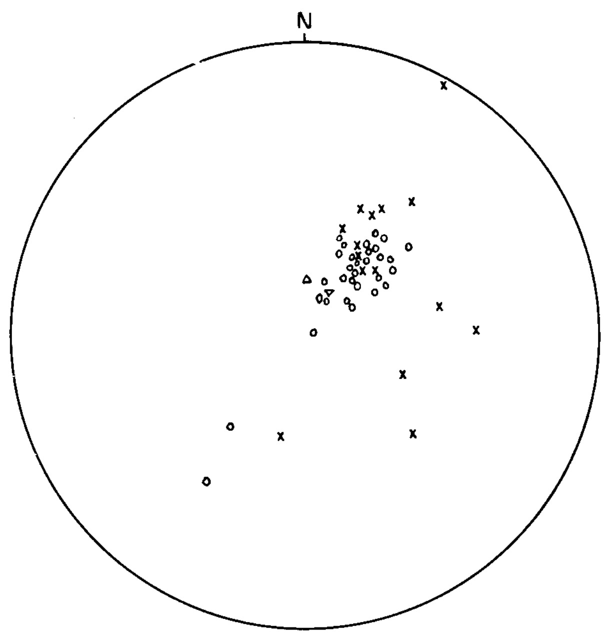


Figure 10. Lineations in the main body of the Albee and Dixville formations. x = axis of minor fold, o = crinkle, △ = boudinage neck. Schmidt net, lower hemisphere.

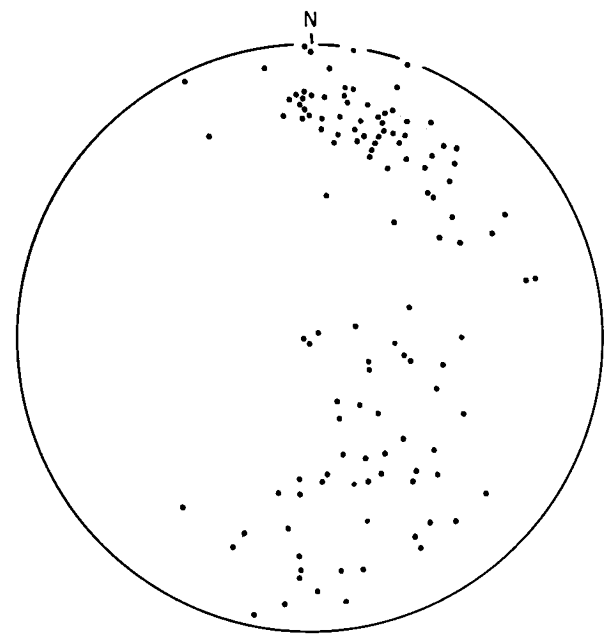


Figure 11. Plot of fold axes and crinkles throughout the Gile Mountain and Waits River formations east of Dearth Hill. Schmidt net, lower hemisphere.

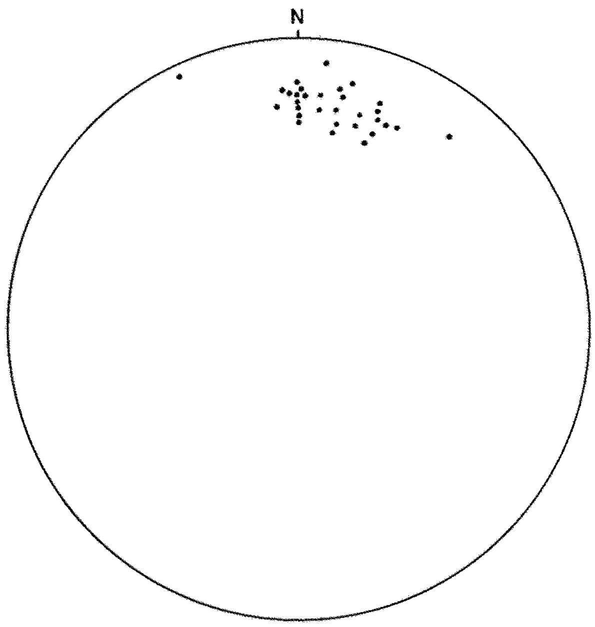


Figure 12. Plot of axes of minor folds and crinkles in the Gile Mountain formation in the vicinity of Dearth Hill. Schmidt net, lower hemisphere.

quadrangle, no special study of them was made. In most outcrops, no two joints have even approximately the same attitude. Readings were taken only on joint sets. Joints are considered to belong to a joint set only if three or more joints in the same outcrop have similar attitudes. Most joint sets meeting these requirements are found in the intrusive rocks, although a few sets are recorded from the more massive beds of the metamorphic rocks.

A plot of the poles of 68 joint sets from all over the quadrangle is presented in Figure 13. The scatter of points around the perimeter of the diagram shows only that most joint sets have steep dips and that strikes in virtually any direction are present. The fair concentration of points at the top of the diagram indicates a slight predominance of joints with east-west strikes and steep dips to the south.

Interpretation and Discussion

The structural features described on the preceding pages were all developed during the succession of events that make up the geologic

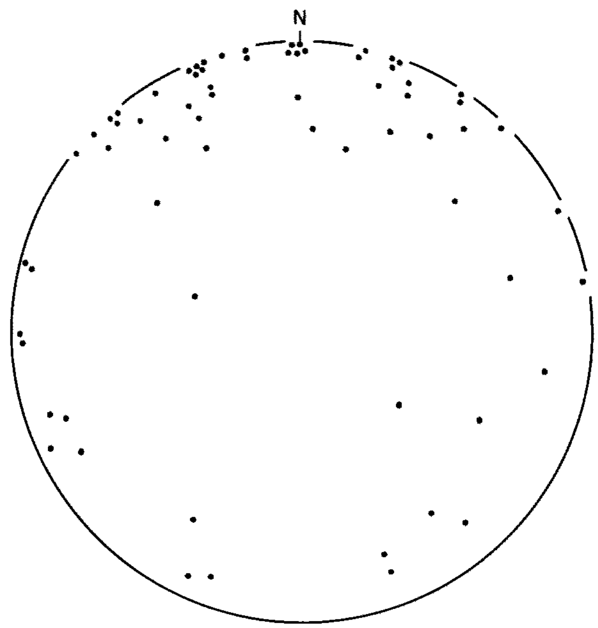


Figure 13. Poles of joint sets throughout the quadrangle.

