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GEOLOGY OF THE CUPSUPTIC QUADRANGLE, MAINE

A THESIS PRESENTED

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ABSTRACT

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The Cupsuptic quadrangle, in west-central Maine, lies in a relatively narrow belt of pre-Silurian rocks extending from the Connecticut River valley across northern New Hampshire to north-central Maine. The Albee Formation, composed of green, purple, and black phyllite with interbedded quartzite, is exposed in the core of a regional anticlinorium overlain to the southeast by greenstone of the Oquossoc Formation which in turn is overlain by black slate of the Kamankeag Formation. In the northern part of the quadrangle the Albee Formation is overlain by black slate, feldspathic graywacke, and minor greenstone of the Dixville Formation. The Kamankeag Formation is dated as late Middle Ordovician by graptolites (zone 12) found near the base of the unit. The Dixville Formation is correlated with the Kamankeag Formation and Oquossoc Formation and is considered to be Middle Ordovician. The Albee Formation is considered to be Middle to Lower Ordovician from correlations with similar rocks in northeastern and southwestern Vermont. The Oquossoc and Kamankeag Formations are correlated with the Amonoosuc and Partridge Formations of northern New Hampshire.

The pre-Silurian rocks are unconformably overlain by unnamed rocks of Silurian age in the southeast, west-central, and northwest ninths of the quadrangle. The basal Silurian

units are boulder to cobble polymict conglomerate and quartz-pebble conglomerate of late Lower Silurian (Upper Llandovery) age. The overlying rocks are either well-bedded slate and quartzite, silty limestone, or arenaceous limestone. The arenaceous limestone contains Upper Silurian (Lower Ludlow) brachiopods.

The stratified rocks have been intruded by three stocks of biotite-muscovite quartz monzonite, a large body of metadiorite and associated serpentinite, smaller bodies of gabbro, granodiorite, and intrusive felsite, as well as numerous diabase and quartz monzonite dikes. The metadiorite and serpentinite, and possibly the gabbro and granodiorite are Late Ordovician in age. The quartz monzonite is considered to be Late Devonian.

Five tectonic events are inferred from the structural features in the area. The earliest was a period of folding producing tightly-appressed, northeast-trending folds in the rocks of pre-Silurian age. In the second stage the folded pre-Silurian rocks were uplifted, eroded, and truncated to produce a major unconformity between the Middle Ordovician and Lower Silurian rocks. These events constitute the Taconic orogeny. The third tectonic event was a period of folding, probably of Middle Devonian age, that warped the unconformity and overlying rocks into open, gently-plunging, east-trending folds. This period of folding undoubtedly changed the attitude of the early folds in the pre-Silurian units but it did not produce any recognizable, cross-cutting planar features in the older rocks. The fourth tectonic event was a period of igneous intrusion that locally deformed the northeast-trending folds in the pre-Silurian rocks into a macroscopic drag fold plunging at 80 degrees in a direction S.10^{o}W. A north-trending, subvertical slip cleavage was produced locally during this period of Late Devonian (?) deformation. A period of faulting, possibly of Triassic age, dislocated some of the earlier features.

The rocks are in the chlorite zone of regional metamorphism, but have been contact metamorphosed to sillimanite-bearing hornfels adjacent to the quartz monzonite stocks. The chemical changes in chlorite, biotite, garnet, cordierite, and muscovite in the chlorite, biotite, andalusite, and sillimanite zones have been studied by optical and x-ray methods and by partial chemical analyses. The progressive changes in mineral assemblages have been graphically portrayed on quaternary diagrams and ternary projections.

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Location, access, and culture

The Cupsuptic quadrangle comprises an area of about 200 square miles in west-central Maine between 45°15' North latitude and 70°45' and 71°00' West longitude. The western border of the quadrangle lies about 3½ miles east of the Maine-New Hampshire state line. The International Boundary between the Province of Quebec (Woburn Sheet) and Maine forms a 5 mile segment of the northern border of the map area. As shown in Figure 1, the eastern third of the quadrangle is in Franklin County, Maine, and the remainder lies in Oxford County, Maine. The southeast corner of the quadrangle is 6 miles northwest of Rangeley, Maine, the principal settlement in the area.

Dr. Samuel Stephenson traversed up the Magalloway River in the summer of 1838 and noted:

> "The land in the vicinity of this lake (Parmachenee) is exceedingly fine; and would most undoubtedly prove a valuable tract of country were it not situated so far north beyond the reach at least of civilized man." (in Jackson, 1839, p. 201).

One hundred and twenty-six years later the land near Parmachenee Lake is remote but not beyond the reach of

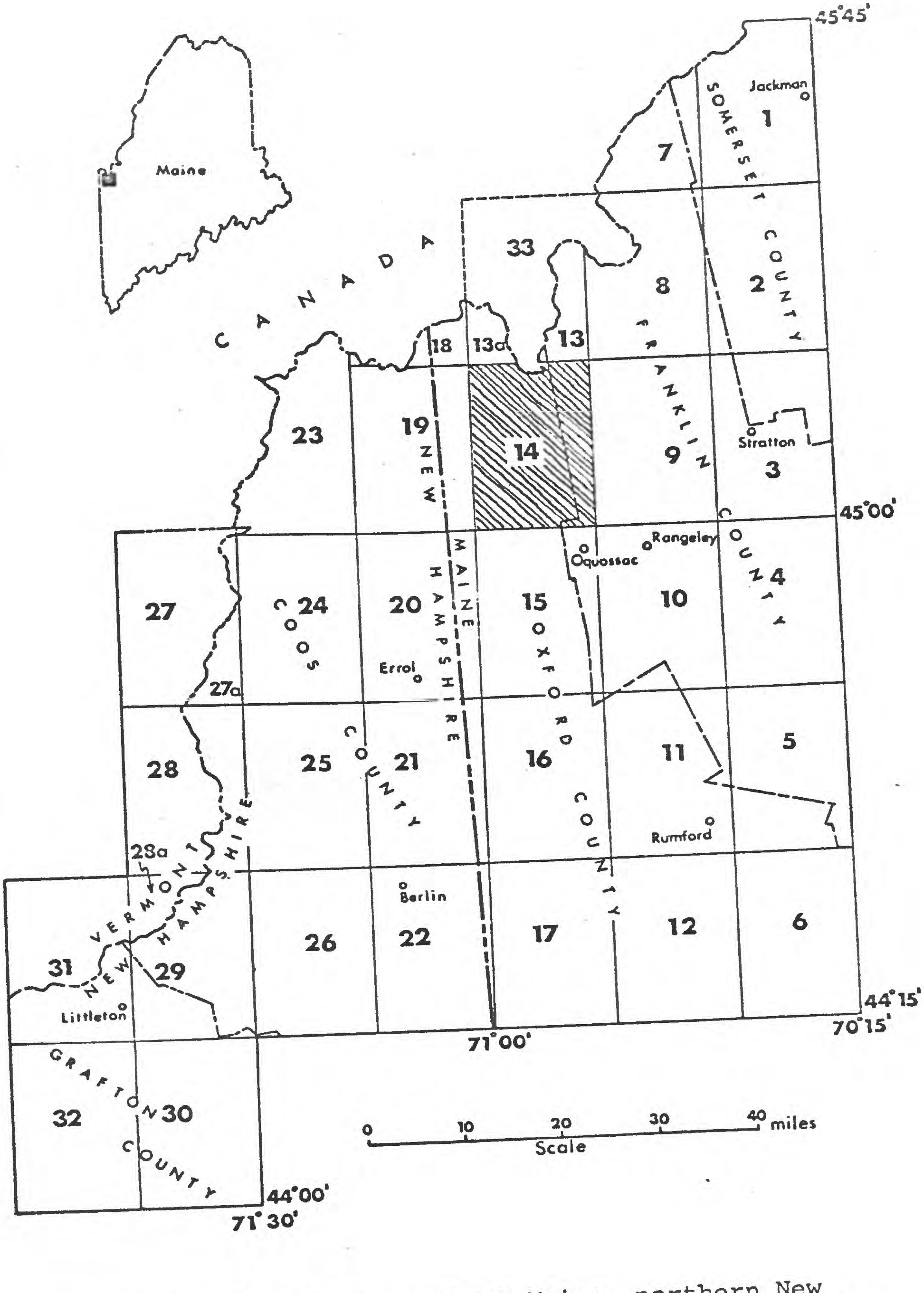

Figure 1: Index map of west-central Maine, northern New Hampshire, northern Vermont and adjacent Quebec. Cupsuptic quadrangle shaded.

Legend to Figure 1:

No.	Quadrangle	Geologic Work
1	Attean	A. L. Albee and E. L. Boudette, U.S.G.S., in preparation
2	Spencer Lake	A. J. Boucot (1961) U.S.G.S. Bull. 1111-E, (in part)
3	Stratton	A. Griscom, U.S.G.S., in preparation
4	Phillips	R. H. Moench, U.S.G.S., MF-259
5	Dixfield	K. A. Pankwiskyj, Ph.D. Thesis, Harvard 1964
6	Buckfield	J. L. Warner, Ph.D. Thesis, Harvard, in preparation
7	Skinner	unmapped
8	Chain of Lakes	unmapped
9	Kennebago Lake	E. L. Boudette, U.S.G.S., in preparation
10	Rangeley	R. H. Moench, U.S.G.S., in preparation
11	Rumford	R. H. Moench, U.S.G.S., in progress
12	Bryant Pond	C. V. Guidotti, Maine Geol. Survey, Quad. Mapping Series #3, 1965
13	Arnold Pond	unmapped
13a	Arnold Pond	J. C. Green, in preparation
14	Cupsuptic	This report
15	Oquossoc	C. V. Guidotti, Maine Geol. Survey, in preparation

Legend to Figure 1 (Continued):

No.	Quadrangle	Geologic Work
16	Old Speck Mountain	D. J. Milton, Ph.D. Thesis, Harvard, 1961
17	Bethel	I. Fisher, Ph.D. Thesis, Harvard, 1952
18	Moose Bog	J. C. Green, in preparation
19	Second Lake	J. C. Green, in preparation
20	Errol	J. C. Green, G.S.A. Spec. Paper 77, 1964
21	Milan	M. P. Billings, reconnaissance
22	Gorham	M. P. Billings and K. Fowler-Billings, in preparation
23	Indian Stream	unmapped
24	Dixville	N. L. Hatch, 1963, N. H. Dept. Res. Econ. Devl. Bull. 1
25	Percy	R. W. Chapman, 1935, Am. Jour. Sci., 5th ser., v. 30, pp. 401-431; Geol. Soc. Amer. Bull., v. 59, pp. 1059-1100
26	Mount Washington	M. P. Billings and others, 1946, Geol. Soc. Amer. Bull., v. 57, pp. 261-274

Legend to Figure 1 (Continued):

No.	Quadrangle	Geologic Work
27	Averill	P. B. Myers, Jr., 1964, Vt. Geol. Sur. Bull. no. 27
27a	SW. Averill	C. Swift, N. H. Dept. Res. Econ. Devl. Bull., in preparation
28	Guildhall	W. I. Johansson, 1963, Vt. Geol. Survey Bull., no. 22
28a	NW. Whitefield	A. J. Boucot, and R. Arndt, 1960, U. S. Geol. Survey Prof. Paper 334-B, in part, M. P. Billings, 1956, Geologic Map of New Hampshire
30	Franconia	C. R. Williams and M. P. Billings, 1938, Geol. Soc. Amer. Bull., v. 49, pp. 1011-1044
31	Littleton	M. P. Billings, 1937, Geol. Soc. Amer. Bull., v. 49, pp. 463-565. Eric, J. H., and Dennis, J. G., 1958, Vt. Geol. Sur. Bull. no. 11
32	Moosilauke	M. P. Billings, same as 31
33	Woburn	R. A. Marleau, 1957, Quebec Dept. of Mines preliminary report no. 336

civilized man, despite the fact that the quadrangle has only 5 miles of paved road where state highway 16 between Wilson's Mills, Maine, and Oquossoc, Maine, arches around the northern end of Cupsuptic Lake. An extensive network of graveled logging roads affords good access to the entire map area; however, travel within the quadrangle is most reliably accomplished in a four-wheel-drive vehicle as many of the logging roads have been abandoned and are badly eroded. Two graveled roads recently constructed by the Brown Paper Company to serve as main haulage-ways for current logging operations have been particularly valuable. One extends from the southwest corner of the quadrangle north to Lincoln Pond, and the second crosses the quadrangle from the vicinity of Deer Mountain in the southwest to Little Kennebago Lake at the central part of the eastern border.

The Cupsuptic quadrangle can be reached only by privately owned conveyance as no regularly scheduled public carrier services the Rangeley Lakes region. Access to the region from the south is via route 16 north and northeast from Berlin, New Hampshire, or via route 17 north from Rumford, Maine, or via route 4 north and northwest from Farmington, Maine. Access south from Coburn Gore on the International Boundary is via route 27 to Stratton, Maine, and then via route 16 south to Rangeley, Maine.

The quadrangle is heavily forested. Logging of both hard and soft wood under the direction of the Brown Paper Company of Berlin, New Hampshire, is the primary use of the land. The Brown Company owns Parkertown, Lynchtown, and Parmachenee townships, and buys standing timber selectively in the rest of the quadrangle from various land owners. There are no permanent settlements in the quadrangle because the logging operations are conducted from temporary camps that can be moved as the cutting proceeds. The actual cutting is done by Canadians, but services such as road construction and maintenance, logistical support, and log hauling are provided by the Brown Company and local businessmen in the Rangeley Lakes region.

The villages of Rangeley and Oquossoc, southeast and south of the quadrangle respectively (Figure 1), are centers of an active summer tourist business from which many of the permanent residents obtain a livelihood. The Cupsuptic quadrangle serves as a recreation area for tourists and sportsmen, many of whom own cabins or stay in tourist camps located around the shores of the major lakes in the area.

Topography

In the northwestern part of Maine two essentially parallel mountain ranges trend in a northeasterly direction.

The more southerly range extends from the New Hampshire border in the vicinity of Gorham, New Hampshire, to Mount Katahdin in northwestern Maine and includes the Mahoosuc Range, the Blue Mountains, and Mount Katahdin. The northern range trends generally parallel to the International Boundary and extends from northeastern Vermont through northernmost New Hampshire to the vicinity of Pittston Farm, Maine. The two ranges are separated by a broad lowland that extends from Umbagog Lake on the Maine-New Hampshire border to the northern end of Moosehead Lake. The Cupsuptic quadrangle lies in the northern range of mountains.

The nomenclature of these physiographic features in Maine is ambiguous and confused. In an unpublished manuscript held by the U. S. Geological Survey in Denver, Arthur Keith proposed the name Boundary Mountains for the northern range, and Fenneman (1938, p. 356) used the name Boundary Mountains citing Keith's manuscript as the reference. The Board of Geographic Names of the U. S. Department of the Interior approved the name Boundary Mountains and cited Fenneman (1938) as a reference. The confusion arises from a 1959 Resolve of the Maine Legislature (H.P. 593-L.D. 839, Chapter 60) effective September 12, 1959, to wit:

> "That those mountains within the state included in, and being part of, the Appalachian Mountain Range shall be officially named and henceforth referred to as the 'Longfellow Mountains of Maine'."

As the whole state of Maine lies in the Appalachian Mountain System, any mountain or group of mountains therein is by definition part of the "Longfellow Mountains of Maine." Because this name was so poorly defined it will not be used in this report; instead, reference will be made to the Boundary Mountains as described briefly in Fenneman (1938, p. 356) and shown by Fenneman (1938, Plate I) and Cady (1960, Figure 1).

The highest peak of the Boundary Mountains in the Cupsuptic quadrangle is White Cap Mountain (NW1/4, NE1/9),*1/ which has an elevation of 3815 feet. The lowest elevation in the quadrangle is 1467 feet at Cupsuptic Lake; thus the maximum relief in the area is 2348 feet. Local relief is 1987 feet between Deer Mountain and Cupsuptic Lake (SW1/9, SC1/9), 1928 feet between West Kennebago Mountain and Kennebago Lake (NE1/4, EC1/9), and 1865 feet between White Cap Mountain and the Kennebago River (NE1/4, NE1/9).

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*1/ (NW1/4, NE1/9) is a locating symbol to be used with Plate I and is translated to mean: the northwest quarter of the northeast ninth of the quadrangle.

The most prominent topographic feature, located in the center of the quadrangle, is a nearly circular group of mountains that is the expression of a hornfels aureole around a large quartz monzonite stock. The intrusive rock tends to form a low swampy area except near the contact with hornfels. Low ridges of variable trend are the most common topographic features in the area and generally reflect the trend of the bedrock.

Drainage and surficial geology

Three main rivers drain the Cupsuptic quadrangle. From east to west they are: the Kennebago River, the Cupsuptic River, and the Magalloway River. The Kennebago River and Cupsuptic River flow south to Cupsuptic Lake, whence the water flows through Lake Mooselookmeguntic and Upper and Lower Richardson Lakes to Lake Umbagog near Errol, New Hampshire (Figure 1). The Magalloway River flows south through Parmachenee Lake and Azischohos Lake and then into Umbagog Lake. From Umbagog Lake the water flows via the Androscoggin River to the Atlantic Ocean at the Gulf of Maine. The three principal rivers originate as small tributary streams on the south flank of the mountains located along the International Boundary. The International Boundary is established in this region on the drainage divide separating water that flows north to the St. Lawrence River from that which flows south to the Atlantic Ocean.

Steep-sided, deeply-incised canyons plus numerous waterfalls and rapids indicate that the rivers are in a youthful stage of development. Glacial deposits have filled many of the low-lying areas along the rivers; hence, swamps and small ponds are abundant, and the major rivers meander over the unconsolidated glacial materials. The northwest trend of the tributary streams is controlled by a strongly developed, ubiquitous, northwest-trending joint pattern in the bedrock.

Evidence for Pleistocene glacial activity is abundant. Northwest-facing slopes are generally veneered with deposits of till, and southeast-facing slopes locally show the effects of ice plucking. The bedrock is commonly polished and striated with the average trend of the striae being S40°E, but local variations to nearly south are common in the northwest corner of the area. Eskers remain intact in several places along present river valleys, and well-sorted, stratified alluvium fills the broad valley floors at the head of the Kennebago Lake and along the lower part of the Cupsuptic and Magalloway Rivers. The alluvium along the Cupsuptic and Magalloway Rivers is commonly medium to coarse sand, whereas that at the head of Kennebago Lake is predominantly gravel. A kame terrace of limited extent is developed on the west bank of the Kennebago River northwest of Johns Pond. The general distribution of the above features is shown on Figure 2.

PREVIOUS WORK

The earliest reported geological reconnaissance in the area was made in the summer of 1838 by Dr. Samuel Stephenson, who traversed up the western border of the quadrangle to locate and verify the position of the corner post marking the boundary between Quebec, New Hampshire, and Maine. His report, given in Jackson (1839, p. 191-205), is an interesting account of the pristine wilderness, but only briefly mentions a few outcrops of slate along the upper reaches of the Magalloway River. J. E. Mason traveled on the major lakes south of the Cupsuptic area and reported (in Hitchcock, 1862, p. 324-329) a thick sequence of conglomerate at the east end of Rangeley Lake, and highly contorted "talco-micaceous schist" at Indian Rock near the mouth of the Kennebago River. His "talco-micaceous schist" is now mapped as the Aziscohos member of the Albee Formation.

The Atlas prepared by C. H. Hitchcock (1878) to accompany his account of the Geology of New Hampshire (1877)

Figure 2: Map of the surficial geology of the Cupsuptic quadrangle

Qal; alluvium

Qt; till

Qk; kame terrace

Qe; esker deposits

X; gravel pit

→; trend of glacial striation

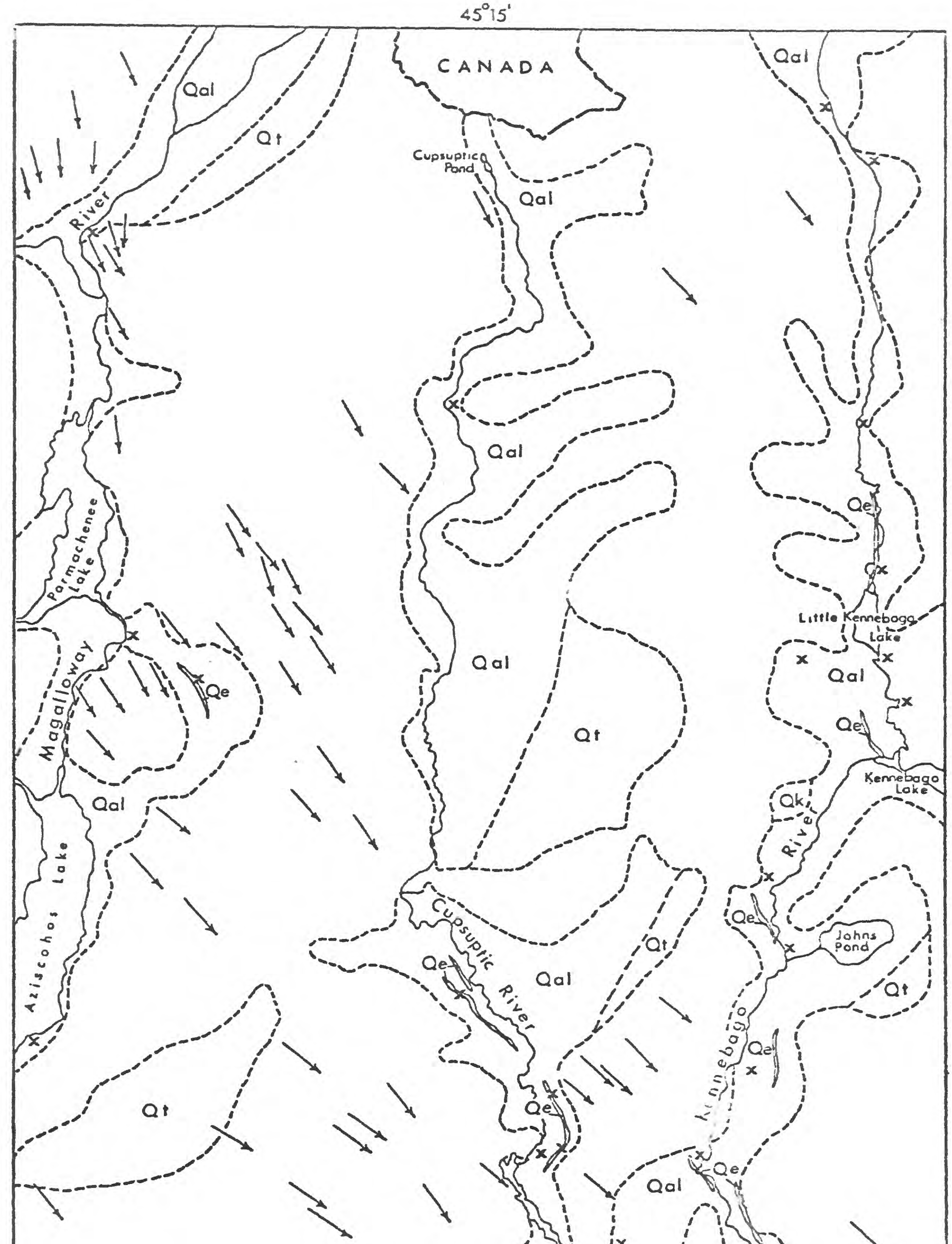
45°15'
CANADA
Qal
Qt
Cupsuptic Pond
River
Parmachenee Lake
Magalloway
Qe
Aziscohos Lake
Cupsuptic River
Little Kennebago Lake
Kennebago Lake
Qk
Kennebago River
Johns Pond
Cupsuptic Lake
0 1 2 4 miles
71°00'
45°00'
70°45'

FIGURE 2

includes a geologic map of the Cupsuptic area that is remarkably consistent with the present work. Hitchcock maps his Lisbon group, which corresponds roughly to the Albee Formation of Billings (1956), in a broad northeast-trending belt that goes through the center of the quadrangle and is overlain to the northwest and southeast by rocks of his Lyman group. The trend of the Lyman group, which corresponds roughly to the Ammonoosuc volcanics of Billings (1956), coincides with the Magalloway member of the Dixville Formation in the northwestern part and the Oquossoc Formation in the southeastern part of the quadrangle. In addition, Hitchcock mapped the granitic intrusives in the central and northeastern ninths of the quadrangle and the serpentine body in the northeast corner of the area. T. N. Dale (1907) mapped the intrusive body in the northeastern part of the quadrangle but did not show the larger central body mapped by Hitchcock, nor did he include the area in his discussion of the granite bodies of Maine. The preliminary Geologic Map of Maine by Keith (1933) shows four map units in the Cupsuptic area: Precambrian rocks, Silurian slate, "greenstone", and granite. Only the position of the "greenstone" in the southeast ninth of the quadrangle is remotely consistent with the present work. A Boston

University summer field camp held in the area for several years during the 1950's under the direction of Dr. C. W. Wolfe resulted in an unpublished map now held at the Department of Geology, Boston University.

Recent work in northen New Hampshire, particularly that of Billings (1937, 1956), Green (1964), and Hatch (1963), describes rocks similar to those exposed in the Cupsuptic area in equivalent or higher grades of regional metamorphism. Marleau (1957) mapped the area adjoining the quadrangle to the north. Discussions and maps by Cady (1960), Billings (1956), Albee (1961), Boucot (1961), and Boucot and others (1965), present important regional syntheses and correlations in northern Vermont, northern New Hampshire, and northwestern Maine.

PRESENT WORK

The present work in the Cupsuptic quadrangle was carried out during the summers of 1963, 1964, and 1965 and represents a total of 15 months in the field. Most of the mapping was done at a scale of 1:48,000 on a topographic base surveyed in 1932. The topographic map was accurate enough to be used for determining positions on traverses along major streams, rivers and sharp ridges. Pace and compass traverses, supplemented with altitude readings from an aneroid barometer, were used in areas of non-distinct topography and thick forest cover. The density of the traverses was determined by the amount of exposure and the complexity of the geology. The topographic base map does not show the recent logging roads in which numerous excavated outcrops represent the only exposures available in certain areas. In such areas, traverses were made on the logging roads and positions were located in the field on aerial photographs. The field stations were transferred to the base map by measuring corresponding bearings and proportional distances from recognizable topographic or cultural features common to both the photographs and the map.

Detailed mapping of the gorge of the Kennebago River in the vicinity of the power dams was done at a scale of 1" = 200' by standard plane table methods. A detailed pace and compass map of the rocks of Silurian age immediately east of Parmachenee Lake was made on a 6X enlargement of the standard 1:62,500 topographic base and thus has a scale of about 1" = 900'.

The object of the study was: to determine the stratigraphic sequence, age, and structure of the rocks in the Cupsuptic quadrangle; to investigate the metamorphism; and to evaluate the economic potential of the area.

ACKNOWLEDGEMENTS

I wish to express particular thanks to Professor M. P. Billings and Professor J. B. Thompson who directed the thesis work at Harvard University and discussed problems in the field during the course of the mapping.

The field work was done while the writer was employed by the U. S. Geological Survey, Branch of Regional Geology in New England, under the direction of Lincoln R. Page as Branch Chief and Eugene L. Boudette as project supervisor. These men gave generously of their time and effort to administer the Cupsuptic project in addition to their own, and to discuss the mapping and this report.

Special thanks are offered to the Brown Paper Company for granting access to their private roads, without which the mapping would have been virtually impossible, and to Mr. C. S. Herr, vice president in charge of the Woods Department, who actively followed the progress of the mapping.

It is a pleasure to acknowledge the helpful discussions and cooperation of Eugene L. Boudette, Robert H. Moench, Charles V. Guidotti, and John C. Green, all of whom mapped quadrangles adjacent to the Cupsuptic.

Dr. Robert H. Neuman, Dr. William B. N. Berry, Dr. Arthur J. Boucot, Dr. William Oliver, and Dr. Robert Finks identified and dated the fossils found in the area. Dr. Neuman and Dr. Boucot visited the field area and helped collect some of the material.

Dr. Cornelis Klein and Mr. Jack Drake made partial chemical analyses of minerals with the Electron microprobe at Harvard University.

Field assistance was provided by Howard Day and Charles Thayer in 1963, Norman Dion in 1964, and Fredric Hoffman in 1965. The enthusiastic and able assistance of Carl Eastwood, Jr. of Rangeley, Maine, offered on weekends from 1963 through 1965 without remuneration, is gratefully acknowledged. Douglas Rumble of Harvard University assisted the writer for the month of June, 1965, without compensation and was particularly helpful in the interpretation of the structure.

The manuscript was read and improved by the comments of M. P. Billings, J. B. Thompson, L. R. Page, and E. L. Boudette.

Special thanks are offered to my wife, Peggy, who proofread and edited the report in various stages of its preparation.

STRATIGRAPHY AND LITHOLOGY

GENERAL STATEMENT

The stratified rocks of the Cupsuptic quadrangle can be divided into two broad lithologic groups that correspond to two major chronological divisions. The rocks of pre-Silurian age are dominantly slate, phyllite, graywacke, and greenstone that form a sequence about 20,000 feet thick deposited in the northern Appalachian geosyncline from late Cambrian (?) to late Middle Ordovician time. The rocks of Silurian age are mainly polymict conglomerate, quartz conglomerate, quartzite, slate, and limestone, present in isolated patches that rest unconformably on the pre-Silurian rocks.

The rocks of pre-Silurian age, which comprise over 90 percent of the stratified rocks in the area, have been divided into the Albee Formation (Billings, 1935), the Dixville Formation (Green, 1964), the Oquossoc Formation (Guidotti, 1964, written communication), and the Kamankeag Formation (new). As shown in Figure 3, the Aziscohos Formation of Green (1964, p. 10-16) is considered here to be a member of the Albee Formation. The rock units of Silurian age have not been named because of their limited extent and exposure in the Cupsuptic quadrangle.

Five fossil localities have been found in the quadrangle, three of which are in rocks of pre-Silurian age. The Kamankeag Formation is assigned a late Middle Ordovician age on the basis of the graptolite assemblage found at fossil locality no. 2 on the geologic map. Deformed shell fragments compatible with a Middle Ordovician age but generically unidentifiable were found in the same formation at fossil locality no. 3. Fragments of *Protospongia* sp. found in the slate of the Dixville Formation at fossil locality no. 4 have too great a range to date the rocks more closely than Cambrian or Ordovician. The rocks near Parmachenee Lake have been dated in part as Late Silurian (Ludlow) by brachiopods found at fossil locality no. 5; and the rocks in the northwestern corner of the quadrangle have been dated in part as Late Silurian by fossils found by John Green (1964, personal communication) at locality no. 6. The Silurian rocks in the southeastern ninth of the quadrangle are considered to be Early Silurian (Upper Llandovery) in age based on fossil evidence at locality no. 1 and correlations with similar rocks in the Kennebago Lake quadrangle.

The stratified rocks have been intruded by three quartz monzonite stocks, a large body of metadiorite and serpentinized ultramafic rocks, several smaller bodies of granitic to gabbroic composition, and numerous granitic and diabasic dikes. Near the contact of the three stocks the slate of the country rock has been metamorphosed to an equigranular, sillimanite-bearing hornfels. The regional metamorphic grade is chlorite.

ALBEE FORMATION

General Statement

The Albee Formation crops out in a broad belt restricted to the southern half of the quadrangle where it forms good exposures on small rounded knobs. The formation has been divided into three members, each of which consists of several rock types.

The principal member consists of green to greenish-gray phyllite and slate with interbedded quartz-feldspar granulite[1/] and gray quartzite. This member most closely resembles the description of the Albee Formation from the

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1/ Granulite is used here in the sense of Harker (1939, p. 246) for a fine-grained, equigranular rock composed primarily of quartz and feldspar with minor amounts of muscovite and chlorite.

type locality given by Billings (1935, 1937). The Kennebago member consists of purple and purplish-gray slate and phyllite, irregular patches and bands of green phyllite, variable amounts of quartz-feldspar granulite, gray-green quartzite, and black phyllite. The southern part of the broad belt mapped as Albee Formation contains rocks lithologically similar to those defined by Green (1964, p. 10-12) as the Aziscohos Formation. Green proposed the new formation for rocks that lay below the Albee Formation in the Errol quadrangle (Figure 1, no. 20); however, these rocks are, at least in part, above the principal member of the Albee in the Cupsuptic area. Hence, the "Aziscohos Formation" of Green is considered to be a less arenaceous, locally carbonaceous facies of the Albee Formation and will be discussed as the Aziscohos member. It consists of green, greenish-gray and purplish-gray phyllite which contains minor amounts of interbedded quartz-feldspar granulite, black phyllite, and greenstone.