history of the quadrangle. The detailed structure of the Waits River and Gile Mountain formations is more complex than that of the older formations of the quadrange. In the older formations the minor folds and lineations are consistent with the pattern of the major folds, and present no serious problems. In the Waits River and Gile Mountain formations, however, the two kinds of cleavage (schistosity and slip cleavage) and the variety of minor folds and lineations cannot easily be resolved into a simple structural pattern. Nearly identical structures with the same interrelations have been described from the same formations in east-central Vermont (White, 1949; White and Jahns, 1950; White and Billings, 1951; Eric and Dennis, 1958; Hall, 1959). All of these men concluded that the rocks have been subjected to two stages of deformation. During the first stage, isoclinal folds were formed, and an axial plane cleavage was developed. Because the folds were isoclinal, the axial plane cleavage was parallel to the bedding on the limbs of the folds. This cleavage is the bedding plane schistosity that is now present in the rocks. A second stage of deformation is superimposed on the first stage. These new folds folded the earlier cleavage (schistosity) as well as the bedding. The slip cleavage now present in the rocks is the axial plane cleavage of the folds of the second deformation. Although all writers speak of two "stages" of folding, it is understood that the stages may not have been separated by a period of tectonic quiet, but may rather represent two peaks in a longer period of deformation. This general theory of two "stages" of deformation with their associated folds and cleavages is compatible with all of the field observations in the Dixville quadrangle, and is accepted by the present writer.

It was noted above that at least some of the folds in the Ordovician rocks were formed prior to the deposition of the Kidderville formation. It must be stressed, therefore, that the two stages of deformation that affected the Devonian rocks are actually the second and third deformations to affect the area.

No evidence for either of the second two stages of deformation can be seen in the Dixville and Albee formations. The schistosity intersects the bedding on the noses of the minor folds and is only slightly deformed. Secondly, the attitude and plunge of lineations in the Albee and Dixville formations are consistent with the attitude and plunge of the major folds. All of these facts indicate that the Albee and Dixville formations have undergone only one major stage of deformation, and that one stage is assumed to have been the pre-Devonian stage.

The rocks of the Kidderville formation show evidence of only one stage of folding. No folded folds were observed, and no slip cleavage is developed in the rocks. In the Waits River and Gile Mountain formations, however, there is abundant evidence for two stages of deformation. Because workers in eastern Vermont have long referred to these two stages as the first and second stage, and because the rocks and structural relations in the Dixville quadrangle are the same as in eastern Vermont, the terms first and second stage are used in this report, despite the earlier deformation of the Ordovician rocks.

Most of the folds that were seen in outcrops of the Waits River and Gile Mountain formations belong to the second stage. The only folds in these two formations that may belong to the first stage are the folds with gently east-dipping axial planes at Beaver Brook Falls.

In Figures 5, 6, 7, 8, and 9, plots are made of both slip cleavage and schistosity in a series of restricted areas throughout the Waits River and Gile Mountain formations. The areas were picked only for their abundance of data, not because of any preferred orientation. The most obvious feature that these diagrams bring out is the fact that the slip cleavage and the schistosity both strike approximately north-south, but that the dip of the slip cleavage is slightly steeper than is the dip of the schistosity. This implies that the axial planes of the folds of the second deformation dip more steeply than do the axial planes of the folds of the first deformation. This in turn implies a slightly different orientation for the stresses causing the first and second deformations. A plot of all attitudes of slip cleavage and the axial planes of associated folds (Fig. 14) shows the consistent attitude of this structure throughout the area.

A second point brought out by Figures 5, 6, 7, 8, and 9, is that the attitude of the schistosity (and bedding) is remarkably constant in all the areas except that represented by Figure 9. The implication is that the folds in the areas in question are nearly isoclinal. The rough girdle formed by the poles of schistosity in Figure 9 suggests that the minor folds in the Dearth Hill area are more open. This suggestion is in agreement with the field observation that the tight folds in the Waits River formation die out to the west.

The structural history of the Devonian formations deduced from the above observations is essentially as follows: During the first stage of deformation, the major folds were formed. The shapes of these folds before the second deformation cannot be determined exactly, but they probably were close to the present shapes.

The second stage of deformation affected only the Waits River and Gile Mountain formations; the affect on the gross structure of the quadrangle was minor. Although mappable folds formed by the second stage of deformation are reported from east-central Vermont (White and Billings, 1951), no such folds are present in the Dixville quadrangle. The small folds and drag folds associated with the slip cleavage are the only folds of the second deformation in the quadrangle. The pattern of these drag folds is the chief clue to the orientation of forces during the second stage of deformation in the quadrangle.

In Figure 15 are plotted a representative sample of the drag folds of the second deformation—i.e. drag folds that deform the schistosity. These drag folds show a pattern that is consistent within themselves in the following respects: Regardless of plunge direction, all of the drags northwest of Dearth Hill have a west-side-up sense, and all of the drags between Dearth Hill and the Mohawk School have an east-side-up sense. East of the Mohawk School, very few drag folds of the second deformation are present, but the few that were noted have a west-side-up sense. This pattern of drag folds must have been formed by large-scale shear couples the orientation of which is shown in Figure 16. Nothing in the rocks gives any indication of the nature of the forces responsible for these shear couples.