The relative abundance of granulite and quartzite interbedded in the phyllite and slate of the Albee Formation ranges from a few percent to as much as 40 percent. No attempt was made to map the variation in the abundance of the arenaceous beds nor was it possible to differentiate areas of slate from areas of phyllite.

Principal Member

Green phyllite and interbedded arenaceous rocks of the principal member form the bulk of the rocks exposed in the west-central and southwest ninths of the quadrangle. Excellent exposures are found in Portage Brook (NW1/4 SC1/9), on Cupsuptic Mountain (SW1/4 C1/9), and on the low hills between the Kennebago River and Johns Pond (SE1/4 EC1/9).

Phyllite and slate: The phyllite and slate are generally very fine grained, dark green to light yellowish green on the fresh surface, and weather soft, chalky-white or light gray. The foliation surfaces are dull in the slate but have a characteristic silvery sheen in the phyllite due to an increase in the size of the muscovite and chlorite flakes.

The foliation surfaces are commonly sheared and crenulated and the phyllite may be dragged into the interbedded granulite and quartzite by cross-cutting slip cleavage or axial plane foliation. In the more fissile varieties, especially in areas of pronounced slip cleavage, the slate at the surface of the outcrop flakes off to form a chip rubble, shown in Figure 4, leaving the arenaceous beds in relief.

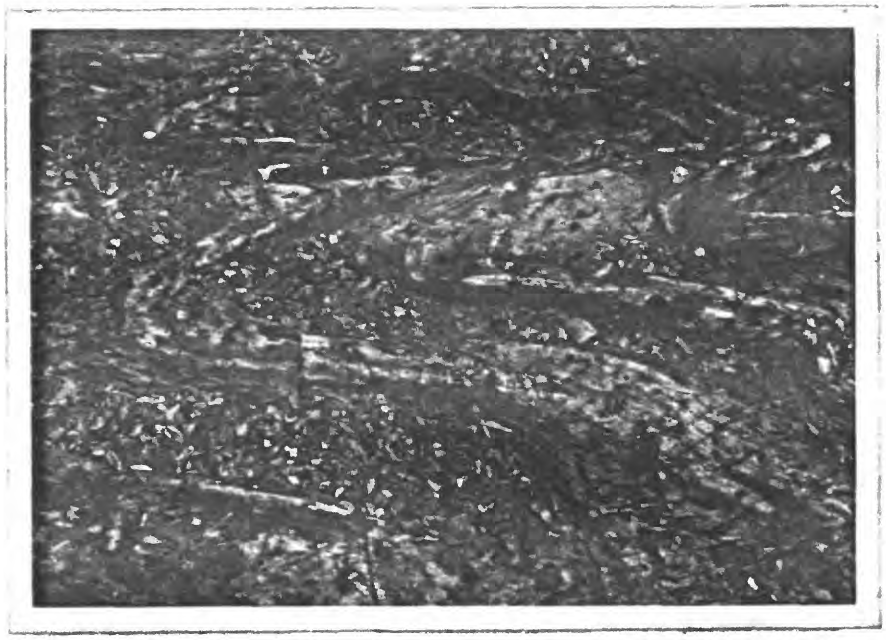


Figure 4: Typical chip-rubble weathering of the phyllite and slate between highly-contorted arenaceous beds in the principal member of the Albee Formation.

The phyllite and slate contain quartz, muscovite, chlorite, albite, and magnetite as primary minerals and variable but minor amounts of tourmaline, zircon, rutile, and potash feldspar. Representative modes are given in Table 1. Positive identification of the major constituents was accomplished only by the combined use of the petrographic microscope and the x-ray diffractometer. The bulk of the phyllite and slate is a microscopic mass of muscovite and chlorite flakes that are characterized by poorly defined crystal boundaries. Quartz is angular to subangular and generally less than 50 μ in maximum diameter. The most common feldspar is albite, which is untwinned and about the same size as the quartz, although two whole-rock samples of the phyllite gave weak x-ray diffraction peaks characteristic of potassic feldspar. Magnetite octahedra up to 0.5 mm on an edge are common in the phyllite and stud the weathered surface. Tourmaline and rutile form euhedral crystals generally less than 20 μ in length, whereas zircon may be euhedral or rounded in outline and about 50 μ in length.

Locally, around the intrusive bodies in the central and southwestern ninths of the quadrangle, the phyllite and slate have been metamorphosed to a maculose hornfels

Table 1. Representative estimated modes of the Albee Formation

				Chlorite Zone							Biotite Zone			Andalusite Zone			Sillimanite Zone		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Quartz	43					48		30	60									75	60
Alkali Feldspar	?	55	45	60	57	2	49	tr(?)		60	72	84	50	60	5	58	55		
Plagioclase	22					6									12			10	19
Muscovite	10	25	32	30	20	30	20	50	15	15	3	1	10	10		12	12		
Biotite										20	5	7	15	18		7	25	3	1
Chlorite	25	20	20	9	20	12	25	10	12	4	12	2	5	5					
Garnet												6						5	7
Staurolite														1					
Andalusite													18	3		1	5		
Sillimanite																4	3		
Cordierite														4		15			12
Actinolite															60			7	12
Epidote															23			1	
Ilmenite		tr				2				tr	tr		2						
Magnetite	<1	1	2	2	3				2	1	2	tr	1	1	tr	2			
Hematite			<1	<1	tr(?)		3												
Pyrite																			
Apatite																		tr	2
Tourmaline	tr	tr	tr	<1	tr	tr	<1		tr	tr	tr								
Sphene						tr													
Zircon	tr	tr	tr	tr	1	tr													
Limonite							tr	tr	tr	tr	tr	tr	tr			tr			
Rutile				tr													tr		
Plagioclase Composition	Alb.	Alb.	Alb.	Alb.	Alb.	Alb.	Alb.	Alb.	Alb.	Alb.	Alb.	Alb.	Alb.	Alb.-Olig.	Olig.	Alb.-Olig.	Sod.-Olig.	Olig.	Al[illegible] Ol[illegible]

Description and location of specimens in Table 1.

1- Green phyllite adjacent to pinstripe granulite; 1.4 miles bearing 274° from camp on west side of Lincoln Pond.

2- Green phyllite; 1.5 miles due west of summit of Deer Mountain.

3- Purple phyllite of Kennnebago member; on 2240' topo knob 0.95 miles, bearing 017 from camp on west shore of Lincoln Pond.

4- Purplish-gray granulite of Kennebago member; 1.1 miles, bearing 303 from 1531' BM at Big Falls on the Cupsuptic River.

5- Green phyllite of Aziscohos member; from 2385' summit of Daddy's Ridge.

6- Green phyllite of Aziscohos member; 1640' elevation, 2400' south of point where Lincoln Brook crosses the western border of the quadrangle.

7- Purplish-gray phyllite of the Aziscohos member: at 2160' elevation, 211 miles bearing 261 from 1578' BM on South Brook.

8- Black phyllite of Aziscohos member; at 1560' elevation in first south-trending branch of Cold Brook 3000' bearing 279 from point route 16 crosses Cold Brook.

9- Pinstripe granulite is Oal; on east shore of Lincoln Pond, 2500' bearing 130° from camp on west side of Lincoln Pond.

10- Light-gray slightly maculose phyllite of Kennebago member; 1920' elevation due south of 2940' summit of Burnt Mountain.

11- Green, maculose phyllite in Oal; at 1540' elevation in Lost Brook, 900' upstream from 1531' BM at Big Falls on the Cupsuptic River.

Description and location of specimens in Table 1

12 - Pinstripe granulite in Oal; same location as 11

12 - Gray, maculose hornfels; 1800' bearing 253 from 2660' summit of Cupsuptic Mountain.

14 - Gray, maculose hornfels; at 2180' elevation, 200' north of 2217' summit of Big Buck Mountain.

15 - Dark-green, very fine-grained, amphibolite in Oal; on east shore of Lincoln Pond, 3300' bearing 153 from camp on west shore of Lincoln Pond.

16 - Dark-Gray, muscovite spangled hornfels; 2620' elevation, 1200' due east of 2940' summit of Burnt Mountain.

17 - Dark-gray, fine-grained, equigranular hornfels; at 2160' elevation 500' due north of 2217' summit of Big Buck Mountain.

18 - Gray-green, fine-grained, calc-silicate granulite; at 2415' elevation 1200' bearing 315 from 2660' summit of Cupsuptic Mountain.

19 - Dark-gray hornfels with large cordierite porphyroblasts; 2450' elevation 900' due west of 2660' summit of Cupsuptic Mountain.

or, next to the intrusive contact, an equigranular hornfels. The outer part of the maculose hornfels contains pale olive-green to light-brown biotite, chlorite porphyroblasts about 0.5 mm in length that have distinct grain boundaries, and ovoid porphyroblasts of cordierite which are highly altered to white mica and chlorite. Albite or sodic oligoclase is the only feldspar present in the maculose hornfels; quartz and muscovite are ubiquitous. Nearer the intrusive body andalusite, which forms lath-shaped porphyroblasts ranging up to 1 inch in length, is present in addition to the minerals mentioned above. Adjacent to the contact of the intrusive body the rock is a dense, dark-gray, equigranular hornfels that contains microscopic mats of fibrous sillimanite in addition to the other minerals. Magnetite octahedra up to 1.0 mm on an edge are commonly scattered in the hornfels and microscopic tourmaline, zircon, and ilmenite are the accessory minerals. Quartz pods and stringers are abundant in the inner part of the contact aureole; but pegmatite dikes and coarse-grained segregations of granitic composition, though present, are extremely rare.

<u>Quartz-feldspar granulite</u>: The quartz-feldspar granulite is fine-grained, light gray or greenish gray on the fresh

surface and weathers to a soft, white or buff surface. Locally the granulite is calcareous and weathers to a dark rusty-brown, soft rind about ¼ inch thick. The granulite beds are commonly about 5 or 6 inches thick but range in thickness from about 1 inch to about 15 inches. The beds are characterized by dark-green to gray, paper-thin laminae composed predominantly of chlorite and sericite, separated by light green or gray bands composed predominantly of quartz and feldspar. The laminae trend parallel to the granulite-phyllite contact as shown in Figure 5, and give the arenaceous beds a striped appearance referred to by Cady (1956) and others as the "pinstripe" texture in equivalent rocks of northeastern Vermont. The micaceous laminae are less resistant than the quartz-feldspar bands, and weather "in" as fine lines accentuating their presence in the rock. The spacing between the laminae, which ranges from less than a millimeter to as much as 1 inch, is commonly but not invariably greatest near the base of those beds that show graded bedding. The spacing of the laminae by itself, however, is not considered a reliable indicator of the stratigraphic top sense. Graded bedding is not a common feature in the quartz-feldspar granulite.

The granulite is composed mainly of subrounded to subangular grains of quartz and albite that are generally less than 0.5 mm in diameter. The albite is untwinned and difficult to distinguish from quartz microscopically, but, it tends to form more elongate grains and has lower refractive indices. Calcite is present as an intergranular mineral to quartz and feldspar in the calcareous granulite. Minor amounts of muscovite and chlorite are scattered in the arenaceous bands but are generally concentrated in the "pinstripe" laminae with magnetite, tourmaline, zircon and limonite. The platy, micaceous minerals lie parallel to the plane of the laminae causing the granulite beds to part along these planes.

In the higher grades of metamorphism biotite is present in the arenaceous bands of the granulite, whereas biotite, cordierite, andalusite or sillimanite may form in the "pinstripe" laminae. The calcareous granulite forms a calc-silicate granulite composed of quartz, feldspar, garnet, actinolite, biotite, and apatite in the inner zones of the contact aureole.

Quartzite: The quartzite is gray, greenish gray or green on the fresh surface and weathers to a hard, greenish-gray,

Figure 5: Light-gray, quartz-feldspar granulite bed with paper-thin, dark-gray "pinstripe" laminae. Granulite bed about 5 inches wide in lower left-hand corner of photograph.

vitreous surface. It is found in the phyllite and slate as beds that range in thickness from a few inches to as much as 2 feet, the average thickness being 6 to 8 inches. Graded bedding is more common in the quartzite than the granulite, and the minerals are generally coarse enough near the base of the quartzite to distinguish individual grains with a hand lens. The quartzite beds commonly contain the micaceous "pinstripe" laminae that characterize the granulite, but the laminae may be indistinct, discontinuous, or absent from the quartzite particularly near the base of a graded bed.

The quartzite is composed of the same minerals as the granulite; predominantly quartz, albite, muscovite, and chlorite. As gradational types exist, the distinction between the two is made arbitrarily on the quartz content. Quartzite contains greater than 80 percent quartz and granulite contains less than 80 percent but greater than 60 percent quartz. The quartz is subrounded to subangular and ranges in size from about 50 μ to 0.5 mm in maximum diameter. Albite grains are subangular, commonly elongate, and smaller than the quartz averaging about 0.1 mm in length. Muscovite and chlorite are present in minor amounts in the arenaceous bands but are concentrated in the "pinstripe" laminae with magnetite, zircon, tourmaline, and limonite.

Biotite forms in the arenaceous bands; and biotite, cordierite, andalusite, and sillimanite may form in the "pinstripe" laminae at the higher grades of metamorphism.

Kennebago Member

General Statement: The Kennebago member of the Albee Formation is composed of purple, purplish-gray and green slate; quartz-feldspar granulite; quartzite; and black slate. The type locality is on the banks of the Kennebago River in the vicinity of the abandoned settlement of Kennebago (SE1/4 EC1/9). The Kennebago member crops out in a narrow band that trends southwest from the type locality and curves to the west around the large quartz monzonite body in the center of the quadrangle. West of the pluton, the Kennebago member outcrops in two narrow bands of variable trend and is well exposed on the low northwest-trending ridge west of Lost Brook (SW1/4 C1/9) and on the hills immediately south of the headwaters of the South Branch of Black Cat Brook (WC1/9).

This map unit, which is predominantly purple slate with variable amounts of interbedded arenaceous rocks, is considered to be a member of the Albee Formation because it contains the "pinstripe" granulite and quartzite beds characteristic of the principal member of the Albee. The purple slate apparently thins and may change continuously into the green phyllite and slate of the principal member in the western part of the quadrangle. Purple slate has not been reported previously in the Albee; but, this may be due to the increased metamorphic grade in the areas of New Hampshire where the Albee has been observed. Apparently an analogous situation exists between the red slate, "Caldwell Facies", of the Mansonville Formation (Cooke 1937, p. 22) in Quebec and the equivalent green slate and phyllite of the Stowe Formation in northern Vermont (Cady 1960, Cady and others, 1963).

Purple-gray slate and phyllite: The slate and phyllite are deep maroon at the type locality but become purplish-gray on strike to the southwest and west. They are soft and weather to light gray or purplish-gray, chalky rind about 0.5 mm thick. Some green slate is present in local, narrow bands adjacent to minor faults that cut the purple phyllite and the arenaceous rocks, and is thus of secondary origin. Larger patches and bands of green slate and phyllite, which trend parallel to the arenaceous beds and blend into the purple phyllite across indistinct boundaries, are probably of primary origin.

The purple slate and phyllite are composed primarily of quartz, muscovite, chlorite, albite, and hematite. Minor amounts of zircon, tourmaline, rutile, and locally magnetite form the accessory minerals. The minerals are generally microscopic except locally in the more phyllitic varieties where magnetite and less commonly muscovite can be seen with a hand lens. Quartz and untwinned albite are angular to subangular and about 50 μ in maximum diameter. Muscovite forms distinct, microscopic flakes; whereas chlorite is present as low birefringent masses that have no distinct grain boundaries. Hematite plates are blood red, about 20 μ in size, and commonly hexagonal in outline. Tourmaline forms as single crystals up to 0.1 mm in length and is strongly pleochroic from blue green to colorless. Rutile is commonly present as euhedral, twinned crystals or acicular aggregates less than 50 μ in length.

The purple slate of the Kennebago member can be distinguished from the green phyllite of the principal member only in the outer margin of the contact aureoles. The two rock types are indistinguishable in the higher grades of metamorphism, because the hematite disappears. The purple slate forms a dark gray maculose hornfels that contains porphyroblasts of cordierite and andalusite. In the sillimanite zone all of the pelitic rocks of the Albee

Formation appear as a dark-gray, equigranular hornfels; thus, the contacts between members in the metamorphic aureoles are, by necessity, projections of the contacts established in the low-grade rocks.

Quartz-feldspar granulite: The quartz-feldspar granulite of the Kennebago member is, for the most part, identical to that in the principal member of the Albee. The granulite is dark green or greenish tan on the fresh surface and weathers to a soft, chalky-white or buff surface which presents a sharp color contrast against the purple phyllite as shown in Figure 6(a). The arenaceous beds contain the paper-thin "pinstripe" laminae characteristic of those in the principal member, but the micaceous layers are purple rather than green due to the presence of hematite. In the Kennebago member the granulite beds range in thickness from less than an inch to about 12 inches, the average being about 4 to 6 inches. They constitute about 25 percent of the Kennebago member at the type locality; but locally, as illustrated in Figure 6(b), they may account for as much as 50 percent of the member.

The granulite is composed of subangular to subrounded quartz and albite, in variable but major proportions, with lesser amounts of muscovite and chlorite scattered in the arenaceous bands and concentrated in the "pinstripe" laminae. Hematite, rutile, tourmaline, and zircon are present as accessory minerals and are most abundant in the micaceous laminae. In the contact aureoles the granulite beds are indistinguishable from those in the principal member of the Albee.

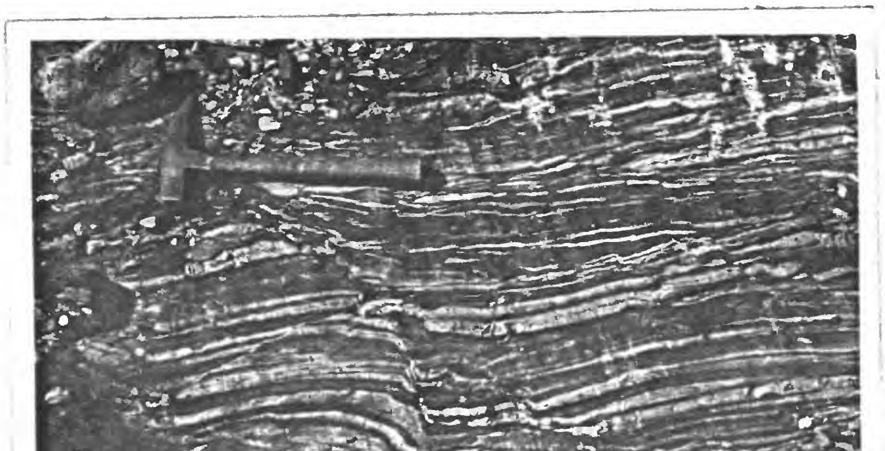
Quartzite: Several discontinuous and highly folded patches of white-weathering, green quartzite have been mapped in the Kennebago member at the type locality. The distribution of the quartzite is shown on the plane table map of the Kennebago River gorge presented as Plate VI, but the number of individual beds could not be determined. The quartzite beds, which commonly do not show any "pinstripe" laminae, have been tectonically thickened and thinned on the hinges and limbs respectively of minor folds.

The quartzite is composed predominantly of subangular to subrounded quartz of medium-to coarse-sand size, with variable but subordinate amounts of albite, muscovite, and chlorite.

Black slate: Thin, discontinuous patches of black slate crop out at different places along the contact between the purple slate of the Kennebago member and the green slate of

Figure 6(a): White-weathering, light gray-green quartz-feldspar granulite beds in purple slate of Kennebago member. On west bank of Kennebago River between upper and lower power dams.

Figure 6(b): Abundant thin beds of tight gray-weathering quartz-feldspar granulite in dark purple phyllite of Kennebago member.



the principal member of the Albee implying, that the black slate is discontinuous along strike.

Virtually no information can be obtained by a microscopic examination of the slate because finely divided carbonaceous material of unknown composition renders the thin sections nearly opaque. The major constituents: quartz, muscovite, chlorite, and albite, however, have been determined by x-ray diffraction methods.

Aziscohos member

General Statement: The Aziscohos member of the Albee Formation is composed of two main rock types: green, greenish-gray or purplish-gray phyllite is predominant; and rusty-weathering, black phyllite is the subordinate type. Quartz-feldspar granulite beds are present in the green phyllite but generally make up less than 5 percent of this map unit. In addition, thin beds of greenstone are found scattered in the green phyllite, but they are most abundant at or near the contact of the green and black phyllite.

The green and black phyllite are well exposed on the north and northwest slopes of Deer Mountain, along the east slopes of the ridge immediately west of South Brook (SE1/4, SW1/9) and on the crest of the northwest-trending ridge northeast of Cold Brook (SW1/9 SC1/9). The black phyllite is well exposed in the upper reaches of Toothacher Brook No. 2 (SW1/4 SE1/9).

The contact between the green and black phyllite is sharp and generally can be located within 50 feet; however, the contact between the green phyllite of the Aziscohos member and the principal member of the Albee Formation is difficult to determine. Green (1964, p. 13) placed the contact at the point where quartzite first appeared in the green phyllite, thus separating the green phyllite and quartzite of the Albee Formation from green phyllite of his Aziscohos Formation in the Errol quadrangle. This criterion is not applicable to the Cupsuptic quadrangle because the Aziscohos member is not devoid of quartzite beds, nor is there a plane which separates green phyllite with abundant arenaceous beds from green phyllite with only minor amounts of the same. The variation in the amount of arenaceous beds from about 5 percent in the Aziscohos member to about 25 percent in the principal member of the Albee can be recognized in the field; but, the transition between the two members covers a zone that ranges in width from about 100 feet to 500 feet. The Aziscohos member lies, in part at least, above the principal member of the Albee, as shown by the predominantly south-facing stratigraphic top determinations located near the contact of the members on Plate VII. This stratigraphic position is most clearly seen in a series of outcrops that straddle the contact at 1600 feet elevation on the low ridge south of Fox Pond (NW1/4 SC1/9). The apparent position of the black phyllite varies from the top of the principal member to well within the green phyllite of the Aziscohos member. None of the map units can be taken unequivocally as time planes, so the actual variation may be between the Aziscohos member and the principal member of the Albee, or the black and green phyllite within the Aziscohos member, or both.

Green phyllite: The phyllite is dark green on the fresh surface streaked with light yellowish-green but varies locally to gray of purplish-gray. The weathered surface is soft, chalky-white or buff. Thin, discontinuous and highly contorted, white quartz pods and stringers are abundant in the green phyllite and, as illustrated by Figure 7, are generally oriented parallel to the pronounced foliation. Quartz-feldspar granulite beds, identical to those in the principal member of the Albee, are found in the green phyllite. Locally the arenaceous beds may comprise as much as 20 percent of the exposure but the average is about 5 percent. Minor amounts of quartzite are present in the green phyllite but are less abundant than the granulite and, indeed, do not characterize the green phyllite of the Aziscohos member.

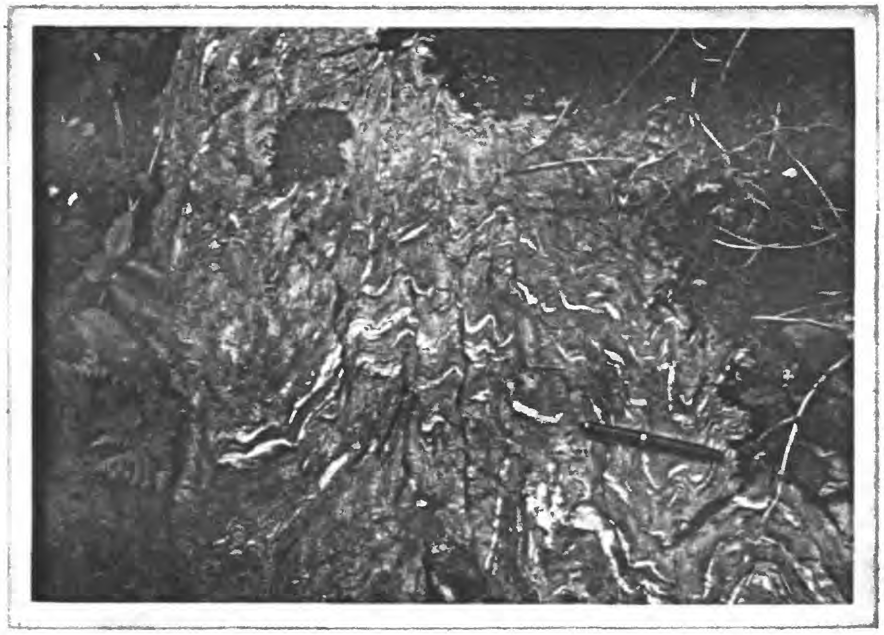


Figure 7: Green phyllite with milky-white quartz pods and stringers of the Aziscohos member of the Albee Formation.

As the arenaceous beds are identical to those in the principal member of the Albee the description of them will not be repeated here.

The green phyllite is composed mainly of quartz, muscovite, albite, and magnetite with minor amounts of tourmaline, zircon, rutile, and locally hematite. In general, the green phyllite of the Aziscohos is similar to that of the principal member of the Albee except that the micaceous minerals are commonly larger and have distinct grain boundaries. Muscovite, chlorite, and magnetite can be recognized in hand specimen, but the other minerals are microscopic. Quartz and untwinned albite are subangular and about 50 μ in maximum diameter. The quartz in the quartz pods and stringers forms anhedral grains about 0.2 mm in maximum diameter that are commonly strained, and have sutured grain boundaries. The green phyllite is at the chlorite grade of metamorphism throughout the quadrangle; however, the micaceous minerals are larger and the rock has the appearance of a fine-grained chlorite schist near the southern border of the map area.

<u>Black phyllite:</u> The black phyllite is commonly very fine-grained with sheared and crenulated foliation surfaces. The fresh surface is soft, dull black or silvery black, and

weathers to a rusty limonite stain. Quartz pods are much less abundant in the black phyllite than in the green phyllite. Arenaceous beds are scarce in the black phyllite although light-gray weathering, dark-gray, quartz-feldspar granulite beds are present locally. Typically, the granulite beds are less than 2 inches thick and are commonly separated by 2 to 5 inch bands of phyllite, producing cyclically-bedded outcrops in local areas. The granulite beds do not contain the paper-thin "pinstripe" laminae, nor do they show distinct graded bedding.

The phyllite is composed primarily of quartz, muscovite, chlorite, albite and pyrite with minor amounts of zircon and tourmaline. In addition the phyllite contains finely-divided, dust-like particles of opaque, carbonaceous(?) material of unknown composition which makes the thin sections nearly opaque. All of the minerals are microscopic or submicroscopic except pyrite, which forms euhedral cubes up to ¼ inch on a side. The granulite beds in the black phyllite are composed of variable but major amounts of quartz and albite with lesser amounts of muscovite, chlorite, pyrite and opaque carbonaceous(?) material.

Greenstone: Thin, discontinuous beds of dark green, massive to crudely foliated greenstone are present in the green phyllite, but they are more abundant in the black phyllite or at the contact of the black and green phyllite in the Aziscohos member. The greenstone ranges from 0 to 75 feet thick and forms low ridges that serve as markers for the black phyllite. The greenstone is highly fractured and contains no visible structure except a weakly developed foliation generally parallel to that in the phyllite.

Thickness

The thickness of the Albee Formation is difficult to determine because the base is not exposed in the map area. Similarly, the outcrop width of the individual members is highly variable due to complex folding, possible tectonic thinning, and apparent facies changes. The following thicknesses, which must be considered as first approximations, have been determined from outcrop width, bedding attitudes and folds shown in Plates I, II, III:

Principal member	1800' - 5700'
Green phyllite of Aziscohos member	2500' - 4500'
Black phyllite of Aziscohos member	0 - 1700'
Kennebago Member	1200' - 2000'
Total Albee Formation	4500' -13900'

A thickness of about 14,000 feet is considered to be a maximum value for the Albee Formation, which is comparable to that of 17,000 feet for the combined Albee and Aziscohos Formations made by Green (1964 p. 16, p. 23).

Age

No fossils have been found in the Albee Formation but it underlies the Kamankeag Formation, which has been dated as late Middle Ordovician; therefore the Albee must be Late Middle Ordovician or older. This agrees with the interpretation made by Billings (1956, p. 98). The lower age limit of the Albee is unknown but may be as old as Early Ordovician, according to tentative regional correlations with fossiliferous areas in New England.

OQUOSSOC FORMATION

General Statement

The Oquossoc Formation is an unpublished name proposed by C. V. Guidotti (1965, written communication) for a thick sequence of greenstone, minor felsic tuff, green slate, and black slate located in the northeast corner of the Oquossoc quadrangle (Figure 1, no. 15). In the Cupsuptic quadrangle the Oquossoc Formation outcrops in a north-trending belt restricted to the southeast ninth where excellent exposures are found along the abandoned Maine Central Railroad, on the low hills north of Kamankeag Brook, and on Cloutman Ridge (SW1/4 SE1/9).

The Oquossoc Formation consists of two map units. One is predominantly greenstone with minor amounts of felsite, black slate, and green phyllite; the other is mainly black slate with minor amounts of feldspathic quartzite and greenstone. South of Kamankeag Brook the Oquossoc Formation is predominantly greenstone that contains thin beds of black slate near the eastern contact, and thin beds of green phyllite near the western contact on the west slopes of Cloutman Ridge. North of Kamankeag Brook the formation is predominantly black slate that interfingers with the greenstone. There are few exposures of black slate except on the hills immediately north of Kamankeag Brook, and the facies relationship between the black slate and greenstone is inferred largely from those exposures.

On the west slope of Cloutman Ridge thin bands of greenstone from 10 to 50 feet wide alternate with bands of green phyllite that range in thickness from 5 to 25 feet. The zone of alternating rock types is about 200 feet wide and suggests that the contact between the Oquossoc Formation and the Aziscohos member of the Albee Formation is the result of deposition and not due to a major unconformity or fault. The Oquossoc Formation is considered to lie above the Aziscohos member on the basis of a few stratigraphic top determinations that face to the east in the greenstone, and the numerous east-facing top determinations in the Kamankeag Formation presented on Plate VII.

Lithology

Greenstone: The bulk of the Oquossoc Formation exposed in the map area is dark-green, massive to crudely-foliated greenstone that forms abundant outcrops on low "hogback" ridges. The outcrops are commonly broken into blocky talus by numerous intersecting fractures, some of which are filled with yellowish-green veinlets composed of epidote, calcite, and quartz. Pods of epidote, calcite, and quartz are common and stand in relief above the soft, rough, dark-gray or greenish-tan weathered surface of the greenstone. Primary structures are rare, although the faint outline of pillow structures was observed at two localities.

The greenstone is composed of albite or sodic oligoclase, actinolite, calcite, chlorite, epidote, and sphene with minor amounts of pyrite, tourmaline, zircon, and magnetite.

Representative modes of the greenstone are given in Table 2. Commonly, the matrix of the greenstone is a felted mass of Plagioclase microlites less than 0.1 mm in length containing scattered euhedral to subhedral needles of actinolite. Chlorite, calcite, and epidote are anhedral and intergranular to the plagioclase and actinolite. Small anhedral to subhedral grains of sphene are scattered in the matrix. Less commonly, the greenstone has an ophitic texture in which the plagioclase and actinolite crystals range in size up to 0.3 mm. Calcite, chlorite, epidote, and sphene are intergranular to the larger grains and commonly embay the plagioclase laths.