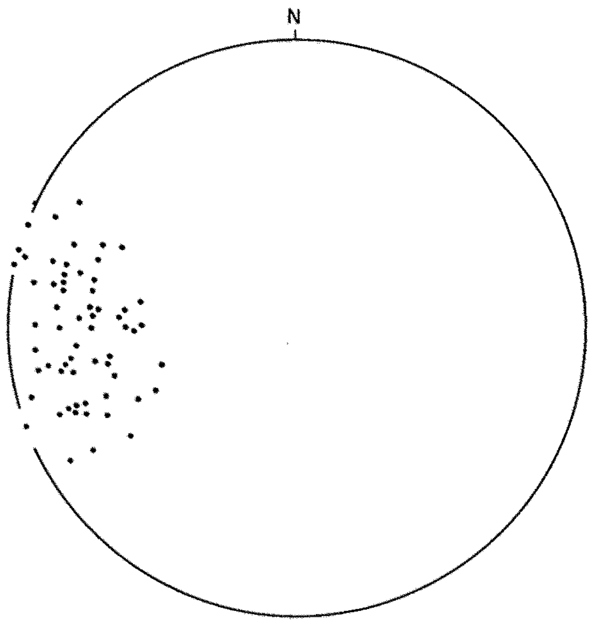


Figure 14. Compilation of the poles of slip cleavage and axial planes of folds formed during the second deformation. Compiled from Figures 5, 6, 7, 8, and 9. Schmidt net, lower hemisphere.

Structure of the Intrusive Rocks

The intrusive rocks of the New Hampshire and White Mountain magma series in the Dixville quadrangle show contrasting structural relationships to the surrounding metamorphic rocks.

The bodies of metadiabase in the north-central part of the quadrangle are concordant with the foliation of the surrounding schists and were apparently introduced by forceful injection. The contacts of the metadiabase are sharp. No blocks of schist were found in the metadiabase, and no subsidiary sills or dikes of metadiabase are present around the contact. The sills were probably intruded during the early stages of the folding and metamorphism in the area.

The quartz monzonite has both concordant and discordant contacts, and shows evidence of both forceful injection and magmatic stoping. In many places, as on the south side of Dixville Peak and the south side of peak 3610 of Whitcomb Mountain, the schistosity and bedding of the intruded metamorphic rocks are deformed into parallelism with the con-

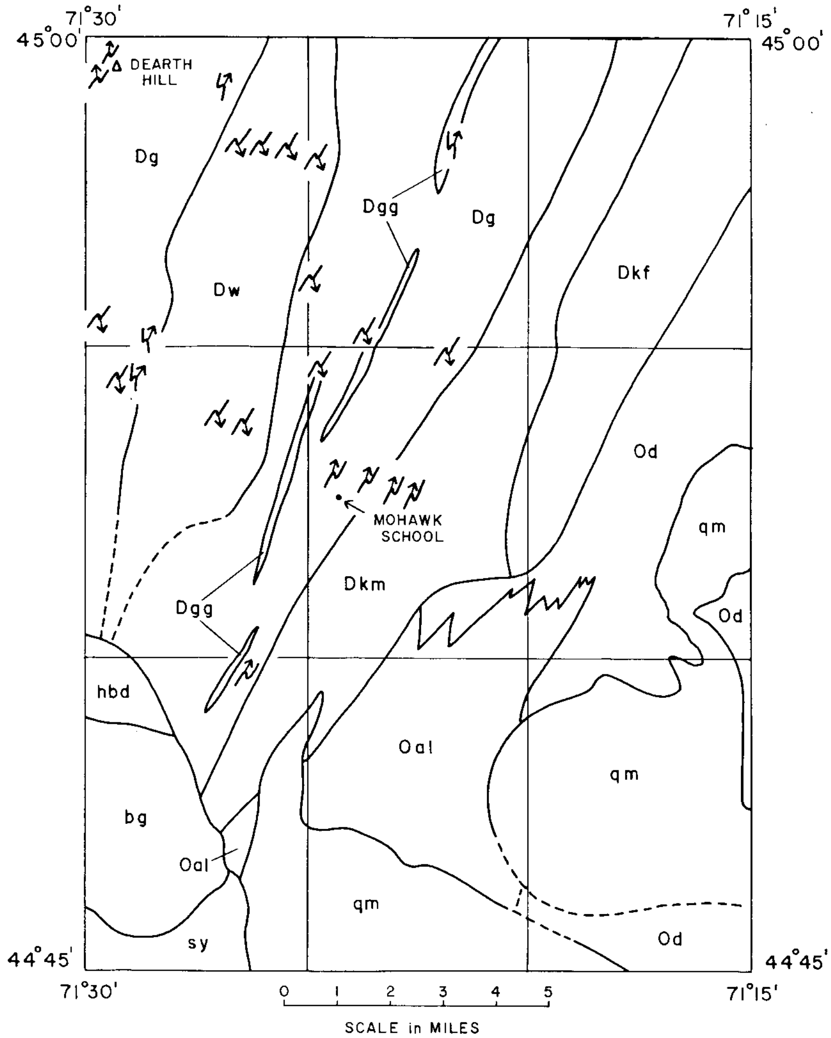


Figure 15. Simplified geologic map showing the map pattern and direction of plunge of drag folds associated with the second deformation. Formation symbols are the same as on Plate I.

tact of the quartz monzonite. Zones of migmatite up to 500 feet wide are present along the contact in many places. A zone up to half a mile wide with abundant dikes and sills of quartz monzonite is present along the contact on the east side of Dixville Peak. The irregular shape of the quartz monzonite bodies is also compatible with a mechanism of emplacement involving both forceful injection and magmatic stoping.