<u>Felsite</u>: Locally, near the contact between the greenstone and black slate, the volcanic rock is a light greenish-gray or gray felsite that weathers light gray and is commonly veneered by a dark rusty-brown limonite stain. The felsite, which ranges in thickness from 0 to 75 feet, does not show any primary structures but contains a crude foliation parallel to the cleavage in the slate.

The felsite is composed primarily of albite, actinolite, quartz, sericite, chlorite, epidote, and calcite with minor amounts of sphene, zircon, tourmaline, and pyrite. The major minerals are present in variable proportions as shown in Table 2; but microlites of plagioclase commonly form the

Table 2. Representative modes of the Oquossoc Formation

	1	2	3	4	5	6	7	8	9	10	11	12
Quartz	0.8	<1	1-2	0.1		3.6	13.9	40	10	2-3	20	
Plagioclase	42.0	60	45	45.5	63	16.7	0.4	30	35	63	32	60
Alkali Feldspar									1-2			
Sericite	tr	tr	tr					5	15	tr	35	30
Chlorite	7.1	5	10	2.2	25	15.2	5.1	7	tr	10	8	7
Epidote	0.8	1	1	2.6	8	27.0	62.0	3	3		2	
Actinolite	30.6	25	35	26.6		30.2	14.4	2	25			
Ilmenite					1							
Magnetite		tr	tr								1	
Pyrite	0.3	tr	tr	tr	3			tr	1	3-4		2
Sphene	9.5	7	5	11.8		6.7	5.5	2	3	5	<1	
Calcite	8.5	12	2	10.0		1.3	4.5	1		15	1	
Limonite	0.5			0.3	tr			tr	1		tr	
Rutile						0.6						
Tourmaline						0.1				tr		tr
Zircon		tr	tr			tr			tr	tr	tr	tr
Opaque												1?
Plagioclase Composition	Alb.	Alb.	Alb.-Olig.	Alb.	Alb.	Alb.	Alb(?).	Alb.	Alb.	Alb.	Alb(?).	Alb(?).
Method of * Analysis	p.	v.	v.	p.	v.	p.	p.	v + x	v.	v.	v.	

* p = point count
v = visual estimate
x = estimate from x-ray intensities

Description and location of specimens in Table 2.

1- Dark-green, massive, greenstone; on east side of abandoned Maine Central R.R., 1700' southeast of 1488' BM at Kamankeag Pond.

2- Crudely-foliated greenstone; at 1900' elevation, 1.7 miles bearing 143° from 1488' BM at Kamankeag Brook.

3- Massive greenstone; at 2075' elevation, 4600' bearing 087° from 1488' BM at Kamankeag Brook.

4- Light-green, massive, greenstone; on 2160' topo knob, 5400' bearing 345° from camp on west shore of Kamankeag Pond.

5- Dark-green, crudely-foliated, greenstone; at 1660' feet elevation on southern-most knob of Cloutman Ridge.

6- Foliated greenstone; on west slope of Cloutman Ridge, 4400' bearing 127° from Franklin-Oxford county corner post.

7- Yellow-green quartz-epidote pod in greenstone; same location as 6.

8- Light-gray, foliated felsic volcanic; on 1780' topo knob, 2600' bearing 047° from 1514' BM on abandoned Maine Central R.R.

9- Light-gray felsic volcanic; on small 1760' topo knob, 3400' bearing 040° from 1514' BM on abandoned Maine Central R.R.

10- Felsic volcanic adjacent to contact between Oquossoc and Kamankeag Formations, at 2120' elevation, 4600' bearing 337° from camp on west shore of Kamankeag Pond.

11- Green phyllite interbedded in greenstone; west slope of Cloutman Ridge, 4000' bearing 134° from Franklin-Oxford county corner post.

12- Black slate; at 1740' elevation, 1300' bearing 045° from 1514' BM on abandoned Maine Central R.R.

matrix in which quartz, actinolite, calcite, chlorite, and epidote form intergranular aggregates.

Green phyllite: Thin bands of green phyllite from 5 to 25 feet thick are interbedded in the greenstone on the west slope of Cloutman Ridge near the contact of the Oquossoc Formation and the Aziscohos member of the Albee Formation. The green phyllite bands are separated by hogback ridges of greenstone that range in thickness from 10 to 50 feet over a zone about 200 feet wide. The phyllite is green or greenish-gray and weathers to a soft, chalky-white or buff surface. It contains numerous quartz pods and stringers and looks exactly like the green phyllite of the Aziscohos member of the Albee. The phyllite is composed of quartz, muscovite, chlorite, albite, and magnetite with minor amounts of zircon and tourmaline as accessory minerals.

Black slate: Bands of black slate up to 150 feet wide are found in the greenstone on the low hills south of Kamankeag Brook near the eastern contact of the Oquossoc Formation. The black slate is soft, highly fissile and dull black where fresh, and weathers to a rusty-brown surface. It is composed primarily of quartz, muscovite, chlorite, albite, and pyrite. Zircon and tourmaline may also be present but they could not be detected optically due to the presence of finely-divided, opaque, carbonaceous material of unknown composition.

North of Kamankeag Brook the Oquossoc Formation consists of black slate that interfingers with and is thus considered equivalent to the greenstone. The slate is soft, dull black to dark gray on the fresh surface and weathers dark rusty-tan. Beds of dark gray feldspathic quartzite, generally less than 2 inches thick, are scattered in the black slate. The arenaceous beds are fine grained and commonly graded. Similarly, bands of dark green, rusty-weathering greenstone up to 50 feet thick are present locally in the black slate.

The slate is composed of quartz, muscovite, chlorite, albite, pyrite, and finely divided carbonaceous material of unknown composition. All the minerals are microscopic. The feldspathic quartzite contains mostly subangular quartz and albite less than 0.1 mm in diameter with variable but minor amounts of muscovite, chlorite and pyrite. The greenstone is identical in composition and texture to that described in the preceding section.

Thickness

The exact thickness of the Oquossoc Formation is difficult to determine because the degree of folding cannot be fixed by the two top sense determinations made in the greenstone. If there has been no minor folding, the formation has a maximum thickness of 5500 feet based on a maximum outcrop width of 6000 feet and an average dip of 70 degrees.

Age

The Oquossoc Formation underlies the Kamankeag Formation of late Middle Ordovician age; hence it is late Middle Ordovician or older.

KAMANKEAG FORMATION

General Statement

The Kamankeag Formation, which is predominantly black slate, is named for the typical exposures found on the low hills northwest and south of Kamankeag Pond (SE1/4 SE1/9) as well as those in Kamankeag Brook in the vicinity of the Oxford-Franklin county line. The rocks of the formation crop out in other scattered localities in the southeast ninth of the quadrangle and are well exposed on the west slope of Ephraim Ridge.

The predominant rock type is black slate that contains variable amounts of calcareous lithic graywacke, dark-gray feldspathic quartzite and minor greenstone. The graywacke is generally found in the lower part of the formation near the contact with the Oquossoc Formation; whereas the pyritic quartzite is most abundant in the upper part of the Kamankeag Formation in the vicinity of Ephraim Ridge (SE1/4 SE1/9). Thin beds of greenstone are scattered throughout the black slate.

The stratigraphic top determinations presented on Plate VII indicate that the Kamankeag Formation overlies the Oquossoc and forms an essentially homoclinal sequence that faces to the east. Alternating bands of greenstone and black slate form a zone about 200 feet wide that marks the transition from the Oquossoc Formation into the Kamankeag Formation. The contact is placed at the eastern-most band of greenstone in this zone. In a macroscopic sense the lower contact of the Kamankeag Formation is gradational. The upper contact of the formation is not exposed in the quadrangle.

Lithology

Black slate: The bulk of the Kamankeag Formation is soft, highly-fissile, rusty-weathering, pyritic black slate. Locally, however, the slate is hard and contains milky-white or black chert laminae, about 3.0 mm thick, parallel to the arenaceous beds. Pyrite cubes up to 2.0 mm on a side are scattered in the slate and commonly constitute the only mineral visible in hand specimen. Along the crest and upper slopes of Ephraim Ridge the black slate has been contact metamorphosed to a hard, maculose hornfels which contains small "knots" of muscovite and biotite.

As shown in the representative modes of Table 3, the black slate is composed mainly of quartz, albite, muscovite, chlorite and pyrite with lesser amounts of zircon and finely-divided, opaque carbonaceous material. All of the minerals except pyrite are microscopic. Biotite flakes about 0.1 mm in maixmum diameter are present in the hornfels, in addition to roughly spherical knots composed of white mica and minor chlorite and biotite. The white mica aggregates are lighter than the matrix in plane polarized light, and may represent pseudomorphs after a mineral such as cordierite or andalusite; however, no relict mineral was found.

<u>Arenaceous rocks</u>: Two types of arenaceous rocks are present in the Kamankeag Formation: calcareous lithic graywacke, and dark gray feldspathic quartzite.

Dark-gray, fine- to medium-grained, calcareous lithic graywacke forms the bulk of the rock exposed for about 150 feet across strike in Kamankeag Brook in the vicinity of the

Oxford-Franklin County line. In addition, several beds of graywacke, as much as 10 feet thick, crop out on the low hills immediately north of this section of Kamankeag Brook, and a 6 foot bed of graywacke is exposed about 75 feet east of fossil locality no. 2 (Plate I). The graywacke is generally located near the base of the formation where it forms beds up to 15 feet thick in the black slate. Thin lenses of soft black slate, which range in thickness from 3 to 10 inches, are present in the thicker beds of graywacke. The graywacke is massive to highly foliated and weathers to a light gray, rough, and pitted surface.

The graywacke contains platy fragments of black slate, chert, and light greenish-gray slate, which range in size from about 0.1 mm to 3.0 mm, in a very fine-grained matrix of muscovite, chlorite, feldspar, and calcite. Pyrite and zircon are present in minor amounts. Calcite is also present as recognizable organic fragments in both hand specimen and thin section. The black slate fragments have a pronounced foliation that is parallel to the foliation in the graywacke beds; hence it is inferred that they were incorporated as mud chips.

Beds of dark gray, feldspathic quartzite as much as 3 inches thick form the second type of arenaceous rock in the Kamankeag Formation. The quartzite beds distributed throughout

TABLE 3. REPRESENTATIVE ESTIMATED MODES OF THE KAMANKEAG FORMATION

	1	2	3	4	5	6	7
Quartz				36	33	10	
Plagioclase	65	67	60		12	30	55
Alkali'spar				20	7	5	
Muscovite		19	18	13			
Biotite		5	3			20	5
Chlorite	12	4	7				
Actinolite						2	35
Epidote							
Pyrite	3	2	7	1		2	1
Calcite				2			1
Zircon	tr	tr					
Opaque	2	3	5				
Sericite	17				40	16	2
Rutile							
Chert				20			
Lithic Fragments				8	8	15	
Clasts				65	60	60	
Matrix				35	40	40	

1- Black slate; 2100' elevation, 500' south of 2360' topo knob bearing 337° from the camp on the west side of Kamankeag Pond.

2- Maculose black slate; at 2080' elevation, 1500' bearing 266° from 2480' summit of Ephraim Ridge.

3- Maculose black slate; at 2560' elevation on west side of 2600' topo knob of Ephraim Ridge.

4- Calcareous, lithic graywacke; on 2040' topo knob 3100' due west of camp on west shore of Kamankeag Pond.

5- Lithic graywacke; at 1920' elevation, 5500' bearing 085° from 1514' BM on abandoned Maine Central R.R.

6- Feldspathic graywacke; at 2580' elevation on northeast side of 2600' topo knob of Ephraim Ridge, 1.2 miles due south of the camp on the west side of Kamankeag Pond.

7- Greenstone; at 1960' elevation, 2000' bearing 245° from 2480' summit of Ephraim Ridge.

the slate comprise less than 5 percent of the lower part of the formation; locally they account for as much as 30 percent of a given exposure in the upper part of the slate exposed on the west slope of Ephraim Ridge. In the upper part of the formation, the arenaceous beds average about 1½ inches thick and are commonly separated by 6 to 15 inches of black slate. On Ephraim Ridge the interbedded slate and quartzite are characterized by pronounced joints parallel to the bedding that produce a flaggstone talus.

The quartzite is composed primarily of microscopic quartz and albite with variable but minor amounts of muscovite, chlorite, and locally biotite in the contact aureole. Pyrite forms cubes a few tenths of a millimeter on an edge or elongate smears parallel to the cleavage. The subangular to subrounded quartz and albite grains are commonly encased or partially surrounded by finely-divided, opaque, carbonaceous material(?).

<u>Greenstone</u>: Thin beds of greenstone and mafic pyroclastic rock are present in minor amounts throughout the formation but are most abundant in the lower part of the slate. The greenstones are identical to those described under the Oquossoc Formation, except that biotite may be present in

the contact metamorphosed pyroclastic rocks on Ephraim Ridge.

Thickness

The true thickness of the Kamankeag Formation cannot be determined in the Cupsuptic quadrangle because the top of the formation is not exposed. Robert H. Moench (1965, written communication) estimates the thickness of the Kamankeag Formation to be 2500 feet to 3000 feet immediately southeast of the area in the Rangeley quadrangle (Figure 1, no. 10) where the top is exposed. The maximum outcrop width of the Kamankeag Formation in the map area is about 6500 feet, which gives a maximum possible thickness of 6000 feet if one assumes an average dip of 70 degrees and no repetition due to folding. The apparent discrepancy in thickness between the adjacent areas may be due to minor folding in the Cupsuptic quadrangle; however, the limited number of top determinations presented on Plate VII suggests that there are no large scale folds. A maximum thickness of 6000 feet is assumed to be essentially correct for the Kamankeag Formation.

Age

The Kamankeag Formation has been dated as late Middle Ordovician on the basis of the graptolite assemblage (Table 4) found at fossil locality no. 2 northwest of Kamankeag Pond. W. B. N. Berry (1964, written communication) identified the graptolites as diagnostic of his zone 12 of the Middle Ordovician (Berry, 1960). Black slate interbedded in the graywacke at fossil locality no. 3 in Kamankeag Brook contained poorly preserved graptolites identified by Berry (1964, written communication) as Climacograptus sp. and Dicellograptus(?) sp.. The graywacke at locality no. 3 contained fragments of bryozoans, brachiopods, pelecypods, gastropods, and pelmantozoans that were studied by Dr. Robert B. Neuman but which were too badly deformed for generic identification.

DIXVILLE FORMATION

General Statement

The Dixville Formation was proposed by Green (1964, p. 23) for black phyllite and schist, quartzite, and amphibolite that overlie the Albee Formation on the west side of the Errol quadrangle (Fig. 1,no. 20). The rocks extend into the eastern part of the Dixville quadrangle (Fig. 1, no. 24) where they have been described by Hatch (1963, p. 12-18). At the type area Green (1964, p. 23-32) subdivided the formation into the Dixie Brook member, which is predominantly

Table 4: List of graptolites from locality no. 2 in the Kamankeag Formation

Climacograptus _bicornis_ (J. Hall)

Climacograptus _scharenbergi_ Lapworth?

Cooynoides sp.

Cryptograptus _tricornis_ (Carruthers)

Dicellograptus _gurleyi_ Lapworth?

Dicellograptus sp.

Didymograptus _sagitticaulis_ Gurley?

Glyptograptus _euglyphus_ var. _pygmaeus_ (Ruedemann)?

Glyptograptus _teretiusculus_ (Hisinger)

Glyptograptus sp.

Hallograptus _bimucronatus_ (Nicholson)

Hallograptus _mucronatus_ (J. Hall)?

Orthograptus _calcaratus_ var. _acutus_ (Lapworth)

Orthograptus _calcaratus_ var. _incisus_ (Lapworth)

Orthograptus sp. (of the _O._ _calcaratus_ group) black phyllite, schist, and quartzite; the Clear Stream member, which is mainly amphibolite; and the Rice Mountain member, which is black schist with interbedded quartzose and spessartitic granofels. Green (1964, written communication) traced the Dixville Formation across the Second Lake quadrangle where he divided it into the Dixie Brook member, consisting of black slate; and the overlying Magalloway member, composed mainly of feldspathic graywacke exposed in the vicinity of the First East Branch of the Magalloway River.

The Dixville Formation outcrops in a broad belt across the northern half of the Cupsuptic quadrangle where it has been subdivided into two members, each of which contain several rock types. The lower member, the Dixie Brook, is predominantly black phyllite with minor amounts of green phyllite, gray quartzite, and greenstone. The larger patches of greenstone within the black phyllite have been shown as a separate map unit. Each rock type in the Dixie Brook member is easily recognized and has a distinct boundary where these have been observed. Similarly, the contact between the Dixie Brook member and the overlying Magalloway member is relatively sharp where observed, but the contacts between rock types within the Magalloway member are gradational.

The Magalloway member consists of feldspathic graywacke, green and purplish gray slate, light greenish-gray felsic tuff (?), and greenstone. The graywacke, slate, and felsic tuff (?) could not be separated at the scale of the map because gradational types exist and none could be traced reliably from outcrop to outcrop. The greenstone is shown as a separate map unit within the Magalloway because it could be easily traced in the field. It grades vertically into the other types over a zone as much as 100 feet wide; hence, its boundaries are somewhat arbitrarily positioned.

Dixie Brook member

Black phyllite: Black phyllite constitutes the bulk of the Dixie Brook member and is exposed in scattered outcrops on the higher hills and ridges in a broad belt extending from Parmachenee Lake on the west to Little Kennebago Lake on the east side of the quadrangle. Excellent exposures of black phyllite are found in the Big Canyon of the Cupsuptic River and on the southeast side of Parmachenee Lake. Black phyllite of the Dixie Brook member also forms the predominant rock type exposed in a narrow belt located north of Green Top Mountain (SE1/4 WC1/9) and in the vicinity of the upper reaches of Lost Brook (SW1/4 C1/9).

The phyllite, which is soft, strongly foliated and locally crenulated, varies from jet black to silvery black if fresh and dark rustybrown if weathered. Locally the rock is an intensely fractured, soft slate that is dull black on the cleavage surfaces. Cubes of pyrite up to ½ inch on a side are common in the black phyllite, and aggregates of pyrite form pods up to 2 inches in length elongated parallel to the foliation.

The bulk of black phyllite is at the chlorite grade of metamorphism and is composed primarily of microscopic quartz, albite, muscovite, chlorite, and minor amounts of pyrite, zircon, tourmaline, limonite, and opaque carbonaceous material(?). Representative modes are given in Table 5. Around the northern side of the quartz monzonite body located in the center of the map area, the black phyllite is contact metamorphosed to a maculose, andalusite-bearing hornfels and an equigranular sillimanite-bearing hornfels. As shown in the representative modes of Table 5, biotite, cordierite, and locally potassic feldspar are present in addition to quartz, plagioclase, and the aluminum silicates. Acicular crystals of andalusite ranging in length from a few millimeters to a few centimeters form the porphyroblasts in the maculose hornfels, the matrix of which is composed of microscopic quartz, sodic-plagioclase, muscovite, biotite, chlorite and locally cordierite. The dark-gray, rusty-weathering, equigranular hornfels contains sillimanite and locally potassic feldspar in addition to the minerals present in the maculose hornfels.

<u>Green phyllite</u>: Green phyllite is found in a few scattered outcrops on the low hills immediately northeast of Moose Brook Camp (SE1/4 NW1/9). The green phyllite is completely surrounded by black phyllite of the Dixie Brook member, but the exact stratigraphic relationship between the two rock types cannot be established due to the scarcity of exposures. The green phyllite is similar to that of the principal member of the Albee and the Aziscohos member of the Albee, except that it lacks the "pinstripe" granulite beds of the former and the quartz pods and stringers of the latter.

The phyllite is soft, green or greenish gray, highly crenulated and weathers chalky-white or buff. It is composed of microscopic quartz, albite, muscovite, chlorite and minor amounts of zircon, tourmaline and magnetite.

<u>Gray quartzite</u>: Dark-gray, fine- to medium-grained quartzite is found in scattered localities in the black phyllite near the base of the Dixie Brook member. The quartzite is well exposed at an elevation of 1990 feet in the Big Canyon of the Cupsuptic River and north of Snow Mountain Brook, and on

Table 5. Representative estimated modes of the Dixie Brook member of the Dixville Formation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Quartz			95													54	72
Plagioclase	60	72	2	55	50	88	71	78	70	76	79	74	80	73	68	1-2	2
Alkali Feldspar			?												1	2	5
Muscovite	35	35	1				25	10	12	6	5	2	10	8	8	1-2	2
Biotite							2	6	10	5	3	10	5	12	10	20	7
Chlorite	10	3	2	10	8	4	7	2	3	2							
Andalusite										<1	10	12	<1	5	4	5	10
Sillimanite													<1	2	8	4	<1
Cordierite								3	5	10	1	?	3		<1	12	<1
Actinolite				25	28												
Epidote				5	7												
Ilmenite	tr			1	?												
Pyrite	tr	tr	tr				tr	<1	<1	tr	tr	tr		tr			
Tourmaline															tr	tr	tr
Sphene	tr	tr		3	1												
Calcite				tr	2												
Zircon	tr	tr								tr	tr	tr	tr		tr	tr	tr
Limonite	tr	tr											tr	tr			tr
Rutile		tr											tr		tr	?	
Opaque	2	<1		tr	tr	tr (Mag)					2	2		tr	tr	tr	
Plagioclase Composition	Alb.	Alb.	Alb(?)	Alb.-Sod.-Olig.	Alb.-Olig.	Alb.	Alb.	Alb.	Alb.	Alb.	Alb.	Alb.-Olig.	Alb.-Olig.	Alb.-Olig.	Alb.-Olig.	Alb.-Olig.	Alb.-Olig.

Description and location of specimens in Table 5.

1- Rusty weathering, black phyllite; 2220' elevation on low hill east of Little Kennebago Lake, 5600' bearing 033^o from Otter Brook Camp.

2- Black phyllite; on west side of 2120' topo knob located on eastern border of the quadrangle 2.7 miles due north of Grants Camps on Kennebago Lake.

3- Light-gray, fine-grained quartzite; at 1990' elevation in Big Canyon of the Cupsuptic River.

4- Massive greenstone; on summit of 3100' mountain on International Boundary, 1000' northwest of 3012' BM west of Cupsuptic Pond.

5- Crudely foliated to massive greenstone; on 3235' mountain 2 miles due west of Cupsuptic Pond.

6- Light-gray to white felsic volcanic; at 2560' elevation, 2700' bearing 223^o from the summit of Bottle Mountain.

7- Maculose black phyllite; at 2200' elevation on northwest slope of 2480' topo knob west of Little Kennebago Lake.

8- Maculose black phyllite; at 2420' elevation on east slope of Bald Pate, 1.7 miles bearing 305^o from Otter Brook Camp.

9- Maculose black phyllite; at 2070' elevation in Otter Brook west of Little Kennebago Lake.

10- Maculose black phyllite; at 2160' elevation in Otter Brook.

11- Maculose black slate; at 1970' elevation in Big Canyon of the Cupsuptic River.

12- Maculose black phyllite; at 1965' elevation in Big Canyon of the Cupsuptic River.

13- Dark gray to black, fine-grained, equigranular hornfels; at 2880' elevation on summit of Bald Pate west of Little Kennebago Lake.

14- Dark gray, muscovite-spangled hornfels; at 2720' elevation in old road that traverses south of the upper reaches of Otter Brook.

15- Dark gray, equigranular hornfels; at 2780' elevation in old road that traverses south of the upper reaches of Otter Brook.

16- Rusty-black, fine-grained, equigranular hornfels; at 3280' elevation on east slope of 3475' mountain northwest of West Kennebago Mountain.

17- Rusty-black equigranular hornfels; at 1955' elevation in Cupsuptic River.

the hill immediately east of the outlet of Parmachenee Lake.

The quartzite beds illustrated in Figure 8 range in thickness from a few inches to as much as 2 feet and are separated by bands of black phyllite as much as 8 feet thick. A zone of interbedded phyllite and quartzite is exposed for a distance of about 70 feet across strike in the Cupsuptic River. This represents a local minimum thickness for the zone of quartzite because till and stream gravel cover the northern end of the last quartzite exposure. The quartzite is massive, highly fractured, locally studded with pyrite cubes and weathers a light rusty gray. Graded bedding is rare.

The quartzite is composed primarily of subangular to subrounded quartz about 50 μ to 0.2 mm in maximum diameter, with minor amounts of angular to subangular plagioclase, muscovite, chlorite, and pyrite.

Greenstone: Greenstone, which ranges from thin beds about 6 feet thick to large, mappable patches several hundred feet thick, is scattered in the black phyllite of the Dixie Brook member. Discontinuous but mappable units of greenstone are found on the east-west trending ridge south of Moose Brook Camp (SE1/4 NW1/9), and on the north-trending ridge between Cupsuptic Pond and the First East Branch of the Magalloway

Figure 8: Thick-bedded, gray quartzite in black phyllite of the Dixie Brook member of the Dixville Formation. About 1990' elevation in the Cupsuptic River.

River.

The greenstone is massive to crudely foliated, dark green where fresh, and weathers light gray or light rusty tan. With the exception of pillows preserved in the greenstone on the south slope of the 3235 mountain due west of Cupsuptic pond, primary structures are absent and the greenstone is characterized by numerous fractures, some of which are filled with quartz-epidote-calcite veinlets. The greenstone is composed mainly of plagioclase and actinolite with minor amounts of chlorite, epidote, sphene, calcite, ilmenite, and pyrite.

Local patches and thin beds of felsic tuff(?) commonly less than 1 foot thick are scattered in the black phyllite. The tuff (?) weathers to a soft chalky-white surface and is light gray or greenish-gray where fresh. The rock is composed of microscopic quartz and feldspar with minor amounts of chlorite and magnetite and finely divided sericite that may be secondary after the plagioclase.

Magalloway member

The Magalloway member is exposed in two broad tracts in the northern third of the quadrangle. One forms the slopes of the valley drained by the First East Branch of the Magalloway River, and the other extends from the vicinity of

Cupsuptic Pond on the west to the eastern border of the map area. Outcrops are found on the higher hills and mountains, notably on the southeast slope of Thrasher Peaks (NW1/4, NW1/9), on Kennebago Divide (NW1/4 NE1/9), and on the sharp ridges that lie east and west of the Kennebago River (NE1/9). The bulk of the Magalloway member consists of feldspathic graywacke, green slate, and light-green felsic tuff (?) interbedded in variable proportions. Transitional types exist between these rocks. The graywacke is distinguished from the slate and pyroclastic rocks by the abundance of clasts composed of quartz, quartzite, chert, slate, and muscovite set in a fine-grained matrix of quartz, feldspar, sericite and chlorite. The mixture of sedimentary and volcanic rocks indicates a complex origin from at least two distinct sources; however, speculations about the origin will be deferred until the rocks have been discussed in detail.

Relatively thin but locally continuous bands of greenstone have been mapped as a separate unit within the Magalloway member.

Feldspathic graywacke: Dark-green, greenish-gray or rusty olive-green, medium- to coarse-grained feldspathic graywacke, as defined by Pettijohn (1957, p. 291, Table 4), is the major rock present in the Magalloway member. The weathered surface is rough and the clastic grains stand in relief above the light-gray or rusty-tan weathering matrix. Bedding is marked by a change in the proportion of clasts to matrix that may be abrupt or gradational across the strike. The beds are commonly discontinuous along strike in a given outcrop. Quartz-feldspar granule conglomerate lenses, as illustrated in Figure 9, are found locally at the base of coarse-grained graywacke beds. The graywacke beds grade continuously into dark green or purplish-gray slate and into light to dark green pyroclastic rocks.

The feldspathic graywacke contains clasts of quartz, quartzite, alkali feldspar, plagioclase, muscovite, greenish-gray slate, and chert in variable proportions; but generally the quartz, quartzite, and feldspar fragments predominate. Textural relationships are shown in Figure 10; representative modes of the graywacke are given in Table 6. The quartz clasts are glassy, white, light blue, or hematite-stained, subangular to subrounded, and range in size from about 0.1 mm to 10.0 mm in maximum diameter. Microscopic needles of rutile are present in some quartz grains. Some of the quartz clasts are polycrystalline aggregates in which the individual grains range in size from 50 μ to 0.2 mm and contain sutured boundaries and strain lamellae. The polycrystalline quartz clasts may be fragments of quartzite or vein quartz. Microcline-perthite and plagioclase grains, present in variable amounts, range in

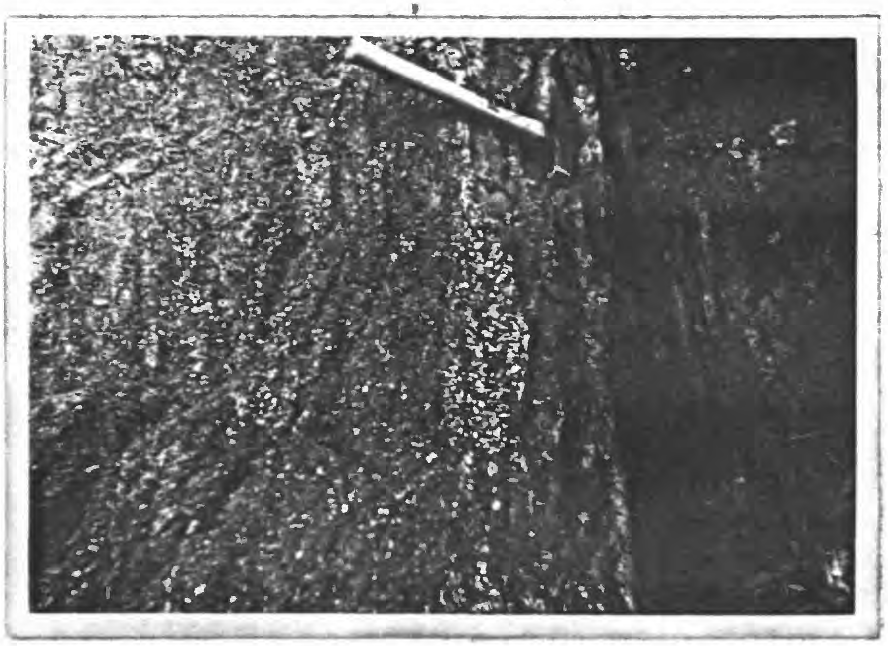


Figure 9: Quartz-feldspar granule conglomerate lens in fine- to medium-grained Magalloway member of Dixville Formation. On Beaver Pond Tote Road 1/8 miles north of Crowley Brook.

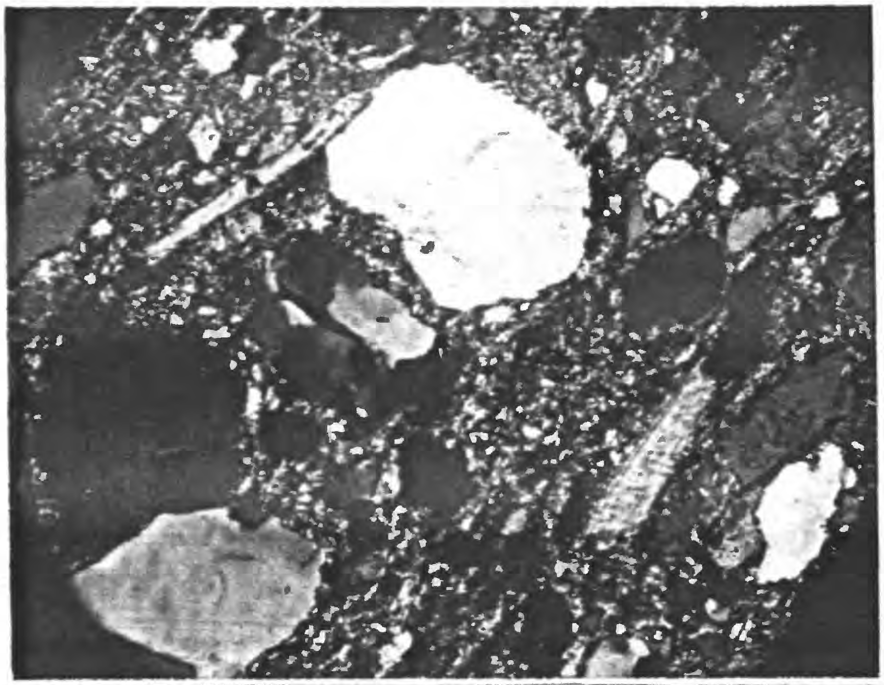
Figure 10: Photomicrographs of typical feldspathic graywacke. Note large muscovite clasts.