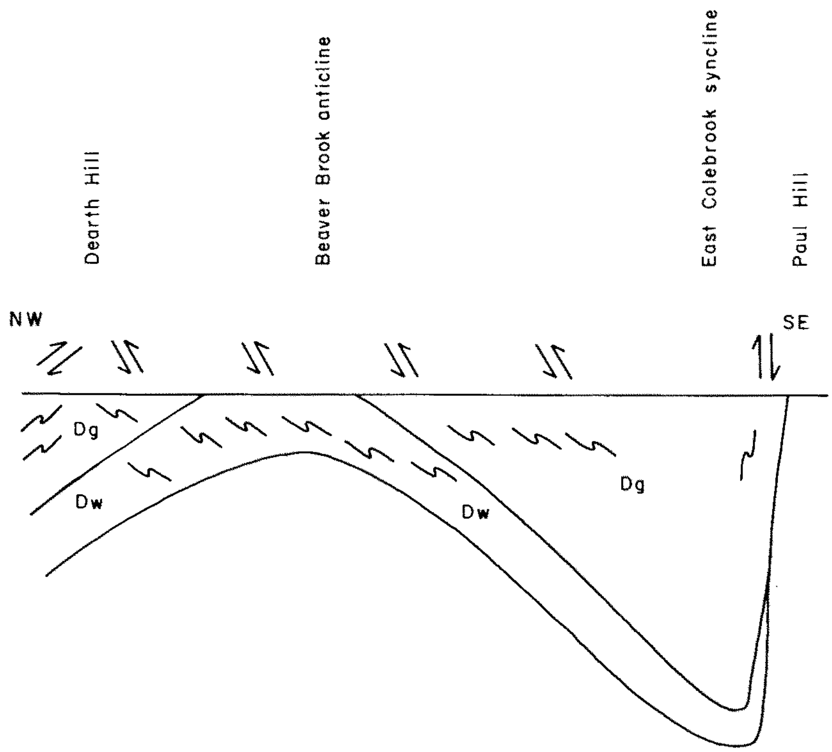


Figure 16. Schematic cross section between the northwest corner of the area and Paul Hill showing the pattern of drag folds formed during the second deformation. The orientation of the shear couples responsible for these drag folds is indicated above the section. Section is not to scale.

In contrast, the rocks of the White Mountain magma series in the Dixville quadrangle form round stocks with sharp cross-cutting contacts. The only bodies exposed in their entirety in the quadrangle are the two stocks of leucogranite. Both of these are round in plan, and both have sharp contacts. No migmatite zones are present around these stocks, and the foliation in the metamorphic rocks around the stock in the West Branch of Simms Stream is cut off sharply by the leucogranite. Less detailed information is available on the composite stock in the southwest corner of the quadrangle. The map pattern suggests, however, that the individual rock types may have formed roughly circular bodies prior to being intruded by later members of the magma series. That part of the body of biotite granite that is exposed in the Dixville quadrangle has a roughly arcuate contact. The foliation in the Gile Mountain and Kidderville formations is not deflected near the intrusive contacts. The presence of blocks of diorite suspended in the biotite granite clearly indicates intrusion by stoping of the biotite granite. A similar origin is assumed for all of the White Mountain magma series in the quadrangle, a conclusion that is in agreement with that reached by most other students of this magma series (Billings, 1956).

METAMORPHISM

General Statement

The rocks of the Dixville quadrangle show a wide range of metamorphic grade. The grade of metamorphism increases to the southeast. In the northwest part of the quadrangle, the rocks are in the biotite zone and much of the southern and southeastern parts of the quadrangle lies in the sillimanite zone. Metamorphic isograds based on the appearance of indicator minerals in pelitic schists are drawn on the geologic map (Plate I).

Pelitic Schists and Felsic Volcanics

The various mineral assemblages observed in pelitic schists and metamorphosed felsic volcanic rocks in the different metamorphic zones are listed in Table 14. These assemblages are also presented graphically in Figure 17, which shows the observed sequence of mineral facies plotted on Thompson's (1957) projection.

Along the northernmost edge of the quadrangle, chlorite is the only ferromagnesian mineral present in the pelitic schists, and the only mineral in these rocks to plot on the projection in Figure 17. In some of the felsic volcanic rocks of the Kidderville formation, however, biotite was seen both with and without potassic feldspar. For this reason, the absence of biotite from the pelitic schists is assumed to be due to bulk composition rather than grade of metamorphism. In the projection of Figure 17 the chlorite field covers the range of compositions of pelitic schists, as projected, for the low grade of metamorphism along the north edge of the quadrangle. With increasing metamorphism to the south, the lower edge of the chlorite field moves toward the Al_2O_3 corner of the projection, thus placing more and more rock compositions in the chlorite-biotite field. Biotite is common in the pelitic schists more than 3 miles south of the north edge of the area. Although garnets are present locally in the biotite zone, their small size, euhedral and graphite-clouded character, restricted occurrence in small lenses, and general absence from the otherwise similar surrounding phyllites suggest that they are spessartitic. Because garnets with appreciable manganese are known to occur in rocks below the garnet zone, these spessartite-bearing rocks are mapped as in the biotite zone.

The garnet isograd, which extends in a northeasterly direction from west of Cranberry Bog Pond to the north side of Cave Mountain, was mapped on the appearance of non-spessartitic garnets. Throughout the garnet zone the most common assemblage is chlorite-biotite-garnet. Other observed assemblages are noted in Table 14 and Figure 17 (b).

The staurolite isograd drawn on Plate I marks the appearance of either staurolite or staurolite plus andalusite. On the north and northeast sides of Dixville Peak, andalusite is common in the staurolite zone; the observed assemblages are shown in Figure 17 (d). In the area east of Baldhead Mountain, no aluminum silicate was found in the rocks of the staurolite zone; the observed assemblages are shown in Figure 17 (c). Because these two sets of assemblages are mutually inconsistent, they must represent slightly different pressure-temperature conditions in the two areas at the time of metamorphism.

The sillimanite isograd represents the first appearance of sillimanite, and presumably represents a rise in temperature such that the field of sillimanite is entered on the pressure-temperature diagram for Al_2SiO_5. The disappearance of andalusite does not correspond exactly with the appearance of sillimanite, however, and the two minerals occur together over a narrow zone immediately inside the sillimanite isograd.

Staurolite, although present in the rocks in the sillimanite zone, was not observed more than a quarter of a mile inside the sillimanite isograd. In this inner zone the only assemblages observed were sillimanite-chlorite-biotite and sillimanite-biotite. This apparent disappearance of staurolite is probably caused by a move toward the iron edge of the diagram of the composition of the biotite in equilibrium with sillimanite and chlorite. The result of such a move would be to greatly expand the range of rock compositions in which the assemblages biotite-sillimanite and biotite-sillimanite-chlorite were stable. This would be at the expense of such assemblages as sillimanite-biotite-staurolite, staurolite-biotite, and staurolite-garnet-biotite, all of which were observed immediately inside the sillimanite isograd. Although garnet is not present in the pelitic schists more than a quarter of a mile inside the sillimanite isograd, the assemblage garnet-biotite-potassic feldspar was observed with muscovite and quartz in some pegmatite dikes. Because the temperature of formation of these pegmatites was probably not appreciably higher than

Table 14

MINERAL ASSEMBLAGES OBSERVED IN PELITIC SCHISTS AND METAMORPHOSED VOLCANIC ROCKS. ALL ASSEMBLAGES INCLUDE QUARTZ AND MUSCOVITE.

Biotite zone
Chlorite
Chlorite-biotite
Biotite-potassic feldspar
(Chlorite-biotite-spessartite)
Garnet zone
Chlorite
Chlorite-biotite
Biotite-garnet
Chlorite-biotite-garnet
Staurolite zone
Chlorite-biotite
Biotite-garnet
Staurolite-biotite
Chlorite-biotite-staurolite
Biotite-garnet-staurolite
Chlorite-biotite-garnet-staurolite
Andalusite-biotite
Andalusite-biotite-chlorite
Andalusite-biotite-staurolite
Andalusite-biotite-garnet-staurolite
Sillimanite zone
Biotite
Sillimanite-biotite
Staurolite-garnet-biotite
Biotite-staurolite-sillimanite
Chlorite-biotite-sillimanite
Chlorite-biotite-sillimanite-andalusite
Biotite-staurolite-sillimanite-andalusite
Biotite-andalusite-sillimanite
Biotite-garnet-potassic feldspar (in pegmatite)

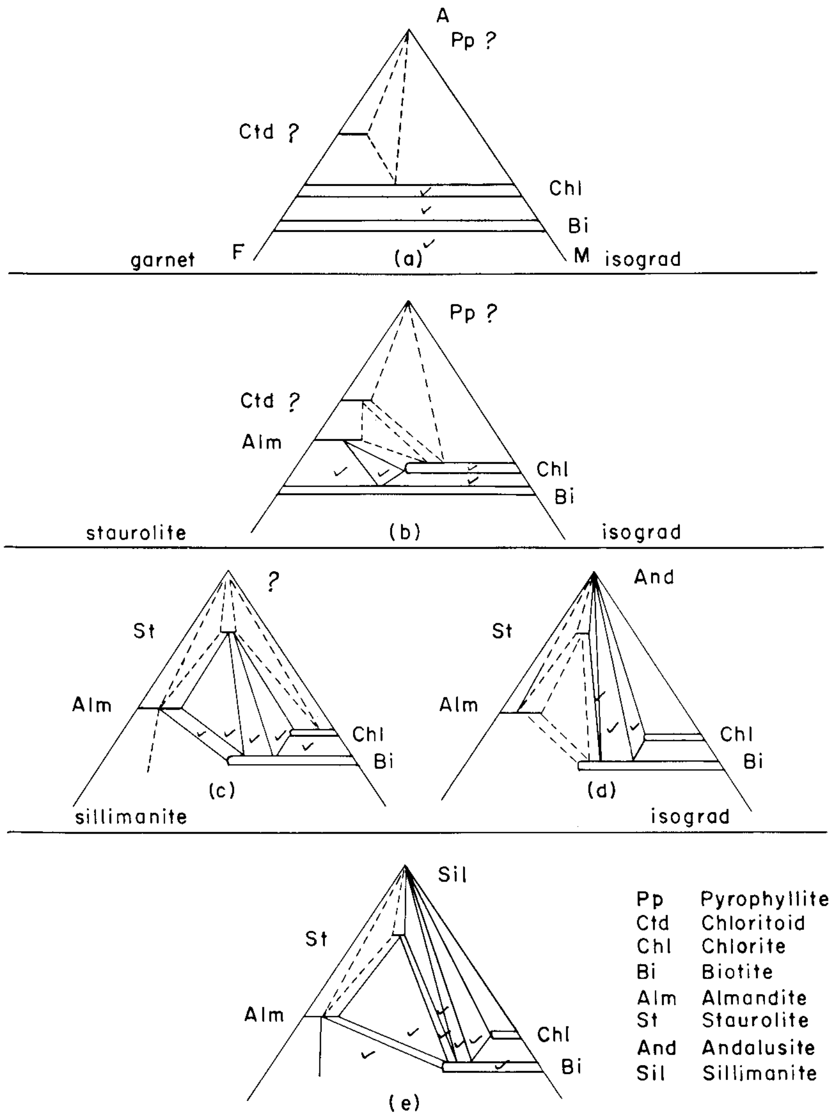


Figure 17. Sequence of mineral facies in the Dixville quadrangle plotted on Thompson's (1957) (Al_2O_3)(FeO)(MgO) projection. Checks indicatate minerals and mineral assemblages actually observed with quartz and muscovite. Dotted lines are inferred parageneses for rock compositions other than those observed.

the temperature of the surrounding schists, this assemblage can be included in Figure 17 (e).

A glance at the checked assemblages in Figure 17 brings out an interesting fact about the composition of the pelitic schists and other quartz- and muscovite-bearing rocks in the quadrangle. With regard to the three corners of the projection, FeO, MgO, and Al_2O_3, and remembering that the projection shows assemblages saturated with both muscovite and quartz, none of the observed assemblages requires a rock composition closer to the Al_2O_3 corner than chlorite composition. This restricted range of compositions is presumably responsible for the absence of such minerals as pyrophyllite, chloritoid, and possibly kyanite from the rocks of the Dixville quadrangle.

The absence of kyanite from the rocks of the quadrangle is of particular interest, and could be explained by one of two things. First, if kyanite is the stable form of Al_2SiO_5 only in the staurolite zone where the compatibilities are as shown in Figure 17 (c), and if it inverts to sillimanite before staurolite and chlorite react to yield aluminum silicate and biotite, no kyanite would be expected in rocks with the restricted range of composition discussed in the preceding paragraph. Second, the pressure during the metamorphism of the rocks of the Dixville quadrangle may have been too low to intersect the kyanite field in the pressure-temperature diagram for the system Al_2SiO_5 (Clark, Robertson, and Birch, 1957; Clark, 1960). The nearest known kyanite to the east of the Dixville quadrangle is on the Hampshire Hills in the eastern part of the Milan quadrangle (D. J. Milton, personal communication). To the southwest, the nearest reported kyanite is in the Hanover quadrangle (Lyons, 1955). Thus, in a large area andalusite is the only aluminum silicate in the rocks between the staurolite and sillimanite isograds. This area stands in contrast to much of southeastern Vermont where kyanite is abundant.