MUS = muscovite

QTZ = quartz

ALK-FSP = alkali feldspar

PLG = plagioclase



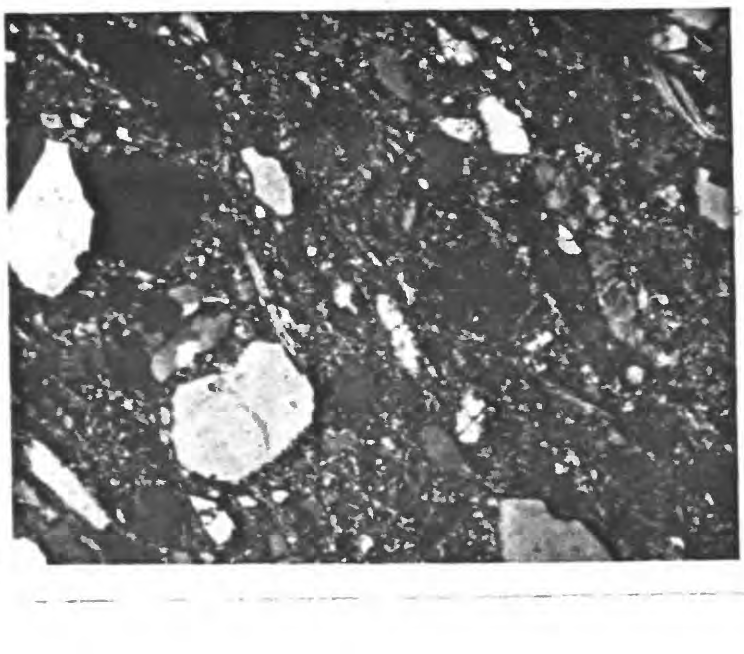


Table 6. Representative estimated modes of the Magalloway member of the Dixville Formation

Feldspathic graywacke

	1	2	3	4	5	6	7	8	9
Clasts (in thin section)	35	80	85	15	79	78	30	38	55
Plagioclase	2	14	20		10		4	5	9
Alkali Feldspar		20	17	10	16	65	3	6	6
Quartz	33	45	29	3	48	7	12	20	28
Quartzite		tr	17	1	5	5	8	5	10
Muscovite	tr	1		1	1		2	1	1
Lithic Fragments	tr	<1	<1	tr		1	tr	tr	
Hornblende	tr								
Zircon							1	1	1
Tourmaline							tr	tr	
Matrix	65	20	15	85	21	22	70	62	45
Quartz	56	15	8	83	17	3	69	40	36
Sericite									
Limonite									
Chlorite	7	2	5					20	
Calcite		1	1		3			1	
Clinozoisite		1	1						7
Zircon									
Rutile		tr			tr				
Pyrite	2	1		2	2	1	1	1	
Magnetite									
Andalusite						tr			
Biotite						18			1
Tourmaline						tr			
Garnet									
Ilmenite									

volcanic rocks

	10	11	12	13	14
Quartz	67	5		20	10
Plagioclase		60	52	33	33
Alkali Feldspar					
Sericite	10	2			
Chlorite	20	5	5	15	1
Clinozoisite		25	10	30	20
Actinolite		tr	30		25
Ilmenite					1
Magnetite				1	
Sphene	1	tr	tr		
Calcite	2	3	3	tr	10
Limonite		1			
Rutile	1				
Clinopyroxene			tr		
Biotite				1	

Description and location of specimens in Table 6.

1- Schistose, rusty-tan, feldspathic graywacke; at 2400' elevation in Sable Mill Brook.

2- Green, crudely-foliated feldspathic graywacke; on top of 2140' topo knob just north of the confluence of Bear Brook and Kennebago River.

3- Dark green, massive graywacke; on top of 2669' topo knob, 3500' bearing 305° from 1922' BM on the Beaver Pond Tote Road.

4- Dark green, very fine-grained, muscovite-rich grit; at 2000' elevation, 3700' bearing 326° from 1869' BM on the Beaver Pond Tote Road.

5- Dark green, coarse-grained feldspathic graywacke; Occurs as lens in fine-grained grit of specimen 4. Same location as number 4.

6- Light-gray flecked with black, biotite granulite, contact metamorphosed graywacke; at 2440' elevation in brook flowing from White Cap Pond.

7- Light-gray-green, foliated feldspathic graywacke; at 2220' elevation, 1400' bearing 144° from 2620' summit of Thrasher Peaks.

8- Greenish-gray, fine- to medium-grained, foliated graywacke; on 3120' topo knob 4800' bearing 232° from 3012' BM on International Boundary west of Cupsuptic Pond.

9- Dark-green, massive graywacke; at 3740' elevation on northern summit of Kennebago Divide.

10- Light apple green, highly schistose felsic volcanic; at 2200' elevation, 1800' bearing 186° from 2620' summit of Thrasher Peaks.

11- Dark-green to rusty-tan, crudely foliated greenstone; western half of the Arnold Pond quadrangle, at 2340' elevation 2200' due south of Lower Black Pond.

12- Light-gray-green, massive, greenstone; western half of the Arnold Pond quadrangle, at 2160' elevation in brook flowing from Lower Black Pond.

13- Dark and light-green, banded greenstone; at 2400' elevation, 1.3 miles bearing 122° from 1950' BM on Beaver Pond Tote Road.

14- Banded, dark-green and yellow-green, very fine-grained, epidote amphibolite; at 2320' elevation, 4300' bearing 129° from 1950' BM on the Beaver Pond Tote Road.

maximum diameter from 0.1 mm to 5.0 mm and may be euhedral, angular, or subrounded. Tabular green slate fragments composed of microscopic quartz, feldspar, chlorite and sericite are present in minor amounts. Muscovite flakes up to 2.0 mm in maximum diameter appear as bent and altered clasts in the fine-grained matrix. Rounded to subrounded fragments of zircon, tourmaline, and hornblende less than 0.1 mm in diameter are present in trace amounts in some rocks.

The matrix of the feldspathic graywacke is commonly a microscopic aggregate of sericite, quartz, feldspar, chlorite, with minor amounts of calcite and limonite present locally. Chlorite appears as aggregates in subrounded to angular patches about 50 μ in size. Locally the graywacke has a siliceous matrix that deeply embays and serates the edges of the clastic grains.

Green and purplish-gray slate: Minor amounts of slate, predominantly green but locally gray or purplish-gray, are interbedded with the arenaceous rocks throughout the Magalloway member. Purplish-gray slate is particularly abundant on the south slopes of the 3527 foot mountain on the International Boundary immediately west of White Cap Mountain (NW1/4 NE1/9). The slate is soft, highly fissile, locally crenulated, and weathers light gray or chalky-white. Beds range in thickness from a few inches to several tens of feet and are gradational into the graywacke and pyroclastic rocks.

The slate is composed of microscopic quartz, muscovite, chlorite, albite, and magnetite with minor amounts of zircon, tourmaline, and locally hematite.

Pyroclastic rocks: Light apple-green to dark-green, very fine-grained, massive- to schistose- volcanic rocks believed to be pyroclastic tuffs are interbedded with and grade into the feldspathic graywacke. The pyroclastic material forms the matrix of the graywacke in the transition rocks and may form the matrix in large parts of the graywacke. In the fine-grained pyroclastic rocks the foliation surfaces have a characteristic sheen and feel greasy to the touch.

The rock is composed primarily of quartz and untwinned feldspar less than 20 μ in diameter, with subordinate amounts of anhedral sericite and chlorite present as scaly aggregates. Euhedral to subhedral crystals of calcite less than 50 μ in diameter are scattered in the matrix composed of quartz, feldspar, sericite, and chlorite. Sphene and rutile crystals less than 20 μ in length are present in minor amounts.

Greenstone: Mappable units of greenstone are found in the Magalloway member along the southeast slope of Thrasher Peaks

(NW1/4 NW1/9), and in a band parallel to the northern border of the quadrangle in the vicinity of White Cap Mountain (NW1/4 NE1/9).

The greenstone is fine to medium grained, commonly dark green but locally yellow green in bands and pods composed of quartz, epidote, and calcite. Much of the greenstone is massive to crudely foliated. Locally the greenstone contains scattered pillow structures and beds of greenstone agglomerate that indicate the map unit as a whole originated as a combination of flows and pyroclastic accumulation. The greenstone "bombs" in the agglomerate are roughly ellipsoidal and have a maximum length of about 6 inches. Thin beds of purple or purplish-gray slate are present locally in the greenstone.

The greenstone is composed primarily of plagioclase (An_{10-20}), actinolite, epidote, chlorite, quartz, and calcite with minor amounts of sphene, rutile, ilmenite, and magnetite.

Origin: The present compositions, textures, and structures in the rocks of the Magalloway member suggest a complex origin from at least two different provenances. First, the composition and structure of the greenstone suggest that the original material was andesite or basalt that accumulated in part as pillowed flows and, in part, as coarse ejecta. The size of the volcanic "bombs" and the absence of sedimentary detritus in the agglomerate beds suggest that the source of the volcanic material was relatively close to the present position of the greenstone unit. However, the abundance of quartz, as single and polycrystalline grains, and the lesser amounts of slate fragments and detrital muscovite in the feldspathic graywacke are inconsistent with a volcanic source, particularly one supplying andesitic flows. These detrital grains suggest a low-grade metamorphic and possibly a granitic source. The muscovite clasts, which are larger than any of the minerals in the slate fragments, may have been derived from a granitic rock. Such a source would be compatible with the variable but significant amounts of perthitic alkali feldspar also found in the feldspathic graywacke. It is conceivable that fine-grained pyroclastic material was mixed with coarse detritus from low-grade metamorphic rocks and possibly granitic rocks to produce the bulk of the rocks referred to here as graywacke. Perhaps an appropriate name would be "volclastic rocks"; however, at present, the rocks have the texture and composition of a feldspathic graywacke.

Thickness

The thickness of the Dixville Formation is difficult to determine because there is little indication of the degree of folding that may be present. On the basis of outcrop width and the folds that have been determined, the total thickness is estimated to be about 8000 feet.

Age

The Dixville Formation was correlated with the Ammonoosuc and Partridge Formations by Green (1964, p. 24) and hence considered to be of Ordovician age. Fragments of *Protospongia* sp. found in the Dixie Brook member at fossil locality no. 4 were identified by Dr. Robert M. Finks who reported that *Protospongia* ranges in age from Cambrian to Ordovician. Dawson and Hinde (1889) reported *Protospongia* in rocks of Lower Ordovician age at Metis Bay, Quebec.

E. V. Post (1964, written communication) has found Middle Ordovician (Caradocian) brachiopods in rocks lithologically identical to the Magalloway member in the vicinity of The Forks, Maine. On the basis of this correlation, the Dixville Formation is considered to be Middle Ordovician in age or slightly older.

ROCKS OF SILURIAN AGE

Rocks of Silurian age crop out in three widely separated areas in the Cupsuptic quadrangle. There are at least three mappable rock units in each area but their exposure and areal extent is so restricted in the quadrangle that it seems inadvisable to give formal formational names to each one in this report. Instead, the rocks will be discussed under three major geographic subdivisions, namely: the Davis Town area, the Parmachenee Lake area, and the Thrasher Peaks area.

DAVIS TOWN AREA

General Statement

The rocks of Silurian age in the Davis Town area form the western limit of an open syncline in the southeastern part of the quadrangle and continue about 12 miles to the northeast into the Kennebago Lake quadrangle (Figure 1, no. 9). The western end of the syncline lies within Davis township and immediately east of the abandoned settlement of Davis Town (SE1/4 EC1/9), for which the area is named. The basal map unit on the south limb of the syncline is a boulder-to-cobble polymict conglomerate. The polymict conglomerate is believed to interfinger with the lowest map unit on the north limb, a coarse granule to pebble quartz conglomerate. A map unit consisting of alternating thin beds of argillite and quartzite overlies the quartz pebble conglomerate on the north limb, and interfingers with and overlies the polymict conglomerate unit on the south limb.

Polymict conglomerate unit

Lithology: This map unit consists primarily of polymict conglomerate with minor amounts of interbedded feldspathic quartzite. It is well exposed on the southeast and west slopes of the 2780 foot hill located between Johns Pond and Kamankeag Pond, and at scattered localities at about 2200 feet elevation ½ mile north of Kamankeag Pond. It rests unconformably upon the Kamankeag and Oquossoc Formations.

Near the base of the unit, the polymict conglomerate contains clasts of black slate, granite, vein quartz, light-gray quartzite, green phyllite, and minor amounts of greenstone, felsite, and light-gray, coarsely-crystalline limestone. The clasts range in size from pebbles about 1 inch in maximum diameter to boulders about 2 feet in diameter. The granite, vein quartz, and quartzite clasts are well-rounded and nearly spherical; whereas, the black slate and green phyllite clasts are platy with an angular shape and show a pronounced foliation.

As well as could be determined, the foliation in the slate fragments trends east-west and lies roughly parallel to the foliation in the argillaceous rocks found above the polymict conglomerate unit. The matrix of the conglomerate is coarse-grained feldspathic quartzite composed of subangular to sub-rounded grains of quartz, alkali feldspar, plagioclase feldspar, and lesser amounts of microscopic muscovite, chlorite, and calcite. The conglomerate is not distinctly stratified near the base of the unit.

In the middle and upper parts of the polymict conglomerate unit the clasts are predominantly vein quartz, light-gray quartzite, and granite with minor amounts of green phyllite, black slate, and greenstone. No limestone fragments were found above the basal 50 feet of the unit. The clasts are well rounded and range in size from about 1/4 inch to about 4 inches in maximum diameter. They are in a matrix of fine- to medium-grained feldspathic quartzite identical in composition and appearance to that forming distinct beds in the conglomerate. The conglomerate beds range in thickness from about 1 foot to 10 feet, whereas the feldspathic quartzite beds are generally less than 1 foot thick as shown in Figure 11. The beds of quartzite and polymict conglomerate are characteristically not graded, but locally the conglomerate fills channels a few inches deep cut into the underlying quartzite beds.

Figure 11: Interbedded, polymict conglomerate and coarse feldspathic quartzite in the Davis Town area.

Pebbles and small cobbles similar to those in the conglomerate beds may be present as apparently isolated clasts in the feldspathic quartzite beds.

The feldspathic quartzite is composed primarily of angular to subrounded grains of quartz, quartzite, chert, plagioclase, and alkali feldspar with minor amounts of muscovite, chlorite, black slate chips and green phyllite fragments. The quartz and feldspar grains range from about 50 μ to 1.0 mm in diameter.

Thickness: The polymict conglomerate unit ranges in thickness from 0 to about 1000 feet.

Age: No diagnostic fossils have been found in the polymict conglomerate unit in the Cupsuptic area; however, at fossil locality 1, shown on the geologic map, boulders of gray, coarsely-crystalline limestone contain numerous, badly recrystallized halysitid and horn corals. Dr. William Oliver of the U. S. Geological Survey identified the halysitid as Catenipora (?) sp., which ranges in age through much of the Ordovician and Silurian. The horn corals could not be generically identified, but Dr. Oliver reported that some were dissepimented and probably Silurian in age. The assemblage of corals, according to Dr. Oliver, is suggestive of a Lower or Middle Silurian age but can be dated with certainty only as pre-Devonian. The polymict conglomerate is definitely post-Middle Ordovician, because it truncates the Kamankeag Formation.

Eugene L. Boudette (1965, personal communication) has found polymict conglomerate associated with fossiliferous quartzite of late Lower Silurian (Upper Llandovery) age about 6 miles east of the Davis Town area near Blanchard Pond in the Kennebago Lake quadrangle. In absence of evidence to the contrary, the polymict conglomerate unit is correlated with that near Blanchard Pond and considered to be of Lower Silurian age.

Quartz-pebble conglomerate unit

Lithology: The major belt of quartz-pebble conglomerate is exposed in scattered outcrops in a belt that extends from the 2300 foot knob southwest of Grants Camps (SE1/4 EC1/9) to the west end of the 2780 foot hill due south of Johns Pond. A second thin and discontinuous patch of the quartz-pebble conglomerate is exposed along the west band of the Kennebago River in the vicinity of the 1566' BM on the abandoned Maine Central Railroad. The quartz-pebble conglomerate rests unconformably upon the Albee Formation and lies conformably below the argillite and quartzite unit. The contact between the quartz-pebble conglomerate and the polymict conglomerate is not exposed; however, outcrops of the polymict variety are found topographically below the band of quartz-pebble conglomerate on the 2780 foot hill south of Johns Pond. It is inferred that the two conglomerate units interfinger.

The bulk of the unit is composed of quartz-pebble conglomerate that is light gray or tannish-green where fresh and white or light gray where weathered. The weathered surface is rough and locally mottled where jet black or rusty-tan iron oxide stain outlines the quartz pebbles. The clasts are composed primarily of milky-white to colorless vein quartz with minor amounts of black chert, gray quartzite, and green phyllite. The quartz clasts are rounded to subrounded, nearly spherical to ovoid in shape, and range from granules about 3.0 mm in diameter to pebbles about 3.0 cm in maximum diameter. The green phyllite fragments are platy with angular outline, highly foliated, and commonly less than 1.0 cm in maximum diameter. The matrix is a yellow-green, lustrous, waxy-looking aggregate of quartz, chlorite, and muscovite that shows a crude foliation if it comprises about 10 percent of the rock. Locally siliceous cement is present.

The basal part of the quartz-pebble conglomerate unit is not visibly bedded, but medium- to coarse-grained quartzite beds up to 3 feet thick are present in the upper part. The beds, which are characteristically not graded, are composed predominantly of subrounded to subangular quartz and minor amounts of plagioclase, muscovite, and chlorite. The quartz grains range in size up to 0.3 mm. The quartz grains in both the quartzite and quartz-pebble conglomerate are commonly strained and have sutured boundaries. Siliceous cement, where present, deeply embays the clastic grains.

Thickness: As the unit does not crop out on the south limb of the syncline in the Davis Town area, it is inferred that the quartz-pebble conglomerate pinches out across strike to the southeast. The maximum thickness is about 450 feet in the vicinity of the 2300 foot hill southwest of Grants Camps.

Age: No fossils have been found in the quartz-pebble conglomerate unit in the Cupsuptic quadrangle. According to E. L. Boudette (1964, personal communication), however, similar rocks are associated with limestone of Lower Silurian (Upper Llandovery) age 12 miles to the east in the Kennebago Lake quadrangle. The rock is lithologically similar to the Clough quartzite described by Billings (1937) and dated as Lower Silurian by Boucot and Thompson (1963). The quartz-pebble conglomerate unit is considered to be Lower Silurian in age.

Gray argillite and quartzite unit

Lithology: The gray argillite and quartzite unit is well exposed on the south slope and top of the 2960 foot mountain southeast of Johns Pond. A few exposures are found on the northwest-trending ridge southeast of the eastern end of Johns Pond, and along the old road that trends northeast from Johns Pond past the 2308 foot knob between Johns Pond and Kennebago Lake. The gray argillite and quartzite unit overlies the quartz-pebble conglomerate unit on the north limb of the syncline and overlies and interfingers with the polymict conglomerate unit on the south limb of the syncline. The facies relationship between the argillite and quartzite unit and the polymict conglomerate unit is well exposed near the upper part of the unnamed brook that rises in the swamp on the ridge between Johns Pond and Kamankeag Pond.

The unit consists of dark-gray, soft, chalky-weathering argillite and dark-to light-gray, fine-grained feldspathic quartzite interbedded in variable proportions. Transitional rocks exist between the primary rock types. The map unit is characteristically well-bedded, particularly in the upper part where feldspathic quartzite beds from 1/4 inch to 3 inches thick alternate with argillite beds from 2 to 3 inches thick. Locally, near the base of the unit, the feldspathic quartzite is calcareous and weathers to punky-brown seams in the gray argillite as illustrated in Figure 12. The feldspathic quartzite beds are commonly graded.

The argillite is composed of microscopic quartz, muscovite, albite, and chlorite with minor amounts of pyrite, zircon, and clinozoisite. Representative modes are given in Table 7. The feldspathic quartzite contains quartz, albite, and muscovite with lesser amounts of chlorite, calcite, alkali feldspar, sphene, and pyrite. The quartz and feldspar grains are angular to subangular and range from about 20 μ to about 0.1 mm in maximum diameter. Representative modes are given in Table 7.

Thickness: The maximum thickness of the argillite and quartzite unit in the area is about 2600 feet.

Age: No fossils have been found in argillite and quartzite unit, but it overlies and interfingers with the basal conglomerate units; thus it is considered to be late Lower Silurian in age or possibly younger.

PARMACHENEE LAKE AREA

General Statement

Rocks of Silurian age form a small syncline northeast of Parmachenee Lake (NW1/4 WC1/9), as shown on the geologic

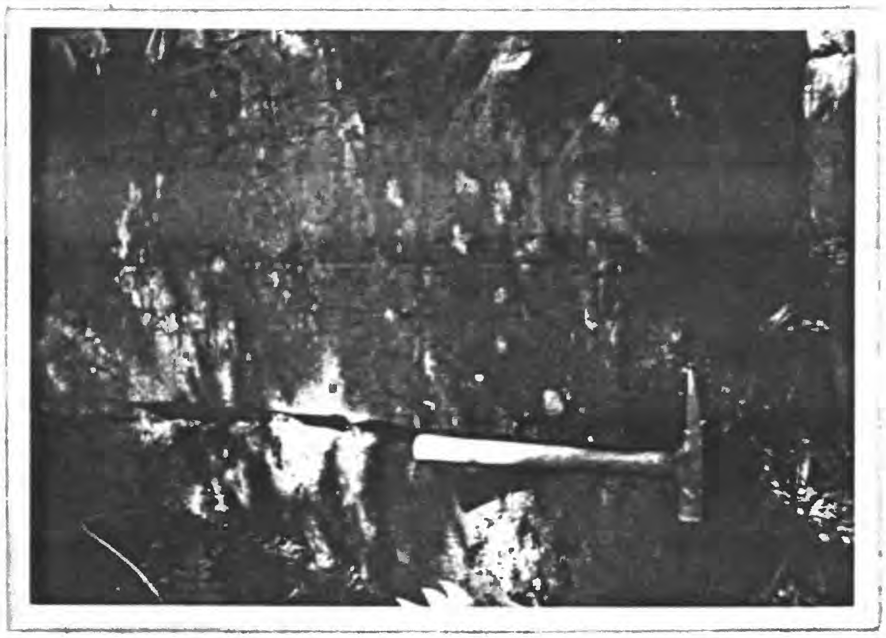


Figure 12: Well-bedded gray argillite and calcareous quartzite of Silurian age on 2960 foot mountain southeast of Johns Pond.

Table 7. Representative estimated modes of the rocks of Silurian age

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Clasts of Rudites (in thin section)	65	75	75	70				70	60	75				
Quartz			75	70				39	3	38				
Quartzite	} 38	} 40						32	10					
Chert	13	20							40	28				
Plagioclase	2							15	5	1				
Granite		<1												
Slate Fragments	8	10	<1	<1						7				
Volcanic Rocks	4	5							2	1				
Zircon	tr	tr	tr							tr				
Matrix of Rudites	35	25	25	30				30	40	25				
(Modes of other rock types)														
Quartz	25	15	21	27	70	65	65	} 5	25			24	} 37	} 78
Plagioclase	4	2			15	12	13				5	10		
Alkali Feldspar					tr					} 20				
Sericite	3	3	2	2	11	20	15	8	3		<1		15	13
Chlorite	3	2	1	1	3	3	2	15				<1		7
Biotite	tr	3											5	
Epidote							3					10		
Calcite									12	3	95	52	41	
Sphene						tr	1							
Zircon												tr	tr	tr
Tourmaline										1				tr
Rutile												tr		
Magnetite								2						
Pyrite					1	1	1			1			1	1
Limonite			2		tr		1		tr			2		
Actinolite												1		

Description and location of specimens in Table 7.

1- Polymict conglomerate; at 2680' elevation, 6000' bearing 355° from the camp on the west shore of Kamankeag Pond.

2- Polymict conglomerate; at 2200' elevation, 4700' bearing 016° from camp on the west shore of Kamankeag Pond.

3- Quartz-pebble conglomerate; on top of smaller, southeasternmost 2300' topo knob, 3300' bearing 220° from Grants Camp on Kennebago Lake.

4- Quartz-granule conglomerate; at 2020' elevation in the south-flowing brook at the northeast end of Johns Pond.

5- Gray argillite and interbedded feldspathic quartzite; at 2440' elevation in brook 5700' bearing 343° from the camp on the west shore of Kamankeag Pond.

6- Gray argillite and interbedded quartzite; at 2580' elevation, 2 miles due east of 1666' BM on abandoned Maine Central R.R. southeast of Johns Pond.

7- Dark-gray, well-bedded argillite and feldspathic quartzite; at 2820' elevation 700' due east of 2960' mountain between Johns Pond and Kamankeag Pond.

8- Green, quartz- and quartzite-pebble conglomerate; at 1800' elevation 3200' bearing 027° from Parmachenee Club.

9- Gray-green, silicified, chert-fragment conglomerate; at 1695' elevation on south side of unnamed brook, 3000' bearing 040° from the Parmachenee Club.

10- Polymict conglomerate; at 1850' elevation; 4000' bearing 074° from the Parmachenee Club.

11- Light-gray, tan-weathering, silty limestone; at 1950' elevation, 7100' bearing 052° from the Parmachenee Club.

12- Highly fossiliferous, arenaceous limestone; at 1880' elevation, 6600' bearing 066° from the Parmachenee Club.

13- Gray-green, pit-weathering arenaceous limestone; at 1690' elevation in small brook 3000' bearing 048° from the Parmachenee Club.

14- Dark gray, well-bedded argillite; on top of 2260' topo knob, 850' due west of Lower Black Pond, western half of the Arnold Pond quadrangle.

map and illustrated in detail by the pace and compass map of Figure 13. In detail, the syncline of Silurian rocks is composed of two small basins that have been offset by at least two east-west trending normal faults. On the north limb of the syncline, north of the more southerly fault, the basal map unit consists of cobble-to pebble-conglomerate and quartzite. The basal conglomerate is overlain by light gray silty limestone which is overlain by a fossiliferous, arenaceous limestone unit. Where present, the conglomerate and quartzite unit rests unconformably on the Dixie Brook member of the Dixville Formation. The silty limestone unit has been faulted into contact with the Dixie Brook member on the north limb of the syncline, and apparently rests unconformably on the Dixie Brook member at the east end of the syncline where the basal conglomerate is missing.

A mappable unit of light greenish-gray argillite and tuff (?) underlies the conglomerate and quartzite unit on the south limb of the syncline but is not exposed on the north limb of the syncline. The southern fault places the fossiliferous arenaceous limestone in contact with the argillite and tuff (?) unit in the eastern basin, and in contact with the conglomerate and quartzite unit in the western basin. The silty limestone unit does not appear on

EXPLANATION

Sup: Gray-green arenaceous limestone. Ludlow shelly fauna.

Sul: Gray silty limestone

Sq: Gray quartz-pebble conglomerate, quartzite, and minor gray slate. Sqp: minor polymict conglomerate.

Sa: Gray-green argillite and tuff(?).

UNCONFORMITY

Odd: Dixie Brook member of Dixville Formation; predominantly black phyllite.

contact

anticline

syncline

Bedding

80

overturned

50

inclined (tops known)

vertical

50

inclined (tops unknown)

Cleavage

80

inclined

vertical

X

Fossil locality

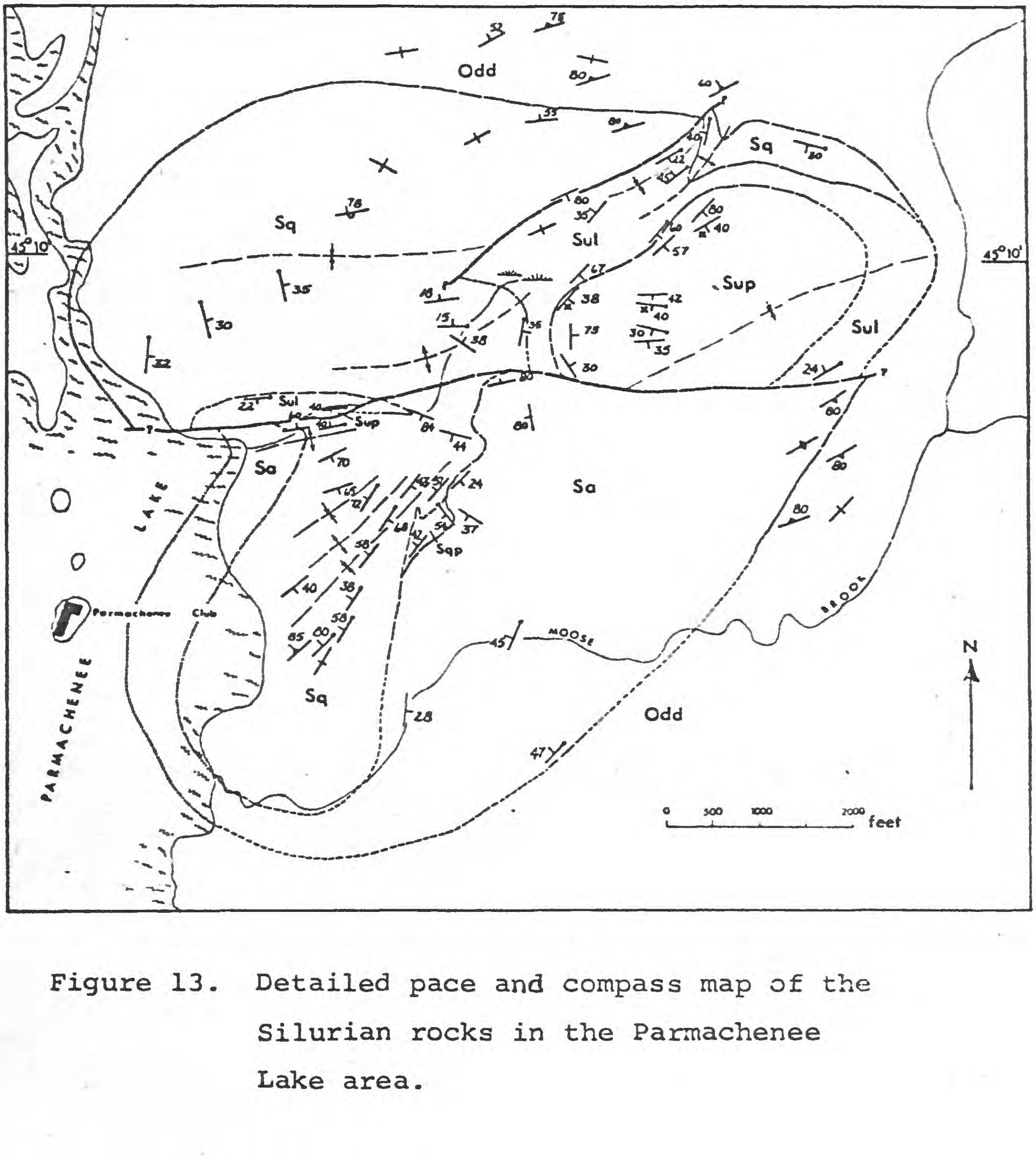


Figure 13. Detailed pace and compass map of the Silurian rocks in the Parmachenee Lake area.

the south limb of the syncline due to faulting and subsequent erosion.

Argillite and tuff(?) unit

Lithology: The argillite and tuff unit is exposed in the vicinity of the broad 1900 foot knob located on the south side of the small swamp in the Parmachenee Lake area. Scattered outcrops are found in the lower reaches of Moose Brook, but in general the unit does not form abundant exposures. Greenish-gray argillite and tuff(?) underlie the conglomerate and quartzite unit in the vicinity of the small 1860 foot knob 4000 feet east of the Parmachenee Club, and at an elevation of 1660 feet in the small unnamed brook that drains the swamp in the center of the area. The unit is inferred to lie unconformably above the Dixie Brook member of the Dixville Formation, although the actual contact has not been observed.

The argillite is dark to light greenish-gray if fresh and light gray or tan if weathered. Bedding is present in the form of light and dark gray or gray-green color bands in some outcrops, but there is no appreciable difference in the grain size in the color bands. The banding is most easily recognized on the fresh surface. Locally the argillite unit contains subvertical cleavage that is highly contorted adjacent to the southern fault, but commonly the argillite is massive to poorly cleaved.

Thin discontinuous beds of light green to greenish-white tuff(?), commonly a few inches thick but locally several feet thick, are scattered in the argillite. As primary structural features are not present in the rock it is difficult to determine whether the tuff(?) originated as pyroclastic ash or flows. The extremely fine grain size of most of the material suggests a pyroclastic origin. The tuff(?) beds weather to a soft, chalky-white rind less than 1.0 mm thick.

The argillite is composed of microscopic quartz, feldspar, chlorite, and muscovite with minor amounts of clinozoisite, zircon, and tourmaline. The tuff(?) is composed predominantly of microscopic feldspar with lesser amounts of quartz, white mica, and chlorite.

Thickness: The exact thickness of the argillite and tuff(?) unit is difficult to determine, due to the scarcity of exposures, but it is estimated to be about 500 feet thick.

Age: No fossils have been found in the argillite and tuff(?) unit. It underlies and locally forms the matrix of the conglomerate and quartzite unit that underlies the arenaceous limestone of Upper Silurian age; hence the argillite must be

Upper Silurian or older. It apparently rests unconformably on the Dixville Formation and is thus post-Middle Ordovician. The argillite and tuff(?) unit may be of Lower or Upper Silurian age.

Conglomerate and quartzite unit

Lithology: The conglomerate and quartzite unit underlies the higher ridges and knobs immediately north of the small unnamed brook that rises in the swamp in the middle of the Parmachenee Lake area. North of the brook the map unit is predominantly conglomerate; whereas south of the brook gray quartzite forms the bulk of the unit. Minor amounts of conglomerate, dark gray calcareous quartzite, and dark gray slate are also present south of the brook.

The conglomerate is dark gray-green if fresh and light gray to chalky-white if weathered. The clasts are composed primarily of fine-grained quartzite, milky-white or reddish vein quartz, and gray chert with minor amounts of green phyllite, and feldspar. The clasts are commonly subangular to subrounded, except those of the phyllite which are platy. The clasts range in size from about 2.0 mm to about 3 inches in maximum diameter and do not show appreciable tectonic deformation. The matrix is composed primarily of subangular quartz and feldspar, generally less than 0.1 mm in maximum diameter, and lesser amounts of microscopic chlorite and muscovite.

Beds of greenish-gray quartzite, from 1 to 4 feet thick, are present in the conglomerate on the north limb of the syncline. The beds are commonly graded. The quartzite is composed of subangular grains of quartz about 50 μ to 0.2 mm in maximum diameter, with minor amounts of feldspar of the same size, and microscopic chlorite and muscovite.

South of the southern fault the conglomerate and quartzite unit is composed predominantly of dark gray to gray-green quartzite. The rock is fine to medium grained and weathers to a smooth, vitreous, light-gray surface. The quartzite is commonly massive, but locally contains beds of dark gray slate ranging in thickness from 1 to 10 inches that alternate with beds of quartzite generally 3 to 5 feet thick. Graded bedding is not common. Near the top of the quartzite unit, dark gray rusty-weathering slate is more abundant and forms beds a few inches thick that alternate with beds of dark-gray to rusty-brown, calcareous quartzite about 1 to 6 inches thick.

The quartzite is composed of subangular grains of quartz, plagioclase, alkali feldspar, and chert with minor amounts of chlorite, muscovite, tourmaline and locally calcite. The quartz grains range in size from about 20 μ to 0.2 mm.

A thin, discontinuous layer of polymict conglomerate is found at the contact between the conglomerate and quartzite unit and the argillite unit in the vicinity of the 1960 foot knob 4000 feet due east of the Parmachenee Club. The clasts of polymict conglomerate are predominantly light-gray felsite porphyry, black chert, gray quartzite, granite, and green phyllite ranging from about 2 inches to as much as 2 feet in maximum diameter. The matrix of the polymict conglomerate is dark-gray argillite.

Thickness: The conglomerate and quartzite unit ranges in thickness from 0 to 1100 feet.

Age: No fossils have been found in the conglomerate and quartzite unit, but as it underlies the fossiliferous arenaceous limestone containing Upper Silurian fossils it must be Late Silurian (Ludlow) or older. The conglomerate is considered to be post-Middle Ordovician as it rests unconformably on the Dixville Formation. In the absence of evidence to the contrary, the conglomerate is correlated with that in the Davis Town area and thus may be of Lower Silurian age.

Silty limestone unit

Lithology: The silty limestone unit crops out in two small patches, one in the eastern basin and the other in the western basin of the syncline. The two patches of silty limestone are separated by the conglomerate and quartzite unit and bounded on the south by the southern fault. Excellent exposures of the unit are found on the north side of the unnamed brook near its entrance into Parmachenee Lake, and on the low hills east of the small swamp in the center of the Parmachenee Lake area.

The silty limestone is very fine grained, mottled light gray and white where fresh; and rough, deeply-grooved, and light rusty-brown where weathered. Calcite and quartz veinlets a few tenths of a millimeter thick commonly form a mesh-work pattern in the limestone.

The silty limestone contains closely-spaced argillaceous beds about 1 inch thick that are most easily seen on the weathered surface where the fine-grained argillaceous bands stand in relief. The beds have been warped into open folds a few inches in amplitude and wave length, and have subvertical axial surfaces that trend east-west parallel to a crude foliation in the rock. Adjacent to the northern fault the bedding is obliterated by closely spaced shear planes that trend about N60°E.

The silty limestone is composed of microscopic calcite with minor amounts of muscovite, quartz, and feldspar scattered throughout the rock and locally concentrated in the argillaceous beds.

Thickness: The maximum thickness of the silty limestone is estimated to be about 250 feet.

Age: No diagnostic fossils have been found in the silty limestone although fossil fragments are scattered in the rock. The silty limestone is considered to be Upper Silurian or slightly older because it conformably underlies an arenaceous limestone unit containing fossils of that age.

Arenaceous limestone unit

Lithology: The bulk of the arenaceous limestone unit is found in the eastern part of the syncline in the Parmachenee Lake area where it is well exposed on the low hills immediately east of the small swamp in the center of the area. A second, smaller patch of this unit is exposed at an elevation of 1670 feet in the small unnamed brook that flows from the swamp to Parmachenee Lake.

The rock is green or gray green if fresh and light gray or tan if weathered, and is characterized by alternating beds of massive and pit-weathering arenaceous limestone as illustrated in Figure 14. The massive layers range in thickness from a few inches to about 15 inches, and the punky-weathering layers are commonly about 2 inches thick and discontinuous in a given exposure. In the eastern basin of the syncline the punky-weathering layers in the arenaceous limestone are composed primarily of shelly fossils. The less resistant layers in this rock exposed in the western basin are composed of silty limestone in which no fossils were found.

The bulk of the arenaceous limestone is composed of calcite, present as a granular matrix or as grains in shelly fossil fragments. The calcite grains are anhedral and range in maximum diameter from about 20 μ to 0.1 mm with the coarser material comprising the organic fragments. Quartz, plagioclase, clinozoisite, zircon, tourmaline, pyrite, and locally actinolite and pale-brown biotite are present in subordinate amounts. The quartz and plagioclase are angular to subangular and range in size up to 50 μ.

Thickness: The arenaceous limestone is about 10 feet thick in the western part of the area and about 450 feet thick on the north limb of the eastern basin.

Figure 14: Characteristic bedding in the arenaceous limestone unit of Late Silurian age in the Parmachenee Lake area. Etched out beds are highly fossiliferous.

<u>Age</u>: The arenaceous limestone has been dated as Upper Silurian (Lower Ludlow) by Dr. Arthur Boucot (1964, written communication) on the presence of the chonetid genus <u>Eccentricosta</u>.

THRASHER PEAKS AREA

General Statement

The rocks of Silurian age in the Thrasher Peaks area are found in a few scattered exposures along the upper part of the northwest slope of Thrasher Peaks, as well as in scattered outcrops where the First East Branch of the Magalloway River crosses the northern border of the quadrangle. This patch of Silurian rocks differs from the two described previously in that it lies on the southeast limb of a vast, regional synclinorium named by Cady (1960, p. 536) the Connecticut River - Gaspé synclinorium. Green (1964, written communication) has mapped the unconformity and overlying rocks of Silurian and Devonian age across the northwestern part of the Second Lake quadrangle (Figure 1, no. 19) and through the Thrasher Peaks area to the International Boundary. Marleau (1957) has mapped the unconformity and overlying rocks north of the quadrangle in the Woburn area (Figure 1, no. 33).

Three map units have been recognized in the Thrasher Peaks area: two of these, the polymict conglomerate and gray limestone, are found as thin discontinuous patches along the unconformity. The third map unit consists of well-bedded, dark-gray slate and feldspathic quartzite that either overlies the discontinuous basal units or rests unconformably on the Magalloway member if the conglomerate and limestone are absent.

Polymict conglomerate unit

Lithology: The polymict conglomerate unit crops out in a discontinuous band less than 100 feet wide, exposed at an elevation of 2400 feet extending from the mid-part of the northwest slope of Thrasher Peaks to the western border of the quadrangle. A second small patch of polymict conglomerate is found at 2260 feet elevation on the southeastern slope of Thrasher Peaks in the vicinity of the western border of the quadrangle.

The polymict conglomerate is dark green to purplish gray if fresh and mottled light green and dark gray if weathered. The clasts, ranging from about 1/4 inch to 8 inches in maximum diameter, are predominantly dark-green or dark-gray greenstone, identical to that in the Magalloway member of the Dixville Formation. In addition, the conglomerate contains minor amounts of vein quartz, purplish-gray slate, feldspathic graywacke and chert. The rounded to subrounded clasts are in a matrix of fine- to coarse-grained quartz, chlorite, plagioclase, and sericite.

Thickness: The polymict conglomerate unit ranges in thickness from 0 to about 80 feet in the Thrasher Peaks area.

Age: No fossils have been found in the polymict conglomerate unit or in rocks immediately associated with this unit. A Silurian age is tentatively assigned to polymict conglomerate because of its position above the regional unconformity that separates the pre-Silurian rocks from those of Silurian and Devonian age. The discontinuous patches of conglomerate occupy the same stratigraphic position with respect to the unconformity as the fossiliferous limestone unit described in the following section. The limestone has been dated tentatively as Upper Silurian (Ludlow?) by Naylor and Boucot (1965, p. 161). The conglomerate unit may be of Lower or Upper Silurian age.

Fossiliferous limestone unit

Lithology: Light-gray, fossiliferous limestone crops out in two small widely-separated patches at and just north of the northern border of the quadrangle. One small outcrop is on an abandoned logging road 1600 feet east of the northernmost fork in the First East Branch of the Magalloway River. A second patch, consisting of a series of rubbly outcrops, is on an abandoned logging road 1250 feet west of the same fork in the First East Branch. The outcrops in both areas are composed of large loose blocks that have been frost-wedged and slightly rotated to different orientations; however, in each area the limestone is believed to represent the local lithology.

The fossiliferous limestone is light gray on the fresh and weathered surface and contains coarse organic fragments scattered in a fine-grained calcite matrix. The fossil fragments are more resistant than the matrix and stand in relief on the weathered surface. No distinct bedding was observed in the limestone unit.

<u>Thickness</u>: The thickness of the limestone is not known. Limestone blocks are exposed for a distance of about 75 feet across the regional trend, and the unit probably has a thickness of this order of magnitude.

<u>Age:</u> The eastern patch of limestone was found by John Green (1964, written communication) and has been dated as Ludlow(?) (Upper Silurian) by Naylor and Boucot (1965, p. 161).

Slate and quartzite unit

Lithology: Only a few outcrops of the slate and quartzite unit have been found on the northwest slope of Thrasher Peaks. Exposures north of that area in the Arnold Bog quadrangle, however, indicate that the slate and quartzite unit underlies the northwest corner of the Cupsuptic quadrangle.

The unit is composed of dark-gray to silvery-gray slate and dark-gray feldspathic quartzite. The slate and quartzite weather light gray or rusty tan. Beds of feldspathic quartzite from 1/2 inch to 3 inches thick are separated by beds of slate from about 8 to 24 inches thick. Graded bedding and locally cross-bedding are common in the feldspathic quartzite.

The feldspathic quartzite is composed of quartz, albite, alkali feldspar, muscovite and chlorite with minor amounts of zircon and tourmaline. Quartz and feldspar, which constitute over 80 percent of the quartzite, are subangular grains less than 0.1 mm in maximum diameter. The muscovite, chlorite, and accessory minerals are less than 50 μ in size. The slate is composed of the same minerals but the quartz and feldspar make up about 60 percent of the rock. All the minerals in the slate are less than 50 μ in size.

Thickness: Due to the limited exposure of the slate and quartzite unit in the quadrangle no attempt is made to estimate the thickness.

Age: No fossils have been found in the slate and quartzite unit. As it overlies the fossiliferous limestone where that unit is present, it is considered to be Late Silurian or younger. The slate and quartzite is probably Devonian in part.

INTRUSIVE ROCKS AND ASSOCIATED ALTERATION PRODUCTS

GENERAL STATEMENT

Four major intrusive bodies lie wholly or partly in the Cupsuptic quadrangle. One of these is metadiorite with associated serpentine and serpentinized pyroxenite, and the other three are biotite-muscovite quartz monzonite. The metadiorite and associated ultramafic rocks crop out in the northeast ninth of the quadrangle, and lie near the western end of a regional belt of small ultramafic bodies that continues northeast toward Moosehead Lake. The quartz monzonite stocks are found in the vicinity of Lincoln Pond; in the central ninth of the quadrangle; and in the northeast corner of the map area in Seven Ponds township. The bulk of the quartz monzonite stock in the Seven Ponds township lies north of the map area in the Arnold Pond quadrangle.

Several smaller bodies composed of granodiorite, gabbro, and intrusive felsite, as well as numerous granitic and diabase dikes, intrude the stratified rocks in the area.

The metadiorite and associated ultramafic rocks and at least some of the diabase dikes are older than the major quartz monzonite bodies since they are metamorphosed by these intrusives. The metadiorite and ultramafic rocks are thought to be of Late Ordovician age largely because of a similar age assigned to serpentinized ultramafic rocks elsewhere in New England. The age of the granodiorite and gabbro is uncertain, but must be younger than Middle Ordovician because these rocks intrude the Dixville Formation. The granodiorite and gabbro could be Late Ordovician and thus related to the Highlandcroft Magma Series of New Hampshire, or they could be younger. The major bodies of quartz monzonite are similar in composition to the New Hampshire Magma Series of Billings (1956) and are considered to be Devonian in age.

MAFIC AND ULTRAMAFIC ROCKS

General Statement

A large body of metadiorite and associated serpentinized ultramafic rocks, two small bodies of granodiorite, and a small body of gabbro constitute the mafic and ultramafic rocks in the quadrangle.

The metadiorite and ultramafic rocks comprise a major east-trending intrusive body in the northern third of the northeast ninth of the map area. Excellent exposures are found on White Cap Mountain west of the Kennebago River and in the vicinity of the 2720 foot hill east of the Kennebago River in the northeast corner of the quadrangle. There are no exposures in the intervening Kennebago River valley, but the ultramafic rocks are mapped as a single body because the aeromagnetic map by Gilbert and Boynton (1964, GP331) shows a continuous positive anomaly in this region. This intrusive body was differentiated into two map units: metadiorite and serpentinized ultramafic rocks; the latter includes patches of serpentinized pyroxenite, serpentinite, and talc-carbonate rock too small to be shown at the map scale. The various rocks are closely related in space, and the contact between them is gradational in the few places where it was observed. The serpentinized ultramafic rock forms layers and patches in the metadiorite ranging in thickness from several tens of feet to several hundreds of feet, and although they cannot be seen in any one outcrop, they are evident from the map pattern.

Granodiorite crops out on the low hills immediately east and west of Little Kennebago Lake and in a smaller body near the top of Bottle Mountain. One small body of gabbro was found on the 3100 foot knob on the ridge between Cupsuptic Pond and the First East Branch of the Magalloway River.

Metadiorite

The largest patch of metadiorite is exposed on the top and upper slopes of White Cap Mountain. Smaller bands are found in the serpentinized ultramafic rocks on the east and north slopes of the mountain and near the crest of the 2720 foot hill east of the Kennebago River.

The rock is dark green to mottled green and white where fresh, and dark rusty-brown or tan where weathered. It ranges from a dense, fine-grained, porphyritic rock to a coarse-grained, locally pegmatitic, equigranular rock with ophitic texture. There appears to be no systematic variation in grain size in the metadiorite with respect to the contacts of the associated ultramafic rocks or the country rock. The pegmatitic variety is commonly found as lens-shaped bodies or irregular stringers in the fine-grained or coarse-grained rocks.

The metadiorite is composed primarily of hornblende, plagioclase(An_{25-35}), actinolite, and clinozoisite with lesser amounts of chlorite, calcite, magnetite, sphene, ilmenite, and zircon. In local areas adjacent to bands of serpentinite or pyroxenite, the metadiorite contains minor amounts of clinopyroxene surrounded by hornblende. Except in the porphyritic variety, the plagioclase and hornblende are of equivalent size and range from about 0.2 mm to as much as 3.0 cm in length. Ophitic texture is common, and is recognizable in hand specimen and thin section. Hornblende encloses or partially surrounds anhedral grains of plagioclase, and is commonly altered around the grain boundaries to fine-grained, bladed aggregates of actinolite. The plagioclase is generally altered to granular aggregates of clinozoisite, calcite, and sericite. Representative modes are given in Table 8.

Serpentinized Ultramafic Rocks

Pyroxenite: Several outcrops of relatively fresh pyroxenite are found in a narrow band at 2500 feet elevation on the north slope of the 2720 foot hill east of the Kennebago River.

The band of outcrops is about 70 feet wide but as the contacts with adjacent rocks are not exposed, the true thickness of the pyroxenite cannot be determined. It is probably less than 100 feet thick. Scattered outcrops of highly serpentinized pyroxenite are found at 3390 feet elevation on the north side of the saddle between the east peak of White Cap Mountain and the north peak of Kennebago Divide.

The pyroxenite is massive, medium to coarse grained, equigranular, dark green to black where fresh and rusty gray or light tan where weathered. The rock is a very hard, dense aggregate of pyroxene grains, the cleavage faces of which reflect the light on the fresh surface. All stages of alteration from granular pyroxenite that contains thin veinlets of light-green serpentine, to serpentinite with a granular texture have been observed.

The bulk of the rock is composed of pale-green to colorless clinopyroxene, tentatively identified as magnesian-augite from an estimated 2V of 50° and a measured β refractive index of $1.685 \pm .003$. The optical properties are consistent with those of magnesian-augite given by Hess (1949) and modified by Muir (1951); but, their curves assume specific values for Al_2O_3, Fe_2O_3, Na_2O, TiO_2 and MnO that may be different from those in the Cupsuptic sample. No exsolution

Table 8. Representative estimated modes of the metadiorite and ultramafic rocks

	1	2	3	4	5	6	7	8	9	10	11
Quartz											
Plagioclase									15	25	45
Hornblende						15	32		30	40	37
Actinolite						80	60	30	25	15	12
Clinopyroxene					1	tr	3	60	10		
Olivine	<1(?)				1						
Clinozoisite							2(?)		15	15	<1
Calcite									5		2
Chlorite						1	1	1	<1	2	1
Magnetite	10	7	10	4	7						1
Sphene						2					
Magnesite		20	15	16	5	2	2	9			
Antigorite	80	63	75	10	83						1
Ilmenite							tr	tr			
Talc	10	10		70	3						
Phlogopite										tr	
Zircon											
Pyrite											
Plagioclase Composition									An25	An27-31	An33

Description and location of specimens in Table 8.

1- Schistose serpentinite; on top of 2720' topo knob, 4500' bearing 106° from the 1950' BM on the Beaver Pond Tote Road.

2- Sugary-textured serpentinite; at 2380' elevation, 2800' bearing 217° from 1950' BM on the Beaver Pond Tote Road.

3- Sugary-textured serpentinite; at 3350' elevation, 1500' bearing 071° from corner post 350 on the International Boundary.

4- Talc-carbonate rock; at 3340' elevation, 2900' bearing 015° from 3740' north summit of Kennebago Divide.

5- Pseudomorphic serpentinite; same location as 4.

6- Metapyroxenite; at 2510' elevation, 1.4 miles bearing 093° from 1950' BM on Beaver Pond Tote Road.

7- Metapyroxenite; at 2520' elevation, 900' due west of the location of number 6.

8- Coarse-grained, serpentinized pyroxenite; at 2400' elevation, 2800' bearing 217° from 1950' BM on Beaver Pond Tote Road, northeast slope of White Cap Mountain.

9- Coarse-grained metadiorite transitional (?) to pyroxenite; at 2500' elevation, 3100' bearing 219° from 1950' BM on the Beaver Pond Tote Road.

10- Fine-grained, porphyritic metadiorite; at 2700' elevation, 3700' bearing 317° from 1950' BM on Beaver Pond Tote Road.

11- Coarse-grained metadiorite; at 2800' elevation, 3900' bearing 219° from 1950' BM on Beaver Pond Tote Road.

was found in the clinopyroxene. The grains range in size from about 0.5 mm to about 10.0 mm, are subhedral, and altered to actinolite at the rim. Dust-like magnetite particles, scattered in the pyroxene grains, tend to concentrate in microscopic shear zones in the crystals. Anhedral patches of calcite and banded veinlets of serpentine are locally present in the pyroxene matrix.

Serpentinite: Serpentinite is the most common rock in the altered ultramafic suite and has three main types of occurrence, specifically: schistose serpentinite that is completely sheared and crudely foliated; massive, fine-grained granular serpentinite; and pseudomorphic serpentinite in which relict pyroxene or olivine grains are visible in hand specimen. The three types may be intermixed on the scale of a large hand specimen and all have several features in common. A mineral of the serpentine group with a felted texture forms the bulk of all the serpentinite, which is dark to light green if fresh, and soft, chalky white or light gray if weathered.

The schistose serpentinite, commonly found near the contact with the country rock, is particularly well exposed in the vicinity of the south knob of the 2720 foot hill east of the Kennebago River. The rock is highly sheared on irregular and anastomosing planes that outline augen-shaped patches of dark-green, crudely-foliated, schistose serpentinite. Thin selvages of magnetite and slip-fiber asbestos are commonly found on the slip planes. No relict texture is visible in hand specimen or thin section.

In thin section the schistose serpentinite is mainly a felted aggregate of serpentine grains commonly less than 50 μ in length. Minor amounts of carbonate, talc, magnetite and coarse blades of serpentine are present in the felted matrix. Representative modes of the serpentinite are given in Table 8.

The massive, granular serpentinite is fine-grained, equigranular, and contains visible cleavage fragments of carbonate. The rock is fractured, sheared and crossed by minute veinlets that weather as light gray to white bands on a gray to rusty tan, pitted surface. The bulk of the rock is composed of a felted matrix of serpentine with euhedral rombs of carbonate and minor amounts of talc and magnetite. It differs from the schistose variety in the greater abundance of carbonate and the lack of coarse, oriented plates of serpentine.

The pseudomorphic serpentinite is not a common variety, although excellent specimens are found at 3390 feet elevation on the north side of the saddle between the east peak of White Cap Mountain and the north peak of Kennebago Divide. The rock is characterized by serpentine pseudomorphs after pyroxene that appear as raised subhedral bumps on the weathered surface, and as anhedral light yellowish-green patches on the fresh surface.

In thin section the bulk of the pseudomorphic serpentinite is a felted mass of antigorite(?) with minor amounts of talc, carbonate, magnetite, clinopyroxene, and olivine. The pyroxene and olivine grains are deeply etched and replaced by very fine-grained, radiating aggregates of serpentine. The serpentine mineral replacing the pyroxene and olivine is distinctly finer grained and of different texture than that in the matrix. The presence of relict olivine in the pseudomorphic serpentinite suggests that peridotite may have been the protolith of at least some of the serpentinite.

<u>Talc-carbonate rock</u>: The only talc-carbonate rock found in the ultramafic suite is present as a thin, discontinuous band completely within the pseudomorphic serpentinite at 3390 feet elevation due south of the eastern peak of White Cap Mountain. The rock is massive, dark green or buff where fresh; and soft, dark tan or gray, and greasy to the touch where weathered.

The rock is composed of talc and carbonate, probably dolomite, with minor amounts of serpentine and magnetite. A representative mode is given in Table 8. Very fine-grained magnetite octahedra form incomplete networks of polyhedra that appear to mark the boundaries of pre-existing mineral grains. The interior of the magnetite network is commonly fine-grained talc, or a mixture of fine-grained talc and euhedral to anhedral masses of carbonate. A mineral of the serpentine group is present in scattered, anhedral patches in which the mineral has a felted texture.

Genetic relationships

There are two basic problems in the genesis of the intrusive body: one involves the origin of the bands and patches of ultramafic rock in the metadiorite; the other involves the serpentinization of the ultramafic rock.

The spatial relationships between the metadiorite and the ultramafic rock could have resulted either from composite intrusions or from the differentiation of the products of fractional crystallization of one parent liquid. Sufficient chemical data are not available at this time to deal with the problem in a rigorous manner, but the field relationships and limited optical work suggest that the metadiorite and ultramafic rocks are differentiates from a common liquid. Specifically, there is no apparent chill zone between the metadiorite and ultramafic rocks, but there is a transition zone that contains more hornblende and less plagioclase than is in the bulk of the metadiorite. The transition rock also contains scattered grains of clinopyroxene surrounded by rims of hornblende. Locally, the transition rock grades into serpentinite that contains relict grains of pyroxene and olivine, but commonly it changes rather abruptly into schistose serpentinite containing scattered patches and bands of pyroxenite.

The country rocks adjacent to the south and west side of the intrusive do not show the effects of metamorphism as would be expected if the body differentiated in place. However, the contact effects may have been obliterated by the later low-grade regional metamorphism. It is tentatively assumed that the metadiorite differentiated in place and was later altered and serpentinized during the intrusion of the quartz monzonite stock in Seven Ponds township. The relatively anhydrous minerals in the metadiorite and ultramafic rocks apparently acted as a local "sink" for fluids from the surrounding country rocks, as suggested by Thompson (1955, p. 89-92, 98-99). The serpentinite lacks the distinct zoning reported elsewhere by numerous investigations (see Chidester, 1962) and it contains bands of relatively fresh ultramafic rock. Both features suggest that the process (or processes) of serpentinization may have been less intense and of shorter duration than that in Green Mountains of Vermont. Interestingly, the regional metamorphic grade in the Cupsuptic area is lower than in central Vermont and this probably influenced the degree of serpentinization of the ultramafic rocks.

GRANODIORITE

The granodiorite forms two small, widely-separated intrusive bodies. The largest body is well exposed on the upper slopes of the hills immediately east and west of Little Kennebago Lake. The southeastern margin of this intrusive is highly sheared and silicified where it is crossed by a major northeast-trending fault. A second, smaller body of granodiorite is exposed near the top of Bottle Mountain (SW1/4 NC1/9).

The rock is medium-grained, equigranular to sub-porphyritic, dark green where fresh and dark rusty brown where weathered. White plagioclase phenocrysts fleck the dark green matrix of the subporphyritic rock. The rock is highly fractured and locally laced with white quartz veins or light yellow-green veinlets composed of quartz, epidote, and calcite.

The bulk of the rock is composed of plagioclase (An_{10-20}), perthite, quartz, biotite, hornblende, chlorite, epidote, and calcite with minor amounts of zircon, ilmenite, pyrite, and apatite. Representative modes are given in Table 9. The plagioclase forms broadly zoned, subhedral laths up to 2.0 mm in length that are commonly altered to calcite, epidote, and sericite. The alkali feldspar is untwinned orthoclase with broad, perthitic lamellae of albite. Quartz and alkali feldspar are anhedral and intergranular to the plagioclase. Biotite and hornblende form anhedral to subhedral grains that are commonly altered to chlorite, ilmenite, epidote, and calcite.

The rock exposed in the vicinity of the major fault east of Little Kennebago Lake is medium-grained, dark gray if fresh and dark rusty brown if weathered. The rock is highly sheared and contains thin solution channels and vugs that are lined with euhedral quartz crystals up to 1/2 inch in length. Patches of milky-white vein quartz are common. The rock in the fault zone is composed of the same minerals as the unaltered variety, although hornblende is rarely present. Plagioclase grains are highly altered to sericite, calcite and clinozoisite; biotite is altered to chlorite and ilmenite.

TABLE 9. REPRESENTATIVE MODES OF THE GRANODIORITE AND GABBRO

	1	2	3	4	5
Quartz	40.0	34.4	20	18.4	
Alkali Feldspar	31.6	35.5	13	32.2	
Plagioclase	19.5	23.4	40	32.7	45
Biotite	4.3		10	7.6	
Muscovite	3.6	0.6		0.9	
Sericite		3.1	tr		
Hornblende	0.4	0.5	6	1.3	25
Chlorite	0.3	0.9	1	2.5	5
Clinozoisite			7	2.0	10
Zircon	tr	tr	tr	tr	
Apatite	0.2		tr	tr	
Calcite				1.6	
Ilmenite			2	0.5	
Magnetite	tr				1
Limonite		1.8			
Actinolite					12
Sphene					2
Plagioclase Composition	An15	An20	An10	An12	An30
Method of Analysis *	p.-1514	p.1505	V	p.-1256	V

* p = point count
V = visual estimate

DESCRIPTION AND LOCATION OF SPECIMENS

1- Dark-gray, highly fractured and sheared, granodiorite; on small 2080' topo knob, 3700' bearing 301 from Otter Brook Camp.

2- Dark-to light-gray, intensely sheared and fractured granodiorite; on top of 2300' topo knob immediately east of Little Kennebago Lake.

3- Dark-gray, ophitic, granodiorite; at 2000' elevation 2100' bearing 296 from Otter Brook Camp.

4- Dark-gray, fine grained, porphyritic granodiorite; 2820' elevation, 400' due south of summit of Bottle Mountain.

5- Dark-gray, fine-grained gabbro; top of 3100' knob, 3200' bearing 227° from 3012' B.M. on International Boundary west of Cupsuptic Pond.

Untwinned alkali feldspar is commonly present as a graphic intergrowth with quartz. The rock has a pronounced cataclastic texture.

The granodiorite intrudes the Dixville Formation; thus it is post-Middle Ordovician. The composition and degree of alteration suggest that it may be pre-Devonian and possibly related to the Late Ordovician Highlandcroft Magma Series of New Hampshire (Billings, 1956).

GABBRO

A small body of gabbro is exposed on the group of 3100 foot knobs about 1 mile southwest of the 3012' BM on the International Boundary. The rock is dark green to gray, massive to ophitic, and weathers dark rusty brown.

The gabbro is composed primarily of plagioclase (An_{35}), hornblende, actinolite, clinozoisite, and chlorite with minor amounts of sphene, ilmenite, magnetite, and calcite. The plagioclase grains range in length from about 50 μ 50 0.2 mm and are commonly altered to sericite and clinozoisite. Hornblende is about the same size as the plagioclase and is surrounded or completely replaced by actinolite, chlorite, and calcite. In thin section the hornblende and plagioclase show an ophitic texture. A representative mode is given in Table 9.

The age of the gabbro is uncertain. It intrudes the Dixville Formation considered to be of Middle Ordovician age; thus the gabbro must be post-Middle Ordovician. The degree of alteration in the gabbro suggests that it was emplaced prior to the regional metamorphism of the area; hence it may be Late Ordovician in age.