Mafic Volcanic Rocks

The lenses of mafic volcanic material in the Gile Mountain and Dixville formations and the mafic volcanic rocks in the Kidderville and Albee formations afford an opportunity to study the metamorphism of basaltic rocks in an area where isograds based on mineral assemblages in pelitic schists can be accurately drawn.

Along the north edge of the quadrangle, the common greenschist assemblage is albite-epidote-chlorite-(calcite). A few miles to the south, actinolitic hornblende is present in these rocks. With increasing grade of metamorphism, calcite decreases in abundance, the plagioclase becomes more calcic, and the common assemblage in the upper part of the biotite zone is epidote-chlorite-hornblende. This hornblende, and the hornblende in the amphibolites of higher grades, is dark-green and pleochroic and shows optical characteristics intermediate between actinolite and hornblende.

In the garnet and staurolite zones, both chlorite and epidote are less abundant, the plagioclase is more calcic, and the typical assemblages are hornblende-biotite, hornblende-chlorite-biotite, hornblende-chlorite, hornblende-epidote, hornblende-biotite-epidote, and hornblende-biotite-garnet.

In the sillimanite zone, the amphibolites contain only hornblende and a calcic plagioclase.

Calcareous Rocks

Calcareous rocks of the Waits River formation lie in the biotite zone in the Dixville quadrangle. The modes of these rocks listed in Table 9 show that chlorite and biotite are the only calcium or magnesium silicate minerals formed during their metamorphism. The typical assemblage is quartz-muscovite-plagioclase-calcite-dolomite-(chlorite)-(biotite).

REGIONAL CORRELATION

Two problems concerning regional correlation need further discussion. The first concerns the age of the Waits River and Gile Mountain formations. Evidence presented above (p. 27) suggests strongly that the Kidderville formation is continuous with the Seboomook and Frontenac formations in Quebec. Northeast of the Dixville quadrangle, the Seboomook formation is dated by fossils as Lower Devonian (Arthur Boucot, personal communication). Because the Waits River and Gile Mountain formations overlie the Kidderville formation in the Dixville quadrangle, they must both be Lower Devonian or younger. The age of these formations has generally been given only as Silurian or Devonian. This age is based on the fact that in Central Vermont (Cady, 1960) the Waits River and Gile Mountain formations overlie the fossiliferous (Arthur Boucot, personal communication) Silurian Shaw Mountain formation. In his columnar sections and restored cross sections, Cady indicates a probable Upper Silurian age for the Northfield slate and Waits River formation, and a Lower Devonian age for the Gile Mountain formation. If the Meetinghouse slate is correlated with the Kidderville formation on the grounds that they occupy the same stratigraphic position between the Gile Mountain (and Waits River) formation and the Ordovician strata (Plate IV), the Meetinghouse, and its possible correlative the Northfield slate, should also be dated Devonian. These relations are indicated in Figure 18.

The second problem that needs further discussion is the relationship between the Ordovician rocks of the Dixville quadrangle and of other nearby areas. In the Littleton-Moosilauke area (Billings, 1937) and throughout most of western New Hampshire, the stratigraphic sequence in the Ordovician rocks is, from oldest to youngest, quartzite and schist (Albee formation), volcanic rocks (Ammonoosuc volcanics), and black phyllite (Partridge formation). Some black phyllites are present in the Ammonoosuc volcanics. In the Old Speck Mountain quadrangle (Fig. 1) (D. J. Milton, personal communication), the sequence of Ordovician rocks is similar to that in the Littleton-Moosilauke area. In the Dixville quadrangle, however, the sequence is slightly different. The volcanic rocks (the amphibolites in the Dixville formation) are near the top of the black phyllites (the Dixville formation) instead of below them (Fig. 2).

Two possible interpretations are presented in Figure 19. In Figure 19 (a) the volcanic rocks are considered to be lenses at different stratigraphic positions in different areas. The fact that they form lenses rather than a continuous stratigraphic unit is clearly shown in the Dixville quadrangle where two separate lenses are mapped (Plate I). In this interpretation, more significance is attached to the change from quartzites to black phyllites plus volcanics than to the change from black phyllites to volcanics. The second interpretation (Fig. 19 (b)) considers the volcanics as the prime stratigraphic marker. That part of the Dixville formation that underlies the amphibolites correlates with the upper part of the Albee formation and the lower part of the Ammonoosuc volcanics; the metamorphosed sedimentary rocks of the Dixville formation above the amphibolites become the correlative of the Partridge formation.

Either of these interpretations is reasonable and possible. The interpretation shown in Figure 19 (a) is followed in this paper for the following reasons: 1) The amphibolites in the Dixville formation form two distinct lenses in the Dixville quadrangle. 2) Although lava flows and tuffs make the most reliable time-stratigraphic units, the presence of volcanic rocks all through the Paleozoic sequence in New England makes it unreasonable to assume that the amphibolites in the Dixville formation are co-magmatic with the Ammonoosuc volcanics. 3) The Ammonoosuc volcanics are predominantly soda-rhyolite tuffs and their metamorphosed equivalents, whereas the volcanics in the Dixville formation are almost entirely mafic. 4) Although some black phyllites are present in the Albee formation to the south and southwest, nothing has been reported that is comparable to the 2000 feet of uninterrupted black and gray phyllite and quartzite of the lower part of the Dixville formation.

PERIOD	DIXVILLE QUADRANGLE	SOUTHERN QUEBEC	EASTERN VERMONT	CENTRAL VERMONT	LITTLETON-MOOSILAUKE
(Lower) Devonian	Gile Mountain Waits River Kidderville	Compton Frontenac Seboomook	Gile Mountain Waits River Meetinghouse	Gile Mountain Waits River (Barton River) Northfield	Littleton
Silurian				Shaw Mountain	Fitch Clough
Middle Ordovician	Dixville Albee	Arnold River Complex		Cram Hill Moretown	Partridge Ammonoosuc Albee

Figure 18. Correlation chart comparing the geologic column in the Dixville quadrangle with the column in neighboring parts of New Hampshire, Vermont, and Quebec.

SUMMARY OF THE GEOLOGIC HISTORY

The deducible geologic history of the Dixville quadrangle begins in the Middle Ordovician when the sands and muds of the Albee formation were deposited. The scarcity of carbonaceous material and sulfide minerals suggests deposition in an oxidizing environment, and the poor sorting of sand and clay suggests relatively rapid deposition. Volcanic activity was minor during this time. At the end of Albee time the depositional environment changed, perhaps by isolation of the basin, and reducing conditions prevailed. The silts and clays of the Dixville formation were colored black by carbonaceous material and sulfides. During the latter part of Dixville time, volcanoes were active and flows and tuffs of basaltic material were deposited over much of the area.

After the period of deposition of the sediments and volcanics of the Dixville formation, the area was uplifted. The rocks were folded, but the exact degree of folding cannot be determined. Weathering and erosion began to wear down the area. South of the Mohawk River, all of the Dixville formation was eroded away. Further north, however, less and less of the Ordovician rocks were worn away, and about 4500 feet of the Dixville formation were preserved in the northeast part of the quadrangle.

The seas advanced across the Dixville quadrangle again in the Lower Devonian. Volcanoes were abundant, and the sands and muds of the Kidderville formation were interbedded with pyroclastic material and flows. At the beginning of Kidderville time, the volcanoes north of the Mohawk River extruded felsic material, whereas the volcanoes south of the Mohawk River extruded mafic material. During the latter part of Kidderville time, however, all of the volcanoes extruded mafic material. Volcanic activity increased, and less and less silt and sand were interbedded with the flows and tuffs as Kidderville time drew to a close.

At the close of Kidderville time, the seas retreated from the Dixville quadrangle, only to readvance almost immediately part way across the area. Apparently, no folding or deformation was associated with this brief period of emergence. The new seas advanced from the west to a line just west of the present contact between the Kidderville and Gile Mountain formations. From this sea were deposited the muds, sands, and limy

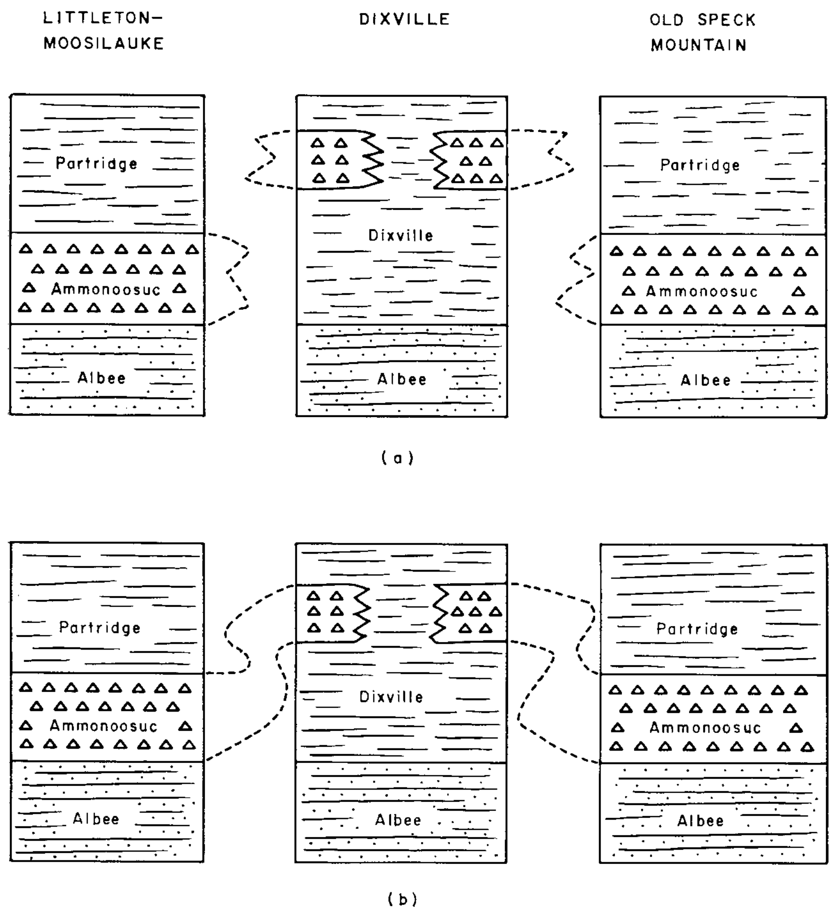


Figure 19. Two possible ways of correlating the Ordovician rocks of the Dixville quadrangle with the Ordovician rocks of the Littleton-Moosilauke (Billings, 1937) and Old Speck Mountain (D.J. Milton, personal communication) areas.

muds of the Waits River formation. As the seas advanced eastward, the deposition of limy mud stopped, and about 8000 feet of mud and sand of the Gile Mountain formation were laid down. During a brief period of volcanism, thin lenses of basaltic material were formed about 7000 feet above the base of the Gile Mountain formation. The exact eastward extent of the sea at this time cannot be determined.

During the Middle Devonian (?) the area was uplifted and irregular stringers and dikes of granite were intruded into the Kidderville formation. During the Upper Devonian, the major tectonic events of the geologic history of the quadrangle took place. Probably the first event was the formation of the major folds. Either immediately before or during this period of folding, sills of diabase were intruded into the Waits River and Gile Mountain formations. The most important events in the geologic history of the area followed immediately, and probably all occurred nearly simultaneously. The minor folds (of the "second deformation") were formed, the rocks were metamorphosed, and the quartz monzonite was intruded.

Following the period of folding, metamorphism, and intrusion during the Upper Devonian, the area was uplifted and erosion began. Little other than continued gradual uplift and erosion happened in the area until the Late Triassic. At this time, the rocks of the White Mountain magma series were intruded. No deformation or metamorphism other than some contact metamorphism was associated with the intrusion of these rocks.