FELSIC INTRUSIVE ROCKS

Quartz Monzonite

Quartz monzonite comprises three stocks and numerous dikes in the quadrangle. From southwest to northeast the stocks are located in the vicinity of Lincoln Pond, Upper Cupsuptic township, and Seven Ponds township and will be referred to as the Lincoln Pond quartz monzonite, Cupsuptic quartz monzonite, and the Seven Ponds quartz monzonite respectively. Numerous exposures of the Lincoln Pond quartz monzonite are found on the slopes of Big Buck Mountain and on the low hills immediately north of Lincoln Pond. The Cupsuptic quartz monzonite is well exposed near the fire tower on West Kennebago Mountain, on Bull Mountain (NE1/4, C1/9) and in the Cupsuptic River between Big Falls and Riverside Camp (SW1/4 C1/9). The Seven Pond quartz monzonite forms a large stock located predominantly north of the map area in the Arnold Pond quadrangle, but a few exposures are found on the low hills adjacent to Kennebago River in the northeast corner of the map area.

Dikes of quartz monzonite up to 300 feet wide have been mapped on the west and south side of the Cupsuptic quartz monzonite body. In addition, numerous smaller dikes ranging in thickness from a few feet to a few tens of feet are found in the country rock adjacent to the three stocks.

The quartz monzonite is a medium- to coarse-grained, equigranular to subporphyritic rock that is light gray flecked with black if fresh and light gray or tan if weathered. Near the southern contact of the Seven Ponds stock the quartz monzonite is gray flecked with pink. Commonly the rock is massive and broken by numerous subvertical joints, but locally near the contacts it is crudely foliated. A chilled margin of dark-gray quartz monzonite porphyry, a few feet thick, is common but not ubiquitous in the Lincoln Pond and Cupsuptic stocks. Porphyry dikes, identical in composition and appearance to the chilled border rock, are found in the Cupsuptic quartz monzonite between Big Falls and Riverside Camp on the Cupsuptic River. The contrast in grain size and color of the two facies of the quartz monzonite is illustrated in Figure 15.

The bulk of the quartz monzonite is composed of plagioclase, quartz, microcline-perthite, biotite, and muscovite, with minor amounts of zircon, apatite, pyrite, and magnetite. Subordinate amounts of clinozoisite, calcite, chlorite and garnet are present locally. Representative modes are given in Table 10. The plagioclase, which is subhedral and strongly zoned, ranges in composition from about An_{38-45} at the core to An_{15-25} near the edge. The grains average about 3.0 mm in length but may be as much as 15.0 mm in length. The microcline-perthite is anhedral and, with quartz, partially fills the interstices between the plagioclase grains. Biotite forms subhedral plates up to 2.0 mm in maximum diameter and is associated with minor amounts of muscovite generally less than 0.5 mm in diameter. Biotite is locally altered to chlorite and magnetite; plagioclase is commonly altered to sericite and clinozoisite.

The chilled margin of the quartz monzonite contains phenocrysts of rounded to dipyramidal quartz, subhedral biotite, and euhedral plagioclase, in a fine grained matrix composed of the same minerals plus alkali feldspar. The phenocrysts have an average size of about 3.0 mm. The matrix of the chilled facies is commonly an intergrowth of quartz and alkali feldspar forming radiating aggregates. Microscopic grains of plagioclase, biotite, and muscovite are intergranular

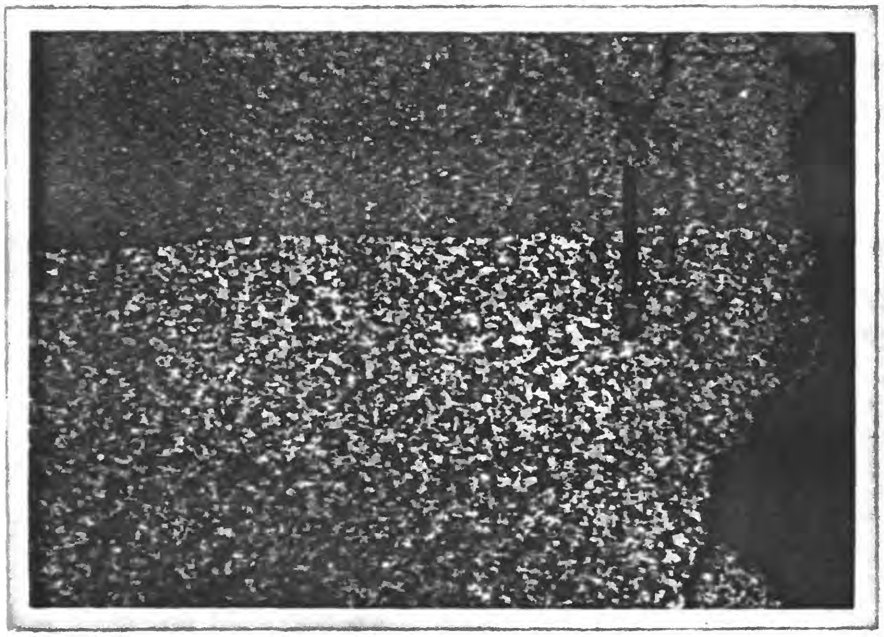


Figure 15: Dark-gray, porphyritic quartz-monzonite (top) and light-gray, coarse-grained quartz-monzinite (bottom). Porphyritic variety is present as chilled margin of Cupsuptic and Lincoln Pond intrusive bodies and as dikes in Cupsuptic stock.

Table 10. Representative modes of the felsic intrusive rocks

	1	2	3	4	5	6	7	8	9
Quartz	34.4	30.3	36.2	32.2	30.6	32.0	38.4	40	38
Alkali Feldspar	9.2	6.5	22.2	16.6	9.0	7.4	22.0	33	43
Plagioclase	39.9	43.2	28.9	36.6	41.1	28.8	27.3	18	17
Biotite	12.6	17.9	6.5	9.4	17.4	19.7	0.1	6	
Muscovite	0.7	1.6	5.8	1.9	1.7			2	2
Sericite	1.3	tr	tr	1.7		10.1	3.1		
Garnet						0.9		tr	
Clinozoisite	tr	tr		tr		tr		1	
Chlorite	tr	tr	0.3	0.9	tr	tr	6.4	tr	tr
Zircon	tr	tr	tr	tr	tr	tr		tr	
Apatite	tr	tr	tr	tr	tr	tr			tr
Calcite							2.3		
Pyrite		tr					tr	tr	
Magnetite	tr	tr	tr	tr	tr	tr		tr	
Hematite									
Ilmenite						tr	tr	tr	
Myrmekite	1.2	tr		tr					
Plagioclase Composition	An_{15-30}	An_{10-35}	An_{15-25}	An_{19-22}	Olig(?)	Olig(?)	An_{10}	An_{10}	An_{15-30}
Method of Analysis *	p.	p.	p.	p.	p.	p.	p.	v.	v.

* p = point count
v = visual estimate

Description and location of specimens in Table 10.

1- Coarse- to medium-grained biotite-muscovite quartz monzonite; at 3705' directly beneath fire tower on Kennebago Mountain.

2- Fine-to medium-grained, porphyritic biotite-muscovite quartz monzonite; from the dike on the west side of Cupsuptic Mountain; at 2420' elevation, 900' bearing 246^{o} from 2640' summit of Cupsuptic Mountain.

3- Medium-grained, equigranular, biotite-muscovite quartz monzonite; at 2960' elevation 4500' bearing 044^{o} from summit of Bull Mountain.

4- Medium- to coarse-grained biotite-muscovite quartz monzonite; at 3340' elevation, on south side of 3360' topo knob, 4100' bearing 250^{o} from the western peak of Twin Mountains.

5- Dark-gray, fine-grained, porphyritic biotite-muscovite quartz monzonite; contact facies; at 1960' elevation, 2300' bearing 197^{o} from 2217' summit of Big Buck Mountain.

6- Fine-grained biotite-muscovite quartz monzonite; at 1860' elevation, 4100' bearing 077^{o} from Nason's Camp on east shore of Aziscohos Lake.

7- Dark-gray, medium-grained, porphyritic quartz monzonite; on top of 2300' topo knob 4800' due south of Grants Camp on Kennebago Lake.

8- Coarse-grained, porphyritic biotite-muscovite quartz monzonite; at 2440' elevation, 2500' bearing 075^{o} from 1950' BM on Beaver Pond Tote Road.

9- White, very fine-grained intrusive felsite; at top of 2540' topo knob that is northern-most summit of Thrasher Peaks; approximately on northern border of the quadrangle.

to the clusters of quartz and alkali feldspar. The alkali feldspar is not perthitic as far as can be determined and rarely shows the cross-hatch twinning of microcline. Locally the matrix of the chilled facies has an equigranular texture and is composed of microscopic quartz, plagioclase, biotite, and muscovite. Plagioclase phenocrysts present in the equigranular matrix show a broad rim of albite about a strongly-zoned core. Alkali feldspar does not appear as a separate mineral in the equigranular matrix.

Several large quartz monzonite dikes which trend about N.40°W. are found on the west and south sides of the Cupsuptic stock. The deeply eroded dikes lie at the bottom of three steep-sided gullies on the west end of Burnt Mountain and form a broad bench at about 2350 feet elevation on the west side of Cupsuptic Mountain. The southwest corner of the Cupsuptic stock, between Big Falls and Riverside Camp, is laced with numerous porphyry dikes that are believed to be contemporaneous with the major dikes on Burnt Mountain and Cupsuptic Mountain.

The major dikes are identical in mineralogy to the main mass of the Cupsuptic quartz monzonite but differ in texture from that rock by being finer grained, crudely foliated and crowded with oriented inclusions of the country rock as shown in Figure 16. The porphyry dikes are identical to the chilled facies of the Cupsuptic quartz monzonite.

The dikes coincide with the northwestern part of a major fault that extends from the Cupsuptic intrusive through the southeastern corner of the map area to the western end of Rangeley Lake. The southwestern corner of the Cupsuptic intrusive may have been cut by the fault after much of the igneous rock had solidified. The fault may have tapped unsolidified magma at depth that intruded the country rock along the trend of the fault and formed the porphyry dikes in the southwest corner of the stock. An alternative explanation for the dikes would be that the main body of quartz monzonite stoped its way into the country rock, partially solidified and was later fractured and cemented by the porphyry dikes as stoping continued.

The quartz monzonite closely resembles the description of the biotite-muscovite adamellite reported by Green (1964, p. 40-41) and the binary granite described by Billings (1956, p. 61-63). For this reason the rock is considered to be a member of the New Hampshire Magma Series (Billings, 1937) and probably is of Late Devonian age.

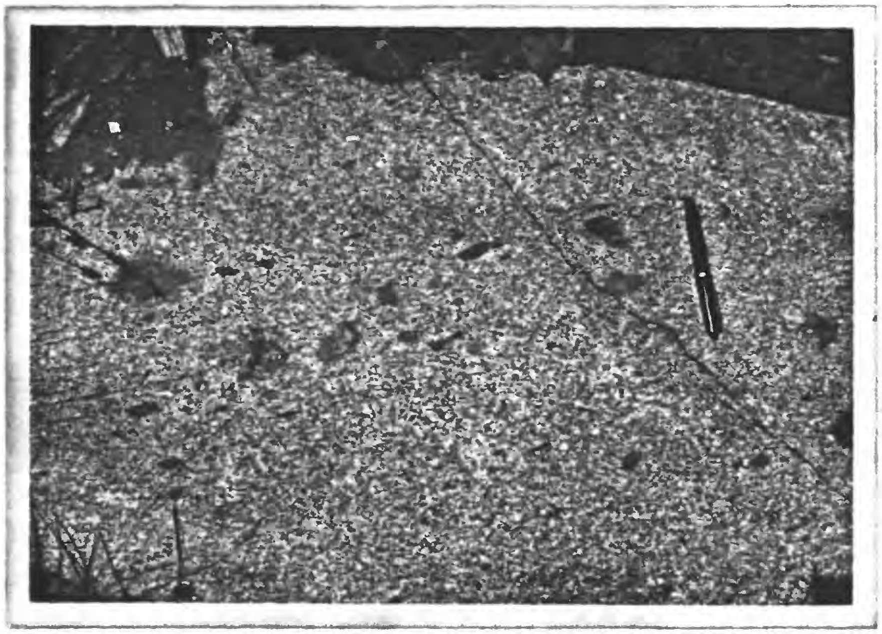


Figure 16: Oriented inclusions of Albee Formation in quartz-monzonite dike on the west side of Cupsuptic Mountain.

Intrusive Felsite

Several small bodies of intrusive felsite are exposed in the northwest corner of the map area on Thrasher Peaks. The bodies are closely associated with the Silurian unconformity but have steeply dipping contacts that cut across the moderately-dipping unconformity.

The rock is extremely fine grained, equigranular, white to light gray if fresh and white to light tan if weathered. The rock is very hard, chert-like in appearance and commonly breaks with concoidal fractures to produce sharp-edged talus. Quartz veinlets a few millimeters wide commonly cross-cut the rock.

The bulk of the rock is composed of microscopic quartz, orthoclase-perthite, plagioclase (An_{25}), and biotite with lesser amounts of muscovite, zircon, and pyrite. Unzoned plagioclase grains range in size up to 0.1 mm and are commonly surrounded by anhedral aggregates of quartz and perthite. Biotite flakes and lesser amounts of ragged, anhedral muscovite grains are intergranular to the quartz and feldspar. A representative mode is given in Table 10.

The microgranite is post-Silurian in age and, because of its peraluminous composition, is considered to be a member of the New Hampshire Magma Series of Devonian age.

REGIONAL CORRELATIONS

GENERAL STATEMENT

The results of the work in the Cupsuptic area, particularly the discovery of graptolites in the Kamankeag Formation, lead to possible correlations elsewhere in New England and adjacent Quebec. The correlations are presented here before the discussion of the structure because the age of several of the local units can be inferred only through regional correlation. The ages thus obtained add corroborating evidence to the local stratigraphic sequence and bear directly on the structure of the quadrangle.

A few pre-Silurian formations throughout northern New England and adjacent Quebec contain fossils diagnostic of the late Middle Ordovician and can be considered exact correlatives of the Kamankeag Formation. The unfossiliferous rocks below the Kamankeag Formation can be correlated with rocks found elsewhere on the basis of lithologic similarity and position in the stratigraphic sequence relative to the late Middle Ordovician "horizon". Dating the pre-Kamankeag rocks is much more difficult than correlating these rocks, because the rocks that can be traced to the quadrangle or correlated on lithologic similarity and stratigraphic position are not fossiliferous. Conversely, the rocks that contain pre-Middle Ordovician fossils are far removed from the Cupsuptic area and cannot be reliably correlated on lithology with the local rocks. Billings (1956, p. 89-98) has discussed the basic philosophy of regional correlation and has used the method effectively in New Hampshire.

PRE-SILURIAN CORRELATIONS

The pre-Silurian correlations will be presented by geographical areas in inverse chronological order. The paleontological correlations between the Kamankeag Formation and its equivalent units will be discussed before the lithologic correlations of the pre-Kamankeag rocks. Repeated reference will be made to Plate VIII, which shows the general distribution of pre-Silurian rocks and the pertinent fossil localities in northern New England and adjacent Quebec.

Maine

General Statement: Pre-Silurian rocks similar to those found in the Cupsuptic quadrangle crop out in a narrow, northeast-trending anticline that plunges beneath rocks of Silurian and Devonian age west of the Katahdin Batholith (Plate VIII). Immediately west, east, and northeast of the batholith, the pre-Silurian rocks appear in several isolated anticlines, the stratigraphy and structure of which have been discussed most recently by Pavlides and others (1964, pp. C28-C38). The map by Boucot and others (1965) shows considerably more detail in north-central Maine than is presented here on Plate VIII.

Northeastern Maine: The Kamankeag Formation (Plate VIII, no.7) can be correlated with part of the Meduxnekeag Formation (Pavlides and others, 1964, p. C31; Plate VIII, nos. 1 and 2) and with the volcanic rocks, argillite, and graywacke in the core of the Pennington and Portage anticlines (Plate VIII) because these rocks contain graptolites diagnostic of zone 12 (Berry, 1960) of the late Middle Ordovician. Similarly, the slate and volcanic rocks described by Neuman (1962) on the flanks of the Weeksboro-Lunksoos Lake anticline (Plate VIII, no. 4) can be considered equivalent to the Kamankeag Formation. Rocks older than the Middle Ordovician are exposed only in the Weeksboro-Lunksoos Lake anticline.

The Grand Pitch Formation (Neuman, 1962), consisting predominantly of green and purple slate similar to that of the Albee Formation, lies at the core of the Weeksboro-Lunksoos Lake anticline. The purple slate has yielded the fossil Oldhamia, reported by Neuman (1962, p. 796) to range in age from late Precambrian to early Ordovician. Neuman (1962) considers the Grand Pitch to be Cambrian(?), but Oldhamia is of little value in dating the Grand Pitch or its apparent equivalent, the Albee Formation, more precisely than Cambrian or Ordovician in age. Evidence elsewhere in northern New England suggests an Ordovician age is more probable for the Albee Formation.

<u>West-central Maine</u>: Two fossil localities (Plate VIII; nos. 5, 6) are known in the pre-Silurian rocks exposed in the narrow anticline northeast of the Cupsuptic quadrangle. Boucot (1961, p. 183) reports brachiopods of Middle Ordovician age from felsic tuff of his Kennebec Formation (Plate VIII, no.5). Mr. E. V. Post (1965, written communication) found late Middle Ordovician brachiopods (Plate VIII, no. 6) in rocks lithologically similar to the Magalloway member of the Dixville Formation. Both of these localities are in rocks that lie northwest of a belt of green phyllite lithologically similar to the Albee Formation. The rocks and their stratigraphic succession in the vicinity of localities 5 and 6 are essentially the same as those in the northern part of the Cupsuptic area; hence at least part of the Dixville Formation is considered to be of Middle Ordovician age. The <u>Protospongia</u> sp. found in the Dixville Formation (Plate VIII, no. 8) is compatible with, but not diagnostic of, a Middle Ordovician age.

In the Cupsuptic quadrangle the Kamankeag Formation lies southeast of the Albee Formation and contains graptolites of late Middle Ordovician age (Plate VIII, no. 7).

It is considered equivalent, in part, to the Dixville Formation. The Dixville Formation and the Kamankeag Formation thus form the northwest and southeast flanks respectively of a regional anticlinorium that contains the Albee Formation in the core.

NORTHERN NEW HAMPSHIRE

There are no known fossil localities in the pre-Silurian rocks in northern New Hampshire. The stratigraphic sequence, Albee-Ammonoosuc-Partridge, of northern New Hampshire (Billings, 1937, 1956) is identical with the succession Albee-Oquossoc-Kamankeag in the Cupsuptic quadrangle. In addition, the units are lithologically similar and the Albee Formation can be traced continuously from the type area (Billings, 1935) to the Cupsuptic quadrangle. On the basis of lithologic similarity and position in the stratigraphic sequence, the Partridge Formation is correlated with the Kamankeag Formation and thus dated as late Middle Ordovician. This supports a similar conclusion reached by Billings (1956, p. 48) from correlations made with the sequence of northeastern Vermont and adjacent Quebec.

Green (1964, p. 62) correlated the Dixville Formation with the Ammonoosuc and Partridge Formations on the basis of lithologic similarity and stratigraphic position above the Albee Formation. This correlation is supported here by the assignment of a Middle Ordovician age to the Magalloway member of the Dixville and a correlation of the Dixville with the Kamankeag and Oquossoc Formations.

<u>The Problem of the "Aziscohos Formation"</u>: The discovery of fossils in the Kamankeag Formation and the stratigraphic succession in the southeastern part of the quadrangle suggests that the "Aziscohos Formation" of Green (1964, p. 10; 63-65) is actually part of the Albee Formation. Green proposed the name Aziscohos Formation for mappable units of green and black slate, phyllite, and schist containing abundant quartz pods and stringers that lie below the Albee Formation in the Errol quadrangle. Green (1962, 1964, p. 65) correlated these rocks on the basis of lithologic similarity with the Stowe Formation and possibly the Ottauquechee Formation of northeastern Vermont.

Rocks similar to those that comprise the Aziscohos Formation of the Errol quadrangle crop out in the southern part of the Cupsuptic quadrangle and have been described as the Aziscohos member of the Albee Formation in this report. They are considered to be a less arenaceous, locally carbonaceous facies of the Albee Formation for the following reasons:

1) The green phyllite of the Aziscohos member is, at least locally, above the principal member

of the Albee.

2) There are areas within the principal member that are predominantly phyllite, and conversely there are areas of abundant "pinstripe" granulite in the Aziscohos type rocks. Thus, the rocks of the two map units appear to be intermixed.

3) The black phyllite is neither at the top nor at the bottom of the Aziscohos member in the Cupsuptic area. It is the lower map unit in the Aziscohos Formation in the Errol quadrangle.

4) Green phyllite with abundant quartz pods and stringers underlies the massive volcanics of the Oquossoc Formation in the southeastern part of the Cupsuptic quadrangle. The contact between the two units is one of alternating phyllite and volcanic layers and is considered to be gradational in a macroscopic sense.

If the Kamankeag and Oquossoc Formations are equivalent to the Partridge and Ammonoosuc Formations, and if the "Aziscohos Formation" as defined by Green lies below the Albee, then the contact between the Oquossoc Formation and the Aziscohos-type rocks in the Cupsuptic area must be a fault or an unconformity. The fault or unconformity would be required to explain the absence of the Albee-type rocks south and east of the Aziscohos-type rocks. As mentioned above there is no evidence to support either a fault or an unconformity at this contact and, in addition, the stratigraphic top determinations presented on Plate VII suggest that the Aziscohos member is actually above the bulk of the principal member of the Albee. Thus the Aziscohos-type rocks in the Cupsuptic quadrangle are considered to be a facies of the Albee Formation. The possibility exists that the Aziscohos-type rocks are, in part, equivalent to the Dixville Formation but there is insufficient evidence to prove or refute this hypothesis.

Northeastern Vermont and adjacent Quebec

One of the most significant pre-Silurian fossil localities in the northern Appalachian region is that on Castle Brook near Magog, Quebec (Plate VIII, no. ~~10~~ 9). Recent mapping in the area by P. Ste. Julien (1963) has uncovered several closely associated localities (Plate VIII, no. 9) in rocks identical to those found on Castle Brook. The fossils from these localities have been studied by Berry (1962) who identified graptolite assemblages characteristic of his zones 12 and 13 of the late Middle Ordovician. The slate near Magog, Quebec can be correlated at least in part with the Kamankeag Formation because each contains graptolites diagnostic of zone 12 of the Middle Ordovician.

The stratigraphic nomenclature of the graptolite-bearing rocks near Magog, Quebec is somewhat confused. Ami (1900) named the rocks the "Magog Formation", but subsequently they have been referred to as the "Magog slate" by Clark (1934), or more recently, as part of the Beauceville Formation by Cooke (1950). The Beauceville Formation will be used in this report and is understood to contain the graptolite-bearing slate near Magog, Quebec.

The graptolite-bearing slate near Magog has had wide-spread influence in dating rocks in northern Vermont and adjacent New Hampshire. Currier and Jahns (1941, p. 1509) correlated their Cram Hill Formation with the graptolite-bearing slate near Magog, Quebec. Billings (1956, p. 98) correlated the Partridge and Ammonoosuc Formations with the Cram Hill, all of which were considered to be Middle Ordovician in age. The Moretown Formation in Vermont and the Albee Formation in New Hampshire, which lie below the Cram Hill and Ammonoosuc Formations respectively, were considered to be Middle Ordovician or older. The discovery of graptolites in the Kamankeag Formation corroborates the correlations made by Billings, but unfortunately, does not date the Albee or Moretown Formations more precisely than before.

Cady (1960, p. 554) correlates the Moretown Formation with the Beauceville Formation because one can be traced into the other across the International Boundary. In addition, each formation contains the same rock types and is separated from the underlying rocks over part of its map length by a thin layer of conglomerate. All of the fossils found to date in the Beauceville Formation are of late Middle Ordovician age. Cady (1960) thus considers the Moretown to be Middle Ordovician. Numerous geologists working in northern New England, apparently beginning with White (1947), have correlated the Moretown and Albee Formations on the basis of lithologic similarity and position in the stratigraphic sequence. If this correlation is correct, then a Middle Ordovician age seems most probable for the Albee Formation.

Northern Taconic Mountains

Further evidence on the possible lower age limit of the Albee Formation is available in the northern Taconic Mountains. Zen (1959, 1961) and Theokritoff (1964) have provided information to suggest that the rocks there are similar to those in the Cupsuptic area.

Berry (in Zen, 1959, p. 62) has identified graptolites of his zone 12 of the Middle Ordovician in the Pawlet Formation

(Zen, 1961, p. 307-308) (Plate VIII, no. ~~11~~ 10) which is lithologically similar to its equivalent, the Kamankeag Formation. Theokritoff (1964) has reported graptolites ranging in age from zone 2 of the Lower Ordovician to zone 12 of the Middle Ordovician in the Poultney slate underlying the Pawlet Formation. The Poultney slate consists of green argillite, dolomitic quartzite, black slate, and thin limestone beds and has been correlated by Theokritoff with the Mount Hamilton group of Zen. The Poultney slate is underlain by Upper Cambrian black slate and quartzite of the Hatch Hill Formation noted by Chang, Ern, and Thompson (1965, p. 43) to be similar to the Ottauquechee Formation in eastern Vermont. The Poultney slate and Mount Hamilton group appear to represent the same time span, Lower to Middle Ordovician, as the Stowe and Moretown Formations in eastern Vermont.

The purple slate, black slate, and green phyllite of the Albee Formation in the Cupsuptic area closely approximates the rocks of the Mount Hamilton group and the Poultney slate. The major differences in the rocks of the two areas are the greater abundance of calcareous rocks and the absence of volcanic rocks in the Taconic Slate belt, and a greater thickness of rock in the Cupsuptic area. The differences in rock types and the disparity in thickness may be a function of the relative proximity of the two areas to the miogeosynclinal sequence in western Vermont. It is conceivable that the Albee Formation in the Cupsuptic area is equivalent to the Poultney slate (and thus the Stowe and Moretown Formations of eastern Vermont) and ranges in age from Lower to Middle Ordovician.

The pre-Silurian correlations are summarized in Table 11.

Correlations of Units of Silurian Age

Fossils are somewhat more abundant in rocks of Silurian and Devonian age than in rocks of pre-Silurian age, both in the Cupsuptic area and elsewhere in New England. The basal units of the Thrasher Peaks area and some of the rocks in the Parmachenee Lake area have been dated as Upper Silurian (Ludlow) by fossils found in the Cupsuptic area (Naylor and Boucot, 1965, p. 160). The rocks in the Davis Town area are dated as late Lower Silurian (Upper Llandovery) by correlation with similar rocks about 6 miles on strike to the east. Eugene L. Boudette (1964, personal communication) found a shelly fauna of Lower Silurian age in thick-bedded, calcareous quartzite associated with polymict conglomerate and well-bedded slate and quartzite. The fossil-bearing quartzite does not crop out in the Cupsuptic quadrangle, but the associated rocks are sufficiently similar in both localities to warrant correlation. The quartz-pebble conglomerate that outcrops on the north limb

TABLE 11. REGIONAL CORRELATIONS

System	Series	Cupsuptic, Maine		Northern New Hampshire	Northern Vermont	SE Quebec	North-central and Northeastern Maine		Taconic Mtns
DEVONIAN	Lower	?	?	Littleton	Gile Mtn	Glenbrook	Undifferentiated Silurian and Devonian rocks		
SILURIAN	U	Sun	Sup / Sus	Fitch	Northfield	Peasely Pond			
	M		Sul						
	L	Slp / Slq	Sq / Sa	Clough	Shaw Mtn			Meduxnekeag	
ORDOVICIAN	Upper								
	Middle	Kamankeag / Oquossoc	Dixville	Partridge / Ammonoosuc	Cram Hill / Coburn Hill	Bolton / Beauceville	Slate / Volcanics		Pawlet
	Lower	Aziscohos	Albee ?	Albee ?	Moretown / Stowe	Upper Mansonville	Grand Pitch ?	?	Poultney
CAMBRIAN	Upper								Hatch Hill
	Middle				Ottauquechee	Lower Mansonville			
	Lower								

of the syncline in the Davis Town area is correlated with the Clough Formation (Billings, 1937) of northern New Hampshire. The Clough Formation has been dated as Late Lower Silurian (Upper Llandovery) by Boucot and Thompson (1963, p. 1313-1334).

As reported by Naylor and Boucot (1964, p. 160-162), the rocks of the Parmachenee and Thrasher Peaks area (Boucot and Naylor localities 19 and 20) are equivalent to the Fitch Formation (Billings, 1937) of New Hampshire, and the sequence near Magog, Quebec that consists of Peasely Pond conglomerate and the Glenbrooke Formation. The correlation of the rocks of the Parmachenee Lake and Thrasher Peaks area with the Shaw Mountain of eastern Vermont is made with reservation by Boucot and Naylor (1964, p. 160).

STRUCTURAL GEOLOGY

GENERAL STATEMENT

Five tectonic events can be inferred from the structural features in the Cupsuptic quadrangle. The earliest of these was a period of folding, probably during late Ordovician time, that produced tightly appressed, northeast-trending folds in the rocks of pre-Silurian age. In the second stage, this folded sequence was uplifted, eroded and truncated to produce a major unconformity between the Middle Ordovician and Lower Silurian rocks. These events constitute the Taconic orogeny in the Cupsuptic quadrangle. The third tectonic event was a period of folding that warped the unconformity into open, east-trending folds and undoubtedly changed the attitude of the early folds in the pre-Silurian rocks. This deformation must have been essentially coplanar with the first, however, because most of the pre-Silurian rocks show the effects of only one period of folding. Locally near the major intrusive bodies, apparently implaced after the second period of folding, the early isoclinal folds in the pre-Silurian rocks were refolded about north-trending axial surfaces. The intrusion of the quartz monzonite stocks and the cross-cutting structural features in the older rocks constitute the fourth tectonic event. The third and fourth tectonic events can be dated as post-Silurian and probably relate to the Middle and/or Late

Devonian deformation referred to as the Acadian orogeny. The fifth tectonic event was a period of faulting that cannot be dated exactly but is probably post-Acadian, and may be of Triassic age. The periods of folding have produced mesoscopic structural features, observed in outcrop, that can be related to either the early macroscopic or the late macroscopic folds in the pre-Silurian rocks. The mesoscopic features include an early foliation, a late slip cleavage, early and late minor folds, folded minor folds, and various types of linear features. The early mesoscopic features are present even in areas of the most intense second deformation; therefore, the order and direction of movement that caused the structural features can be inferred from the superimposed record.

The relationship of the mesoscopic features to the macroscopic folds has been studied in detail. The map area was divided into eighteen domains of essentially homogeneous folding. The geometry of the folding in each domain is shown by S-pole diagrams (π-diagrams) and plots of the early and late linear features on equal area nets.

MACROSCOPIC STRUCTURAL FEATURES

Early folds in the rocks of pre-Silurian age

General Statement: The dominant structural feature of the rocks of pre-Silurian age is a complexly folded anticlinorium.

The Albee Formation, exposed at the core of the anticlinorium, is overlain by the Dixville Formation on the northwest limb and the Oquossoc and Kamankeag Formations on the southeast limb of the anticlinorium. This interpretation, as well as the delineation of the numerous anticlines and synclines subsidiary to the regional anticlinorium, is based on the map pattern, stratigraphic top sense determinations, and limited paleontological evidence. Reference will be made in the following sections to the stratigraphic top sense determinations shown on Plate VII and the geometry of the folds shown on Plate V.