Between the Late Triassic and the Pleistocene, the only geologic activity in the quadrangle was the gradual wearing down of the topography developed during the period of folding. During the Pleistocene, the area was covered by the continental ice sheet. In addition to depositing large quantities of boulders and drift, the ice sheet rounded and modified the topography. One of the interesting modifications produced by the glacier was the re-routing of the Connecticut River from a probable pre-glacial course through Stewartstown Hollow to its present course.

Since the retreat of the Pleistocene ice sheet, the streams and brooks have only slightly modified the topography of the area.

REFERENCES CITED

Billings, M. P. (1928) The petrology of the North Conway quadrangle in the White Mountains of New Hampshire: Proc. Am. Acad. Arts and Sci., v. 63, p. 67–137.

—— (1934) Paleozoic age of the rocks of central New Hampshire: Science, v. 79, p. 55–56.

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

—— (1955) Geologic map of New Hampshire: U. S. Geological Survey.

—— (1956) The Geology of New Hampshire, Part II—Bedrock Geology: New Hampshire State Planning and Development Commission, Concord, New Hampshire.

Boucot, A. J. (1953) The Lower Devonian rocks of West-Central Maine: doctoral thesis, Harvard University.

——, Griscom, A., Allingham, J. W., and W. J. Dempsey (1960) Geologic and aeromagnetic map of Northern Maine: U. S. Geological Survey.

Cady, W. M. (1960) Stratigraphic and geotectonic relationships in northern Vermont and southern Quebec: Geol. Soc. America Bull., v. 71, p. 531–576.

Chapman, R. W. (1935) Percy ring-dike complex: Am. Jour. Sci., 5th ser., v. 30, p. 401–431.

—— (1948) Petrology and structure of the Percy quadrangle, New Hampshire: Geol. Soc. America Bull., v. 59, p. 1059–1100.

Clark, S. P. (1960) Kyanite-sillimanite equilibrium: Annual report of the director of the Geophysical Laboratory, 1959–1960, p. 52–55.

Clark, S. P., Robertson, E. C., and F. Birch (1957) Experimental determination of equilibrium relations at high temperatures and pressures: Am. Jour. Sci., v. 255, p. 628–640.

Cooke, H. C. (1950) Geology of a southwestern part of the Eastern Townships of Quebec: Geological Survey of Canada, Memoir 257, 142 p.

Dennis, John G. (1956) The geology of the Lyndonville area, Vermont: Vermont Geol. Survey, Bull. No. 8, 98 p.

Eric, J. H. and J. G. Dennis (1958) Geology of the Concord-Waterford area, Vermont: Vermont Geol. Survey, Bull. No. 11, 66 p.

Eric, J. H., White, W. S., and J. B. Hadley (1941) Monroe Fault of New Hampshire and Vermont (Abstr.): Geol. Soc. America Bull., v. 52, p. 1900.

Green, John C. (1960) Geology of the Errol quadrangle, New Hampshire-Maine: doctoral thesis, Harvard University.

Hall, Leo M. (1959) The geology of the St. Johnsbury quadrangle, Vermont and New Hampshire: Vermont Geol. Survey, Bull. No. 13, 105 p.

Hitchcock, C. H. (1877) The geology of New Hampshire: part II, Stratigraphical Geology: Concord, New Hampshire, 684 p.

Holmes, Arthur (1959) A revised geological time-scale: Edinburgh Geol. Soc. Trans., v. 17, part 3, p. 183–216.

Lyons, J. B. (1955) Geology of the Hanover quadrangle, New Hampshire-Vermont: Geol. Soc. America Bull., v. 66, p. 105–146.

——, Jaffe, H. W., Gottfried, D., and C. L. Waring (1957) Lead-alpha ages of some New Hampshire granites: Am. Jour. Sci., v. 255, p. 527–546.

Marleau, R. A. (1957) Preliminary report on Woburn Area, Electoral District of Frontenac: Quebec Dept. of Mines Prelim. Rept. No. 336.

—— (1958) Preliminary report on East Megantic and Armstrong Areas, Electoral Districts of Frontenac and Beauce: Quebec Dept. of Mines Prelim. Rept. No. 362.

—— (1959) Age relations in the Lake Megantic Range, southern Quebec: Geol. Assoc. Canada Proc., v. 11, p. 129–139.

McGerrigle, H. W. (1935) Mount Megantic area, southern Quebec, and its placer gold deposits: Quebec Bur. Mines Ann. Rept., 1934, pt. D, p. 63–104.

Modell, David (1936) Ring-dike complex of the Belknap Mountains, New Hampshire: Geol. Soc. America Bull., v. 47, p. 1885–1932.

Murthy, V. R. (1957) Bedrock geology of the East Barre area, Vermont: Vermont Geol. Survey, Bull. No. 10, 121 p.

Myers, Paul B., Jr. (1960) Geology of the Vermont portion of the Averill quadrangle: doctoral thesis, Lehigh University.

Quinn, Alonzo (1937) Petrology of the alkaline rocks at Red Hill, New Hampshire: Geol. Soc. America Bull., v. 48, p. 373–402.

Ruedemann, R. (1947) Graptolites of North America: Geol. Soc. America Memoir 19, 652 p.

Thompson, J. B., Jr. (1957) The graphical analysis of mineral assemblages in pelitic schists: Am. Mineralogist, v. 42, p. 842–858.

Tilton, G. R., Davis, G. L., Wetherill, G. W., and L. T. Aldrich (1957) Isotopic ages of zircon from granites and pegmatites: Am. Geophys. Union Trans., v. 36, p. 360–371.

White, Walter S. (1949) Cleavage in east-central Vermont: Am. Geophys. Union Trans., v. 30, p. 587–594.

White, Walter S., and M. P. Billings (1951) Geology of the Woodsville quadrangle, Vermont-New Hampshire: Geol. Soc. America Bull., v. 62, p. 647–696.

White, Walter S., and R. H. Jahns (1950) Structure of central and east-central Vermont: Jour. Geology, v. 58, p. 179–220.

Williams, C. R., and M. P. Billings (1938) Petrology of the Franconia quadrangle, New Hampshire: Geol. Soc. America Bull., v. 49, p. 1011–1044.