<u>Relationships in the axial anticline and Green Top Mountain syncline</u>: The axial anticline of the regional anticlinorium lies in the Kennebago member of the Albee Formation and forms an arc around the east, south, and west sides of the quartz monzonite stock in the center of the quadrangle. East of the stock the axial surface is vertical or subvertical and trends about N.50°E. The axis of folding, as shown in domain 7 on Plate V, plunges about 55° to the southwest. The amount of folding and the symmetrical nature of the minor folds in this section of the axial anticline are shown on the plane table map of Plate VI. The minor folds on Plate VI have a neutral drag sense that indicates they lie on the axial portion

of a major fold. East of the intrusive body, stratigraphic height within the Kennebago member is gained or lost only on a traverse to the southwest or northeast; that is, by moving up or down the plunge of the macroscopic fold. The southwest plunge of the axial anticline persists to the southeast corner of the quartz monzonite stock where the Kennebago member plunges under the principal member of the Albee Formation.

South of the quartz monzonite stock, the axial anticline trends roughly east and splits into a southern and northern anticline at the southwest corner of the intrusive body. The beds generally dip to the south in domain 8 on Plate V and the axial surface of the major folds is overturned toward the north. Minor linear features related to the early folds in domain 8 plunge about 45° toward the southwest and southeast corners of the intrusive body, indicating that the axial anticline passes through an axial culmination in this domain.

West of the central intrusive body, the Kennebago member forms a northern and southern belt of rocks separated by rocks lithologically identical to the Dixville Formation. Two hypotheses are feasible to explain the symmetrical repetition of map units. The two tracts of rocks mapped as the Kennebago member may represent distinct stratigraphic horizons separated by a tongue of black phyllite similar to that of the Dixville

Formation, but located within the Albee Formation. These units would thus represent an essentially homoclinal sequence folded once about north-northeast trending axial surfaces. If such were the case, the bulk of the rocks should face in the same direction on opposite sides of any given map unit. The top evidence presented on Plate VII does not agree with this hypothesis. Indeed, the bulk of the rocks face in opposite directions on opposite sides of the Kennebago member and the belt of Dixville-like rocks. From this, it is concluded that the symmetrical repetition of map units west of the central intrusive is the result of folding. These early folds are tightly appressed and have subvertical axial surfaces that have been refolded about north-trending late axial surfaces.

In Table 12 top determinations from the area west of the central intrusive body have been grouped in zones generally bounded by the axial traces of the early macroscopic folds. In zone 1, north of the northern axial anticline, 14 of the 21 top determinations face north. In zone 2, south of the northern axial anticline but north of the Green Top Mountain syncline, 11 out of 15 top determinations face south. Beds on opposite sides of the Kennebago member predominantly face in opposite directions. Similar relationships hold for the rocks on the opposite sides of southern axial anticline. The data in Table 12 cannot be treated by rigorous statistical analysis. Each measurement is independent in the sense that it was made on a different outcrop; but the sample is certainly not random, in the sense that every possible top determination in the area had an equal chance of being measured. The majority of the top determinations, as well as those nearest the contacts of the map units, however, strongly suggest that the repetition of units north and south of the Green Top Mountain syncline was caused by folding.

The early macroscopic folds adjacent to the western margin of the quartz monzonite stock trend to the southeast. The axial traces are vertical or steeply overturned toward the northeast. The plunge of the fold axes is variable, but in general must be to the northwest to explain the disappearance of the belt of Dixville Formation at the southwest corner of the intrusive body. The early folds trend to the northeast near the west-central border of the quadrangle and in general should plunge to the northeast near the southwest limit of the Green Top Mountain syncline. The number of early linear features measured in this area is limited, but the few shown on Plate IV suggest that the early folds plunge toward the central part of the Green Top Mountain syncline.

<u>Folds southeast of the axial anticline</u>: South of the axial anticline there are 9 south-facing top determinations at or

TABLE 12. Top determinations from graded bedding in area of complex folding in the west-central part of the Cupsuptic quadrangle

	Total number of top determinations	North-facing tops	South-facing tops	Indeterminant tops	Geologic Setting from Plate VII
ZONE 1	21	14	7		North of northern axial anticline to vicinity of Albee-Dixville contact
ZONE 2	15	2	11	2	South of northern axial anticline and north of Green Top Mtn. Syn-cline
ZONE 3	9	8	1		South of Green Top Mtn. syn-cline; north of southern axial anticline
ZONE 4	28	4	23	1	South of southern axial anticline and north of Deer Mtn. syncline

near the northern contact of the Aziscohos member. This suggests that the Aziscohos member is above the bulk of the Albee Formation in the Cupsuptic area. If the top determinations are reliable and if the northern contact of the Aziscohos member is not a fault, the Aziscohos member occupies the same stratigraphic position on the south side of the axial anticline that the Dixie Brook member of the Dixville Formations occupies on the north limb. No paleontological evidence or marker beds were found that might support or refute the possible complex facies relationships between the Axiscohos, Albee, and Dixville. The green phyllite unit of the Aziscohos member appears to be in part equivalent to the principal member of the Albee as both of these units lie conformably below the black phyllite in the Moocher's Home anticline.

Despite these possible facies changes, the geometry of the folds south of the axial anticline has been determined largely from the map pattern of the black phyllite unit of the Aziscohos member. Six macroscopic folds are outlined by the black phyllite southwest of the Daddy's Ridge Fault. They trend generally to the northeast and have vertical or subvertical axial surfaces. The plunge of the early mesoscopic fold axes is variable in direction and magnitude as shown by the S-pole diagrams for domains 12, 13, 14, 15 and 16 on Plate V.

The variable trend of the minor lineations is related to the pronounced second deformation in the southern part of the map area. In a broad sense, however, the axes plunge to the northeast in the southwestern part of the fold belt (domain 12) and to the southwest in the northeastern part of the belt (domains 7, 14, 16). This change in plunge, particularly in the axis of the Deer Mountain syncline (Plate VII), apparently produced the northward bulge in the contact between the Aziscohos member and the principal member of the Albee Formation. Similarly, the change in plunge caused the disappearance of the Deer Mountain syncline and the Moocher's Home anticline northeast of the Daddy's Ridge Fault. Actually the present map pattern shows the combined effects of the change in plunge of the folds, movement on the Daddy's Ridge Fault, and subsequent erosion. The evolution of the map pattern in the vicinity of the Daddy's Ridge Fault is illustrated in the idealized drawings of Figure 17. Figure 17(a) shows the idealized shape of the folds in the Aziscohos member prior to movement on the fault. The Deer Mountain syncline and the Moocher's Home anticline pass through an axial depression southwest of the fault, but the smaller folds to the southeast have an essentially constant northeast plunge. This is consistent with the S-pole diagrams for domains 7, 12, 14, and 16 on Plate V. Figure 17(b) shows the effects of inferred movement on the Daddy's Ridge Fault with the northeast block moving up and southeast with respect to the southwest block. This movement placed the northern end of the Deer Mountain syncline and the Moocher's Home anticline farther above the present erosion surface. The movement was not sufficient to bring the southeastern-most anticline and syncline to the present erosion surface north of the Daddy's Ridge Fault. The Deer Mountain syncline and the Moocher's Home anticline were removed by erosion from the northeast block of the fault (Figure 17(c)). Only the southeast limb of the Moocher's Home anticline is exposed as a narrow band of black phyllite that follows the crest line of the Daddy's Ridge.

The Aziscohos member is overlain by the Oquossoc Formation, which in turn is overlain to the southeast by the Kamankeag Formation. The south-facing top determinations in these units indicate that they form the west limb of a north-trending syncline or the east limb of an anticline. The Kamankeag Formation is the youngest pre-Silurian unit exposed on the southeast limb of the regional anticlinorium in the Cupsuptic quadrangle.

<u>Folds northwest of the axial anticline</u>: The Dixie Brook member of the Dixville Formation lies above the Albee Formation,

Figure 17: Schematic block diagrams illustrating the geometry of the folds in the Aziscohos member of the Albee Formation near the Daddy's Ridge Fault.

(a) Geometry of folds prior to movement on Daddy's Ridge Fault.

(b) Inferred movement on the Daddy's Ridge Fault (Blocks separated for clarity).

(c) Map pattern on present erosion surface.

according to the top evidence on Plate VII and Zone 1 of Table 12. The Dixie Brook member is predominantly black phyllite that contains scattered arenaceous beds, some of which are graded. In general, however, top determinations are too widely separated and too sparse to delineate the axial traces of macroscopic folds undoubtedly present in this unit. To the northwest and north, the Dixie Brook member is overlain by the Magalloway member in two highly folded synclines. These macroscopic folds will be referred to as the Frist East Branch syncline and the Kennebago Divide syncline, respectively.

Nine top determinations have been made in the vicinity of the Magalloway-Dixie Brook contact on the southeast limb of the First East Branch syncline. All of the tops face to the northwest, indicating strongly that the Magalloway member lies above the Dixie Brook member. Similarly, a macroscopic drag fold, outlined by 4 top determinations just northwest of the contact, indicates that the axial trace of the major syncline lies to the northwest. The exact location of the axial trace of the major syncline is unknown, due to poor exposure and the lack of top determinations on the southeast slopes of Thrasher Peaks (NW1/4 NW1/9). It is inferred to lie in the valley of the First East Branch of the Magalloway River on the basis of one southeast-facing top determination northwest of the Magalloway River.

The pattern of the macroscopic folds in the Kennebago Divide syncline is difficult to determine. There is no marker horizon, and indeed, bedding is rarely observed in this rock. There is uncertainty as to the scale and significance of the folds shown by the opposing top determinations in the eastern part of the area. Somewhat arbitrarily, the limited number of top determinations have been taken as indicators of macroscopic folds. A total of 29 top determinations was made in this patch of the Magalloway, 10 of which are near the southern contact with the Dixie Brook member. Of the 10 determinations, 9 face to the north and 1 faces south, indicating that the Magalloway member lies above the Dixie Brook member. The overturned syncline north of the contact is determined on the basis of 1 south-facing top on its north limb and may represent a fold of much smaller scale. Similarly, the three folds north of this overturned syncline are fixed by only 2 opposing top determinations on their respective north or south limbs. The northern-most syncline is located on the strength of only 1 south-facing top determination on its north limb.

The folds shown in the Magalloway member are consistent with the map pattern and the stratigraphic sequence, which shows the First East Branch syncline separated from the Kennebago Divide syncline by a thin patch of the Dixie Brook member. This thin band of black phyllite and greenstone forms an overturned anticline that is believed to be continuous with the belt of greenstone along the northeastern border of the quadrangle.

Summary of the early macroscopic folds: The basic structural feature in the pre-Silurian rocks has been interpreted as a regional anticlinorium. The Kennebago member of the Albee Formation is the lowest map unit in the sequence and outlines the trace of the axial anticline. The Albee Formation is overlain by the Dixville Formation on the northwest limb, and by the Oquossoc and Kamankeag Formations on the southeast limb of the Anticlinorium. The interpretation of the regional structure is based primarily on map pattern and stratigraphic top sense determinations. The limited paleontological data presented on Plate VIII, (nos. 5, 6, 7, 8), and discussed in the section on Regional Correlations supports the interpretation of the regional anticlinorium.

Late Ordovician-Earliest Silurian Unconformity

General Statement: Numerous investigators in the northern Appalachians, apparently beginning with Rogers (1838), have noted a break, either an unconformity or a disconformity, between the Ordovician and Silurian rocks. This break in the sedimentary record, ascribed to the Taconic orogeny, was first noted in southeastern New York and eastern Pennsylvania where it has been discussed by Schuchert (1925), Stose (1930), and Schuchert and Longwell (1932). The physical break between the Ordovician and Silurian strata is not apparent over large areas of northern New England, nor are there enough fossils in most of the rocks in New England to demonstrate a major hiatus in the sedimentary record. Billings (1937, p. 17-18) discusses the unconformity at the base of the Silurian rocks in the Littleton-Mossilauke area of New Hampshire. Boucot et.al. (1964, pp. 88-93) summarizes the data for the Taconic orogeny in the northern Appalachians.

<u>Location of the unconformity in the Cupsuptic quadrangle</u>: From the map pattern it can be seen that the rocks of Silurian age rest with pronounced angularity on the underlying pre-Silurian rocks in the Davis Town (SE1/9) and the Parmachenee Lake areas (NW1/4 WC1/9). In the Thrasher Peaks area (NW1/4 NW1/9) the Silurian units are so poorly exposed that little information is available on the angular relationships above and below the supposed unconformity. On a regional scale, however, Hatch (1963, Plate III) has shown that these Silurian units truncate the Magalloway and Dixie Brook members of the Dixville Formation and the Albee Formation southwest of the Cupsuptic quadrangle. For this reason the surface separating

the Silurian rocks from the pre-Silurian rocks in the Thrasher Peaks area is considered to be an unconformity, even though the trend of the respective map units is roughly parallel. A thin discontinuous band of quartz-pebble conglomerate, identical to that mapped in the Davis Town area, is exposed on the west bank of the Kennebago River in the vicinity of the 1566' B.M. on the abandoned Maine Central Railroad. The conglomerate is lithologically similar to that exposed north of Johns Pond and is considered to be Silurian in age. The discontinuous band of conglomerate is definitely broken by an east-trending fault, and may be bounded on the east by a fault that trends roughly parallel to the Kennebago River. Only one exposure of conglomerate was found on the east bank of the Kennebago River; hence the eastern extent of the conglomerate and the nature of the eastern contact are not known.

Davis Town Area: Although the unconformity was not seen in the Davis Town area, the divergent dips in the Silurian and pre-Silurian units and the truncation of three different pre-Silurian formations offer the best evidence for its existence in the quadrangle. Furthermore, the basal part of the polymict conglomerate contains abundant black slate fragments and variable amounts of vein quartz, quartzite, black chert, greenstone, and green phyllite. All of these could have been derived from the pre-Silurian rocks in the immediate area. There is no known source in the Davis Town area that could have supplied the abundant granite clasts or the few boulders of coarsely-crystalline limestone. The closest granitic rocks of known pre-Silurian age are 25 miles to the northeast in the vicinity of Jackman, Maine (Figure 1, no. 1). The porphyritic granite mapped by Guidotti (1965, written communication) 10 miles southwest of the Davis Town area may be pre-Silurian and, if so, a possible source of the granite clasts.

The presence of black slate and green phyllite fragments, and the absence of clasts of schist and gneiss, indicate that meta-sedimentary rocks of the source area were not metamorphosed to a higher grade than the chlorite zone, if at all, prior to the time of the unconformity. The black slate fragments are platy and have a pronounced cleavage that closely parallels the poorly developed, east-trending cleavage in the Silurian rocks. In general, the slate fragments are not deformed into shapes conformable to the outline of adjacent, nearly spherical clasts. This suggests that the fragments came from indurated rocks and not unconsolidated mud. The slate fragments are believed to have been incorporated as slate or argillate, but the pronounced cleavage in the fragments appears to have formed after the slate was incorporated in the conglomerate. The steep dips and tight folding on the underlying pre-Silurian rocks, however, support the hypothesis that these units were slate or argillite prior to the deposition of the Silurian rocks.

The quartz-pebble conglomerate in the Davis Town area consists predominantly of clasts of vein quartz with lesser amounts of quartzite, green phyllite, and chert in a pasty matrix of chlorite and sericite. All of this material could have been derived locally from the Albee Formation. The most plausible source for the clasts of vein quartz appears to be the quartz pods and stringers in the Aziscohos member. If this is so, then the quartz pods formed either during diagenesis or during the period of deformation that preceded the deposition of the Silurian rocks.

The exact amount of the pre-Silurian material that was removed prior to deposition in Silurian time is difficult to determine, because of the intense folding in the older rocks and the limited extent of the Silurian units. The Silurian rocks truncate the Kamankeag, Oquossoc, and Albee Formations over a map width of about 14,000 feet perpendicular to strike. If one assumes an average dip of 70 degrees for the pre-Silurian rocks and considers them to be essentially homoclinal, then about 13,000 stratigraphic feet of material was removed from the southeast limb of the anticlinorium prior to the deposition of the Silurian rocks. Intense folding in the pre-Silurian rocks would reduce this value, while a greater extent of Silurian rocks would increase the value. In the absence of additional data, it is clear that 13,000 feet of rock was removed at least locally by erosion prior to the deposition of the Silurian units.

The basal units in the Davis Town area are considered to be late Lower Silurian (Upper Llandovery). The age has been determined from correlations with similar units associated with fossiliferous rocks of that age found 6 miles on strike to the east. The basal Silurian units rest conformably on the Kamankeag Formation, the lower part of which is dated as late Middle Ordovician by graptolites at fossil locality no. 2. From this paleontological evidence, the unconformity can be dated as post Zone 12 of the late Middle Ordovician but pre-late Lower Silurian and is thus considered to be of Late Ordovician-Earliest Silurian age.

<u>Parmachenee Lake area</u>: The unconformity was not seen in the Parmachenee Lake area, but the divergent trends in the bedding of the pre-Silurian and Silurian units are taken as evidence of its presence. The black phyllite of the Dixie Brook member is the only pre-Silurian unit that directly underlies the small

syncline of Silurian rocks. Curiously, however, black phyllite fragments are virtually absent from the basal Silurian units. Most of the clasts are vein quartz, quartzite, chert, and lesser amounts of greenish-gray phyllite. Only one small patch of conglomerate was found that contained clasts of granite, felsite porphyry, and abundant black chert in addition to variable amounts of vein quartz and quartzite. No clasts of schist or gneiss were observed; hence, it is assumed that the metasedimentary rocks were derived from a source area with rocks of no higher grade than the chlorite zone exposed at the surface.

The youngest Silurian rocks have been dated by the fossils at locality no. 5 as Late Silurian (Ludlow), but the basal units may be Lower or Upper Silurian. The Dixville Formation is correlated with the Oquossoc and Kamankeag Formations and is considered to be Middle Ordovician in age. The hiatus represented by the unconformity is inferred to range in time from Late Ordovician to Early or possibly Late Silurian.

<u>Thrasher Peaks area</u>: The unconformity in the Thrasher Peaks area is only a small segment of the regional unconformity that separates the Silurian and Devonian rocks of the Connecticut River -- Gaspé synclinorium (Cady, 1960) from the pre-Silurian rocks of the Boundary Mountain anticlinorium (Albee, 1960; Cady, 1960). The unconformity is most readily apparent on a

regional scale as shown by Hatch (1963, Plate III). In the Thrasher Peaks area the trend of the units above and below the inferred unconformity is essentially parallel, but the dip of the Silurian units is generally less than the dip of the older rocks. The discontinuous patches of the basal conglomerate contain clasts of volcanic rocks, purplish-gray siltstone, and lesser amounts of graywacke, all of which are identical to rocks in the Magalloway member. No high-grade metamorphic rocks were found in the clasts of the conglomerate.

Two patches of fragmental limestone have been found at the base of the Silurian sequence at the northern border of the quadrangle. John Green (1964, written communication) found the eastern patch of limestone dated as Late Silurian (Ludlow(?)) in Naylor and Boucot (1965). The age of the Magalloway member is considered to be Middle Ordovician; hence the unconformity is inferred to represent the time from Late Ordovician to Late Silurian.

Macroscopic Folds in the Rocks of Silurian Age

Macroscopic folds have been determined in the three small patches of Silurian rocks on the basis of the map pattern and top determinations shown on Plate VII. The number of recognizable folds varies greatly in the three Silurian synclines, but in general the number of folds increases and the waves length of the folds decreases from southeast to northwest. Even though the intensity of the folding in the Silurian units is different in each small area, the general characteristics of the folds are the same and show a marked contrast to the folds in the pre-Silurian rocks. The folds in the younger rocks are open and have relatively broad troughs and crests in contrast to the tightly-appressed folds in the pre-Silurian rocks. The axes of the folds in the Silurian units plunge at shallow to moderate angles, whereas those in the pre-Silurian units commonly have steep plunges.

The Silurian units in the Davis Town area form an open syncline, the axial trace of which trends east-west and is vertical or subvertical. From the S-pole diagram of domain 18 on Plate V, it is apparent that the axis of the syncline plunges about 10° to the east. The beds on the south limb dip from 15° to 30° to the north and, as shown on Plate VII, consistently face to the north. Beds on the north limb dip from 40° to 70° to the south and face in the same direction.

The macroscopic folds in the Silurian units of the Parmachenee Lake area are tighter and more complex than those in the Davis Town area. The broad structural feature is a syncline composed of two smaller basins located in the eastern and western parts of the area. A distinctive arenaceous limestone unit lies in the trough of each basin and is underlain by silty limestone and conglomerate on the north limb of the syncline. The south limb of both the smaller basins has been truncated by a post-Silurian normal fault that places the youngest unit north of the fault in contact with the oldest unit south of the fault. The axial surfaces of the macroscopic folds are vertical or subvertical and the fold axes plunge at gentle angles to the west.

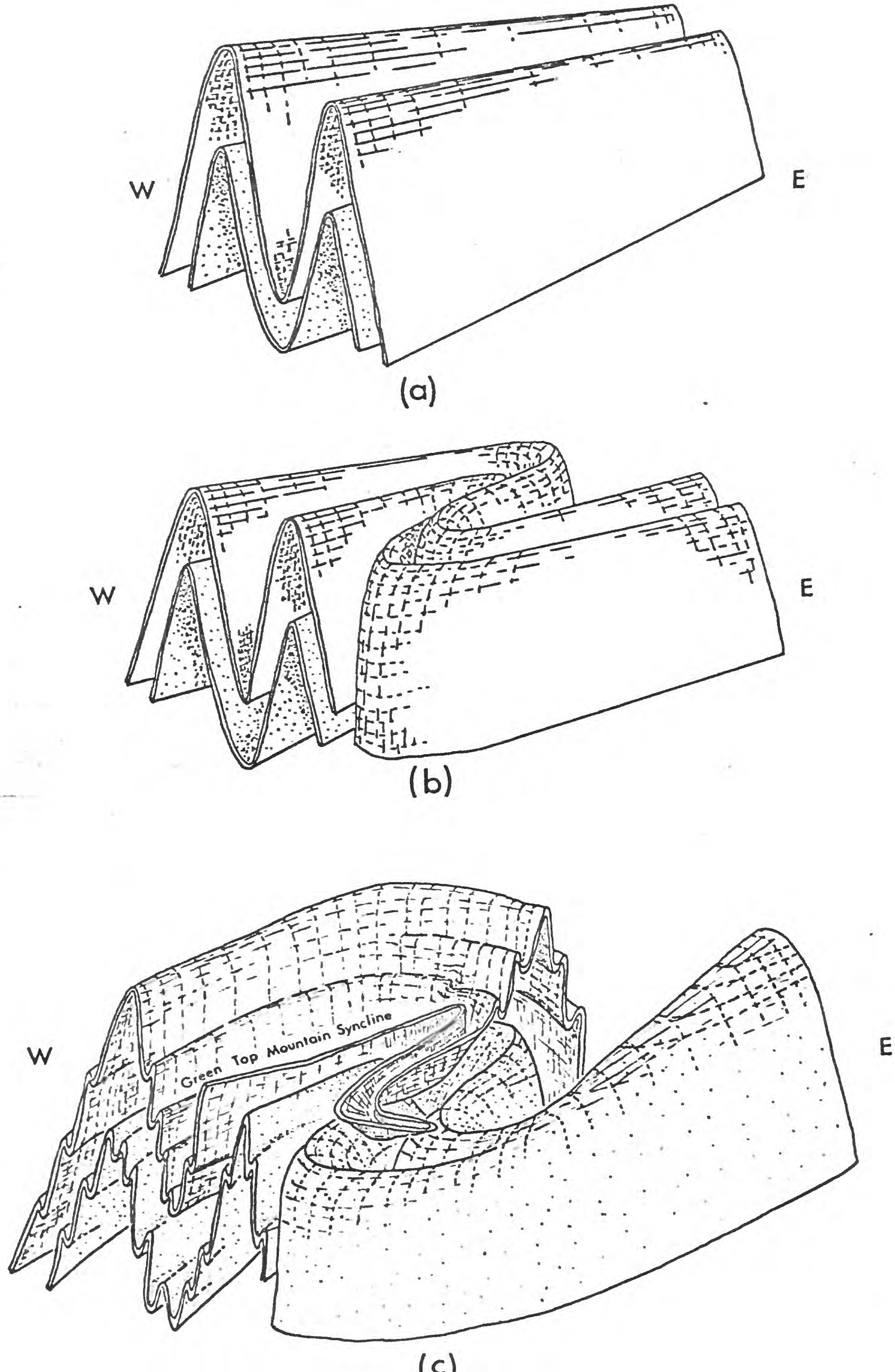
There are insufficient data to outline macroscopic folds in the Silurian rocks on the northwest slope of Thrasher Peaks, but a small northeast-plunging syncline is inferred from the map pattern at the northeast end of the area.

Late Macroscopie Folds in the Pre-Silurian Rocks

The axial surfaces of the early macroscopic folds in the pre-Silurian rocks have been deformed into a major asymmetrical fold around the west and south sides of the central quartz monzonite stock.

The deformation is spacially related and probably genetically related to the igneous intrusion. As the igneous body has not been deformed it is believed that the late folding in the pre-Silurian rocks post-dates the folding of the Silurian rocks but the two events may have been essentially contemporaneous. This late structural feature has the shape of a macroscopic drag fold in which the regional trend of the pre-Silurian units has been off-set to the southeast around the intrusive body. The evidence for the major "drag fold", as well as subsidiary folds on its short limb, comes largely from the map pattern and stratigraphic top determinations. Specifically, the top determination, on Plate VII and discussed in detail in the section on Early Macroscopic Folds, indicates that the symmetrical repetition of the pre-Silurian units north and south of the Green Top Mountain syncline is caused by early isoclinal folds. These early folds are shown schematically in Figure 18(a). The map pattern indicates that the early folds have been refolded about north-northeast-trending, vertical axial surfaces similar to the idealized pattern in Figure 18(b). The idealized drawings in Figure 18(a) and (b) show the axes of the early macroscopic folds with constant, horizontal plunge. In fact, the plunge of the early folds cannot be horizontal or constant because the Dixville Formation in the trough of the Green Top Mountain syncline disappears along its trend to the east and west. Figure 18(c) attempts

Figure ~~17~~ 18: Schematic diagrams to indicate inferred steps in the development of present map pattern west and south of central intrusive body. Upper surface represents base of Dixie Brook member; dotted surface represents the top of the Kennebago member.


W
E
(a)
W
E
(b)
W
Green Top Mountain Syncline
E
(c)

to show how the present map pattern west and south of the central intrusive body is dependent on the plunge of the macroscopic folds. The dotted surface represents the top of the Kennebago member of the Albee Formation and the upper folded surface represents the base of the Dixie Brook member of the Dixville Formation. Part of the upper surface has been removed near the front of the diagram to show the shape of the Dixville Formation in the trough of the Green Top Mountain syncline. The syncline generally plunges to the west in the central part of the diagram, but the plunge changes to the northeast near the southwestern face of the diagram. The single anticline on the east side of the diagram splits into two anticlines symmetrically located about the Green Top Mountain syncline. The early linear features shown on Plate IV generally support this interpretation, which has been deduced largely from the map pattern and stratigraphic sequence.

The late deformation produced a slip cleavage in the rocks adjacent to the central intrusive body that generally trends north-south and is vertical or subvertical. The slip cleavage is parallel to the axial surfaces of minor folds in the bedding and the early foliation.

Major Faults and Fault Zones

<u>General Statement</u>: Five major faults or fault zones have been mapped in the area; four have a general trend of about N.50°E.; the fifth and largest fault has a trend of N.40°W. None of the faults have continuous exposure or even topographic expression over their entire map length, but evidence for each fault can be found in scattered outcrops along the projected trend of the fault. Each fault, where it is exposed, is characterized by one or more of the following features: a) massive vein quartz or quartz-cemented breccia of the enclosing rocks; b) light rusty-tan, limonite-rich gouge; c) thin granitic dikes parallel to the strike of the fault that may or may not show cataclastic texture, oriented inclusions, and a high degree of alteration; d) abundant slickensides in either the country rock, the massive vein quartz, or the granitic dikes; e) apparent off-set of map unit contacts across the fault zone. Small faults (see Figure 6b, p. 34) and shear zones a few inches to a few feet wide are common in the rocks of the Cupsuptic quadrangle, but these features generally die out in the width of the outcrop and do not, in themselves, constitute evidence for a fault large enough to be shown on the geologic map.

Daddy's Ridge Fault: Evidence for this fault is exposed for a distance of about 3500 feet along its strike near the 2385 foot summit of Daddy's Ridge (NW1/4 SE1/9). The fault is intruded by a sheared and sericitized granitic dike that weathers more rapidly than the surrounding phyllite, producing a steep-walled gully along the trend of the fault. Massive pods of quartz, or quartz and calcite, are found at scattered localities along the walls of the gully. The fault strikes N.40°W., is vertical or subvertical, and contains slickensides that plunge from 40° to 60° to the northwest. The northwest block is believed to have moved up and southeast with respect to the southwest block.

The major quartz monzonite dikes south and west of the central stock are believed to have intruded along the northwestern extent of the Daddy's Ridge Fault. The faulting apparently was contemporaneous with the period of igneous intrusion; hence it is considered to be Middle or Late Devonian.

Little Kennebago Lake Fault: The Little Kennebago Lake Fault trends N.50°E. and is exposed for a distance of about 4300 feet along the crest of the ridge just east of Little Kennebago Lake. According to E. L. Boudette (1965, personal communication), the fault continues to the northeast into the Kennebago Lake quadrangle. The fault may continue farther to the southwest than is shown on the geologic map but exposures are scarce in that area and no evidence for the fault could be found.

The fault crosses the southeastern edge of the granodiorite body near Little Kennebago Lake, where it forms a sericitized and silicified zone about 200 feet wide in the intrusive rock. The dip and relative movement of the fault is difficult to determine, but slickensides found on subvertical surfaces plunge steeply to the northeast and indicates a steeply-dipping normal fault.

The age of the fault is probably post-Ordovician, but no upper limite can be determined. It may be as late as Triassic.

<u>South Brook Fault Zone</u>: Four separate faults that trend about N.50°E. are exposed on the west side of the Brown Company road that traverses the ridge between South Brook and Lincoln Pond (SE1/4 SW1/9). One of the faults has been projected along strike to the northeast because it apparently coincides with the fault exposed in the lower reaches of South Brook. The other faults may have greater extent than is shown on the geologic map.

All of the faults are characterized by intensely sheared, limonite-rich gouge that forms tan-weathering zones from 20 to

100 feet wide in the green phyllite of the Aziscohos member. Sericitized granitic dikes with pronounced cataclastic texture, lie parallel to the trend of two of the faults for a limited distance. Movement on the four faults was not limited to a single plane but took place on closely-spaced surfaces that trend from N.30°E. to N.50°E. and dip steeply to the northwest. The off-set of lithologic units suggests that the north blocks moved down and west with respect to the south blocks of the faults.

The faults can be dated only as post Ordovician on the data in the Cupsuptic area.

Faults in the Parmachenee Lake area: Two major faults cut the Silurian rocks in the Parmachenee Lake area. The southern fault trends east-west and coincides roughly with the small brook that drains the swamp in the center of the area. Patches of vein quartz and coarsely-crystalline calcite are scattered along the trace of the fault, but an interruption in the normal stratigraphic sequence is the major evidence for the fault. The silty limestone unit does not appear south of the fault; instead, the arenaceous limestone rests directly on the basal units. The north block of the fault is believed to have moved down with respect to the south block.

The northern fault trends about N.60°E. and forms the northern contact between the silty limestone unit and the basal conglomerate. The silty limestone on the south block of the northern fault has been faulted down into contact with the Dixville Formation at one point along the northern border of the syncline.

The age of the faults can be determined only as post-Silurian.

<u>Smaller, unnamed faults:</u> Evidence for two faults, unnamed in this report, is found in a few outcrops in two widely separated areas. The first is on the east bank of the Kennebago River about 100 feet south of the lower power dam. Here, a limited exposure of silicified breccia, gouge, and sheared rock suggest a major fault, but no evidence for the same could be found away from the river. No information is available as to the direction and magnitude of the fault movements.

Similarly, a second major fault may occur in the vicinity of the headwaters of South Branch of Black Cat Brook (NW1/4, WC1/9). Limited exposures of massive vein quartz and sheared gouge occur where the fault is mapped, but this evidence could not be found along the projected trend of the fault.

MESOSCOPIC STRUCTURAL FEATURES

Planar Features

Bedding: Bedding in this study is defined as essentially parallel layers or discontinuous layers of material that show changes in either total mineralogy or relative proportions of major minerals. The change in composition is generally accompanied by a change in grain size in the layers. Alternating layers of light gray-green and dark green phyllite or similar layers of purple and green slate were not recorded as bedding.

Significant differences were noted between the bedding characteristics in the rocks of pre-Silurian age and those in the rocks of Silurian age. The Silurian units generally contain more beds in a given exposure and the alternating layers tend to be more nearly equal in thickness in the Silurian sequence. Thus the Silurian sequence is commonly well-bedded or cyclically-bedded; whereas, the bedding in the pre-Silurian sequence is highly variable in thickness and irregular in distribution. Primary sedimentary features such as graded-bedding, cross-bedding, and channel scouring are more common and much more distinct in the rocks of Silurian age. Graded-bedding is present in the arenaceous beds of the Albee Formation and in the Magalloway member of the Dixville Formation, but the feature is not widespread or pronounced. The beds in the pre-Silurian sequence, and particularly those in the Albee Formation, are tightly folded, steeply dipping, and commonly sheared and discontinuous. In contrast, the beds in the rocks of Silurian age are generally continuous in a given exposure and have moderate to gentle dips on the limbs of open folds.

Foliation: Foliation is used here in the sense defined by Mead (1940) as the property of rocks to break along approximately parallel surfaces. This broad, descriptive term is preferred because it encompasses the slaty cleavage in the eastern part of the quadrangle, the crenulated foliation of the phyllite in the central and northern part of the area, and the schistosity along the southern margin of the map. It is believed that the different types of foliation had a common origin in the early episode of folding because each is parallel to the axial surfaces of the early folds. The progressive change from slaty cleavage in the east to schistosity in the southwest may have formed during the first period of deformation, or it may represent progressive recrystallization during later regional metamorphism.

The slaty cleavage is well developed in the eastern third of the quadrangle but patches of pelitic rocks may show slaty cleavage in areas where phyllite predominates. The slaty cleavage is vertical or subvertical and generally has a northeast trend, except in the southeastern ninth where it strikes north or north-northwest. The cleavage surfaces are soft and dull with the parallel alignment of platy minerals developed on a microscopic scale.

In the phyllite, which predominates in the western 2/3 of the quadrangle, the foliation surfaces are commonly parallel or subparallel to the bedding, but locally intersect the bedding on the noses of minor folds. The foliation surfaces are commonly crenulated, and mottled by patches of silvery-white mica and chlorite. In the vicinity of the Green Top Mountain syncline (Plate VII) the foliation commonly intersects the bedding and both of these features are crenulated and folded by the late slip cleavage.

The foliation present in the phyllite grades imperceptibly into a schistosity restricted to a zone about 3 miles wide along the southern border of the quadrangle west of the Kennebago River. In this zone the foliation surfaces are characterized by fine- to medium-grained muscovite flakes, and platy aggregates of muscovite and chlorite about ½ inch in diameter. The grain size of the micaceous minerals is larger than in the phyllite and numerous quartz pods and stringers lie parallel to the foliation surfaces. The schistosity is parallel to the axial planes of early minor folds and locally has been intensely deformed by the late slip cleavage.

Slip cleavage: Slip cleavage is here used in the sense of White (1949) for closely spaced, parallel zones or planes along which there has been transposition of a pre-existing planar feature such as bedding or foliation. As such, it is analogous to strain-slip cleavage as discussed by Turner and Weiss (1963, p. 98), and akin to fracture cleavage as defined by Leith (1905, p. 120). The slip cleavage is strongly developed in the rocks immediately south and west of the Cupsuptic stock, and in a separate zone that covers the southern half of the south-central and southwest ninths of the quadrangle.

The slip cleavage in the southern part of the quadrangle generally strikes north-south and has a vertical or subvertical dip. The trend of the slip cleavage gradually changes to about N. 40°E. in the area immediately west of the central intrusive body. The spacing between the shear planes ranges in width from less than a millimeter to several centimeters, and the width of the actual shear planes ranges over the same interval. As seen in Figure 19, the wider shear zones are generally spaced farther apart than the narrow shear planes.

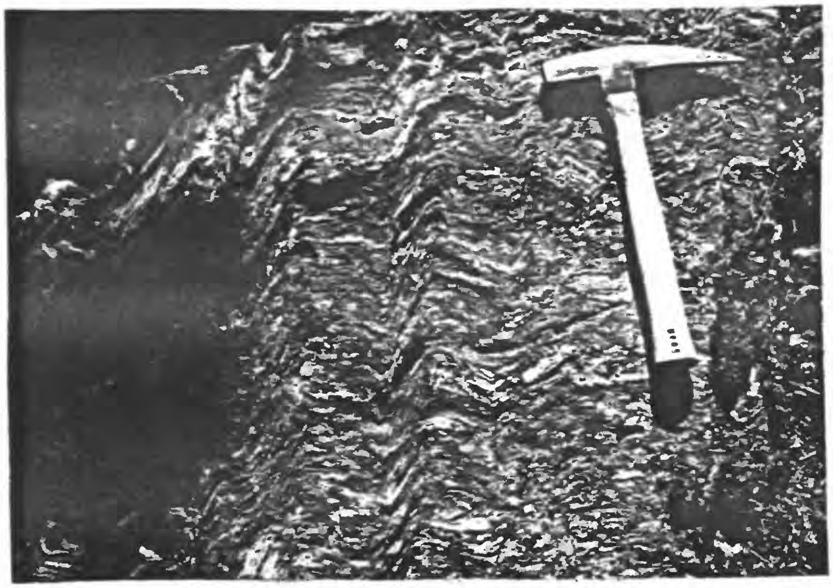


Figure 19a: Widely spaced slip cleavage planes (about 5" apart)

Figure 19b: Thin shear zones of slip cleavage separated by zones about 1" wide. Early foliation trends roughly parallel to the pencil which is about 4 inches in length.

Where the bedding, foliation, and slip cleavage are exposed in one outcrop, the slip cleavage lies parallel to the axial planes of the late minor folds and clearly post-dates and deforms the other planar features.

Minor folds: Minor folds are common in the Albee Formation but less common or less easily recognized in the other units in the quadrangle. For that reason the discussion of minor folds will deal primarily with those in the Albee Formation.

The minor folds in the quadrangle show a wide variety of forms, but most could be generated by a line moving parallel to itself in space; hence they are planar, cylindrical folds. The plunge of the planar cylindrical folds is essentially constant in a given outcrop, but the wave length and amplitude commonly range from a few inches to a few feet, as shown in Figure 18. The minor folds observed in the rocks of Silurian age are essentially planar cylindrical folds.

Several examples of a second type of minor fold are exposed in the Albee Formation on the east side of the Kennebago River about 100 feet downstream from the upper power dam. These folds, shown in Figure 20, have a planar axial surface, but their form cannot be generated by a line moving parallel to itself in space. The plunge of the axis changes from about

Figure 20(a): Folded granulite beds in green phyllite of Aziscohos member. Folds are roughly symmetrical, concentric and of variable wavelength and amplitude.

Figure 20(b): "Hogback" folds in pinstripe granulite beds of Kennebago member. Axial surface is vertical and trends left to right in photo. Fold axis changes plunge from about 50° SW to about 15° NE. Upper Power Dam Kennebago River (East Bank).

50° to the southwest through the horizontal to about 15° to the northeast. The folds are planar non-cylindrical forms that appear to have formed by differential movement in the "a" direction of the fold. There is no cross-cutting planar feature, such as the late slip cleavage, in this area of planar non-cylindrical folds.

In areas of pronounced slip cleavage, the minor folds may be planar cylindrical forms or they may be nonplanar non-cylindrical features. Both types of minor folds are found in scattered exposures on the southeast side of Deer Mountain (SW1/4 SC1/9). The cylindrical folds have either the early foliation or the late slip cleavage parallel to their axial surfaces. In those outcrops where the late slip cleavage parallels the axial surfaces of cylindrical folds the early foliation is parallel or subparallel to the bedding, indicating that the exposure is on the limb of an early fold. The direction and magnitude of the plunge of late minor folds is determined by the attitude of the bedding and the angle of intersection of the bedding and the late slip cleavage. As the trend of the bedding is northeast to east with sub-vertical dip and the attitude of the slip cleavage is north-south and nearly vertical, the late fold axes plunge either steeply north or south. The folds are assymetrical, often disharmonic, and commonly show a dextral movement sense.

The amplitude and wave length of the late folds are smaller than comparable features in the early folds.

Nonplanar, non-cylindrical folds result from the refolding of the hinge lines and the axial surfaces of the early minor folds. The folded folds range from a few inches to a few feet in outcrop length and commonly have a basic pattern similar to that illustrated in Figure 21; although variations on the basic theme, as sketched in Figure 22, have been observed. Most of the folded folds consist of essentially isoclinal early folds with vertical axial surfaces that have been refolded about late slip cleavage. The late folds, in general, have very steep plunges resulting from the intersection of the vertical slip cleavage with the subvertical limbs of the early folds. This basic pattern in the minor folds closely resembles the map pattern in the pre-Silurian formations south and west of the central intrusive body.

The most notable departure from the basic pattern of the minor folded folds is shown by the field sketch in Figure 22(h). In this case the early minor folds trend east-west, and plunge in different directions on the opposite sides of the axial surface of the late folds. The plunge of the early folds becomes essentially zero on the crest of the late fold in Figure 22(h), and would have a maximum value on the limbs mid-way between the crest and trough of adjacent late folds. Thus the early minor folds pass through axial culminations

Figure 21: Folded fold in pinstripe granulite bed showing typical style of multiple deformation in Cupsuptic area. Early axial surface (a.p.^{1}) trends northeast and is subvertical; late axial surface (a.p.^{2}) trends north and is subvertical.

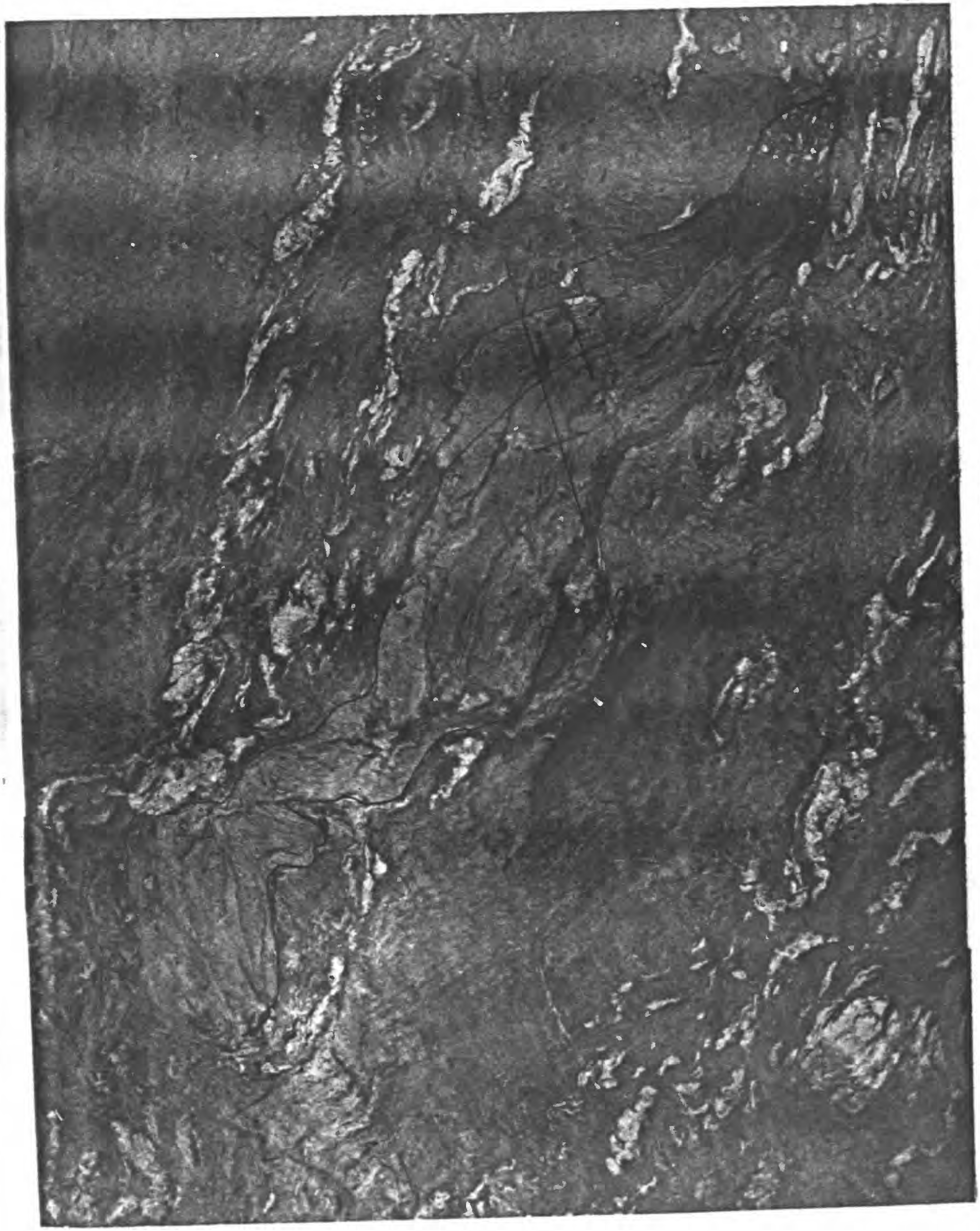


Fig 21

Figure 22: Field sketches of minor folds. Bearing of plunge of fold axes and strike of planar features given in degrees -- Sketches are not oriented with respect to each other.

and depressions on the crests and troughs, respectively, of the late folds.

Linear features

The linear features measured in the Cupsuptic quadrangle include hinge lines of minor folds, minor crenulations in the bedding or foliation, quartz rods, bedding-cleavage intersections, and a few bedding-boudinage lines. Over much of the area the combination of steeply plunging folds and flat, pavement-like outcrops restricted the observable linear features to hinge lines of minor folds.

Fold hinges: Hinge lines of minor folds are abundant in the Albee Formation and constitute the bulk of the linear features measured in the southern half of the quadrangle. In the Aziscohos member the hinge lines of folded quartz stringers were measured and were found to be essentially parallel to either the early or late fold hinges in the bedding. The measurement of the hinge lines of folded quartz veins was easier and more accurate than the measurement of the same feature in folded beds, because the quartz veins stand in marked relief on the surface of most pavement outcrops.

In areas of cylindrical folding, the attitude of the hinge lines closely coincides with the statistically determined axis of folding. In areas of non-cylindrical folding, for example domain 13 on Plate V, the hinge lines of early minor folds form an east-west girdle on the equal area net. The hinge lines of the late minor folds in such areas form a north-south girdle.

Crenulations: Minor crenulations are common in the early foliation intersected by closely spaced slip cleavage. Technically the crenulations are minor folds of the type $B_{S_2}^{S_3}$ (Turner and Weiss, 1963, p. 136-137), but their amplitude and wave length are on the order of a few millimeters or tenths of millimeters. Crenulations are commonly parallel to the hinge lines of late minor folds.

Quartz-rods: Quartz rods are abundant in parts of the Aziscohos member. They represent sheared and transposed fold hinges and linear segments of quartz stringers that lie in zones of pronounced shearing parallel to the slip cleavage direction. The plunge of the quartz rods is parallel to the intersection of the slip cleavage and the early foliation.

Bedding-cleavage intersections and bedding boudinage: The intersection of bedding and the early foliation is rarely observed because the folding is essentially isoclinal. Where measurements were made the intersection was parallel to the axis of the early minor folds. The intersection of bedding and slip cleavage produced either minor folds or crenulations described in preceding sections.

Boudinage is not a common feature in the Albee Formation. A few boudined beds were observed in the Magalloway member and one "macro-boudin" was observed in a folded greenstone bed in the Aziscohos member. The boudinage neck lines are roughly parallel to the early fold axes.

STRUCTURAL GEOMETRY

General Statement

The geometrical relationships between the mesoscopic structural features and the associated macroscopic folds were analyzed in detail by dividing the quadrangle into eighteen domains. Ideally the domains are chosen so that each one contains a cylindrically folded segment of a complex, non-cylindrical macroscopic fold. In the Cupsuptic area most of the domains represent areas of nearly homogeneous folding; in some, however, the multiple deformation is on such a small scale that it was impossible to isolate a domain of homogeneous folding.

In each domain the poles to the bedding were plotted on the lower hemisphere of an equal area net. In domains of homogeneous folding these poles lie on a great circle of the net. The pole of this great circle is the axis of folding for that domain. After Turner and Weiss (1963, p. 157) this type of diagram will be referred to as an S-pole diagram; the axis of folding is labelled π. In domains of cylindrical folding the mesoscopic linear features should plot on the lower hemisphere of an equal area net in the same position as the pole to the great circle, π.

The S-pole diagrams are presented in correct spatial orientation on Plate V, and the linear features measured in each domain are superimposed on the S-pole diagrams. The most straight-forward presentation of the data on an S-pole diagram is simply a plot of the poles. As the linear features have been superimposed on the S-pole diagrams presented here, the poles to bedding are contoured on the number of poles per 1% area. Each diagram contains a different number of poles; hence, if the statistical maximum were to be compared from domain to domain, as in β-diagrams, the data should be contoured as percent per 1% area. In S-pole diagrams, however, the maximum concentration of poles is not as significant as the widely scattered few that determine the shape of the great circle. The diagrams as contoured here show at a glance those areas in which the data was sparse, and do not camouflage this fact by normalizing the information on a percent basis.

Geometry of the macroscopic folds

The changes in the geometry of the axial anticline of the Boundary Mountain anticlinorium are shown on Plate V by the S-pole diagrams for domains 7, 8, 9, 10, and 11. These diagrams scanned in the above order show:

1) East of the Cupsuptic intrusive (domain 7) the structure is symmetrical about a vertical axial surface that strikes N.50°E. The folding is cylindrical about an axis that plunges 55° in a direction of S.50°W. Folding of a second generation, if present, must be coplanar and coaxial with that of the first generation.

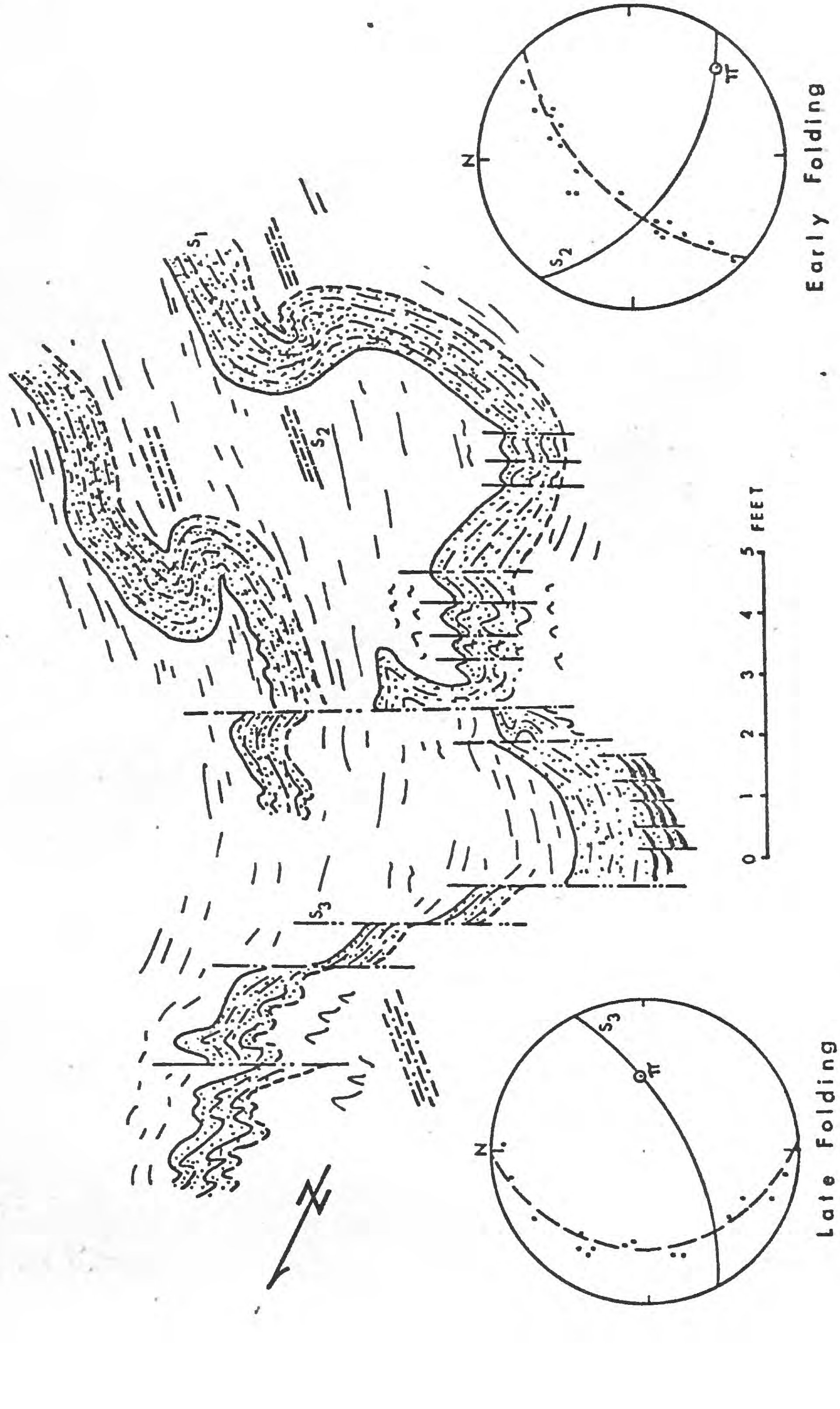
2) South of the Cupsuptic stock (domain 8) the structure is overturned to the north. The axial surface strikes N.86°E. and dips 80°S. The linear features scatter in an east arc through the axis of folding. Folding deviates from the cylindrical form due to a broad north-south trending culmination which parallels the trend of the late slip cleavage; however, the early fold trend predominates.

3) In domain 9 at the southwest corner of the intrusive body there are two pronounced girdles on the S-pole diagram. The more pronounced girdle emphasizes the late folding about

an axis of S.10°E. at 72°. The weaker girdle indicates folding about an axis at S.42°E. at 27°. The domain is centered on a major bend in the axial anticline. The trend of the slip cleavage ranges from north-south to N.60°E., which is exceptional and possibly due to the influence of the Daddy's Ridge Fault. The nature of deformation in domain 9 is shown by the field sketch in Figure 23. The axis of folding at S.42°E at 27° represents measurements near the hinge lines of early folds, the limbs of which have been deformed by the late slip cleavage.

4) The S-pole diagram for domain 10 indicates a geometry that could be obtained from a steeply dipping homoclinal sequence on the limb of a planar, cylindrical fold. On the basis of the stratigraphic sequence, however, it is known that domain 10 contains three tightly-appressed early folds which form the east limb of a late major fold. This example points out the weakness of a purely geometrical approach to structural analysis. The axial surfaces of the early folds strike N.42°W. and dip 85 degrees to the southwest.

5) The S-pole diagram for domain 11 is complimentary to that for domain 10. Tightly appressed limbs of early folds form the west limb of the late macroscopic fold. The axial surfaces of the early folds strike N.27°E. and are subvertical. The folding in domain 11 is not cylindrical,


S1
S2
S3
0 1 2 3 4 5 FEET
N
π
Early Folding
Late Folding

because the folds plunge to the southwest in the northern part of the domain and to the northwest in the southern part of the domain.

The geometry of the axial anticline and the Green Top Mountain syncline can be summarized by plotting the segments of the axial surfaces of the early folds from the above domains on one equal area net as shown in Figure 24. The segments of the axial surfaces of the early folds should intersect in a point if the late folding is cylindrical. The deviation of the intersection from a point gives the deviation from cylindrical folding. The intersection of the axial plane segments is an axis of folding, designated $B_{S_2}^{S_3}$ by Turner and Weiss (1963, p. 181) and represents the axis about which the early folds have been refolded. The intersection of the axial plane segments on Figure 24 approaches a single point to a greater degree than might be expected and centers roughly on the average trend of the late slip cleavage. The axis of late folding plunges about 80 degrees in a direction of S.10°W.

The structural analysis of the mesoscopic features in the Dixville Formation provides little information about the geometry of the macroscopic folds that is not apparent from the map pattern and the top determinations. However, the

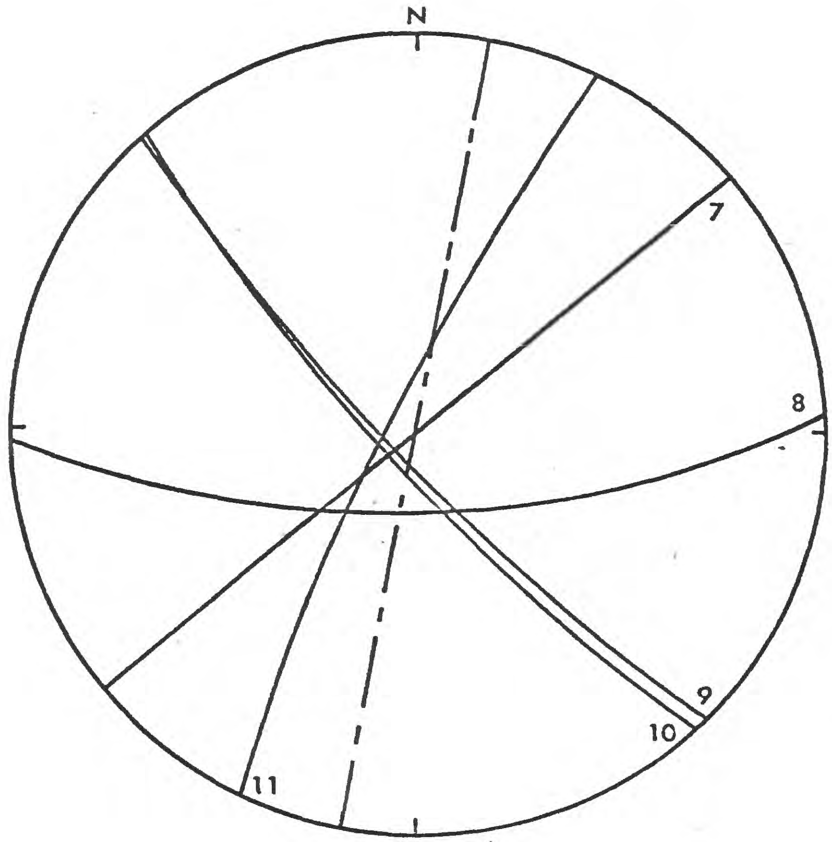


Figure 24: Equal area plot of segments of axial surfaces of axial anticline. Broken line is average stike and dip of late slip cleavage. Intersection of early axial plane segments show axis of late folding at about S.10°W./80°. Numbers on segments of axial surfaces correspond to domains on Plate V.

S-pole diagram for domain 1, which combines data in the First East Branch syncline, indicates that folding is symmetrical and essentially cylindrical about an axis of folding that plunges 65 degrees in a direction of S.44°W. This suggests but does not prove that the axial trace of the syncline lies within domain 1 or approximately along the course of the First East Branch of the Magalloway River. The nearly vertical axis of folding in domain 2 represents the axis of late folding in the area about the central intrusive body. Domain 3 combines a little information from a very large area in which the folding is undoubtedly more complex than shown on the S-pole diagram. The bulk of the information combined in domain 3 comes from the eastern half of the Kennebago Divide syncline, which suggests that the axis of folding there plunges about 55° to the west. This may not represent the only axis of folding in this macroscopic fold, however, and should be viewed with caution.

The macroscopic folds southeast of the axial anticline, particularly those in the Aziscohos member, have a non-planar, non-cylindrical form. Two important features of the geometry of the major folds in this area can be seen in the Deer Mountain syncline. First; the axial surface of the fold which trends roughly northeast at its southwest and northeast end, trends more to the east in its center and thus is curviplanar.

Secondly; the fold plunges about 50° to the southeast at its northern end in domain 14, and about 60° to the east-northeast at its southern end in domain 12. Domain 13 is approximately centered on the plunge depression and the inflection point of the axial trace. These two features of the macroscopic fold produce a geometry that is distinctly non-cylindrical, as shown by the S-pole diagram for domain 13. The S-pole diagram for domain 15 indicates that the axial surfaces of the macroscopic folds dip to the southeast and the folds plunge about 40° to the east.

The S-pole diagrams for domains 18 and 4, the Davis Town and Parmachenee Lake areas respectively, show the contrast in the style of folding in the rocks of Silurian age with respect to that in the pre-Silurian rocks. The girdles near the centers of the two diagrams indicate that the beds dip gently and the axis of folding in each domain plunges at a low angle. The contrast between the S-pole diagrams for domains 17 and 18 shows the presence of the unconformity very well.

AGES OF FOLDING

The ages of the deformations described previously cannot be determined exactly, but certain limits can be set from the following observations:

1) Sedimentation, which began possibly in Cambrian time, continued without any observable breaks to at least late Middle Ordovician time. Thus all the deformation recorded in the Cupsuptic quadrangle is post late Middle Ordovician.

2) The marked unconformity in the quadrangle is at least younger than late Middle Ordovician because it truncates the Kamankeag Formation. The unconformity is overlain by rocks inferred to be late Lower Silurian (Upper Llandovery) at the oldest.

3) The unconformity truncates the Albee, Oquossoc, and Kamankeag Formations in the Davis Town area; hence the pre-Silurian rocks must have been folded, uplifted and eroded between late Middle Orodovician and late Lower Silurian time. This period of deformation must have produced more than broad warps in the pre-Silurian sequence because of the marked contrast in the folding between the rocks above and below the unconformity. If the Silurian rocks were intensely deformed, then some of the folding in the pre-Silurian might be assigned to post-Silurian deformation. This is not the case.

From the above evidence, the time limits for the Taconic Orogeny in the Cupsuptic area can be given as post late Middle Ordovician but pre- late Lower Silurian. This age assignment agrees closely with previous information on the Taconic orogeny reviewed by Boucot and others (1964, p. 88-93). The mechanical deformation in the Cupsuptic area during the Taconic orogeny was intense; however, there is no evidence to indicate that the regional metamorphism was ever of higher grade than the chlorite zone. This is in contrast to, but does not necessarily negate, the suggestion made by Albee (1961, p. C-53) that the Taconic disturbance was accompanied by high grade metamorphism to the north-northeast.

At this time the age of the late deformation in the quadrangle can be stated as post Silurian. It is probably late Devonian; but until a radiogenic age is established for the Cupsuptic intrusive, no definite age can be given. The late Devonian age is inferred from Paleontological and geological relationships given by Billings (1956) for New Hampshire, and Boucot (1958, 1964, p. 93-99) for Maine.

METAMORPHISM

GENERAL STATEMENT

The rocks of the Cupsuptic quadrangle have been regionally metamorphosed to chlorite grade, and have been locally contact metamorphosed to sillimanite grade around three quartz monzonite stocks. Three metamorphic zones have been mapped around the Cupsuptic pluton (C1/9) and the Lincoln Pond pluton (SW1/9). Two metamorphic zones have been mapped in the southeast ninth of the quadrangle around the west end of a large gabbro body that lies just east of the southeastern border of the quadrangle. Exposures of rock of appropriate composition are too few to permit the mapping of similar zones around the part of the Seven Ponds pluton exposed in the northeast corner of the Cupsuptic area. Each metamorphic zone is bounded by a line on the geologic map that marks the first observed appearance of the mineral for which the zone is named; specifically: biotite, andalusite, and sillimanite.

The detailed study of the metamorphism of the area has been restricted to minerals and assemblages of minerals found in metamorphosed aluminous sediments because this is by far the most abundant and best exposed rock-type in the area. This chapter discusses first the physical and chemical changes in specific minerals or members of a mineral group with progressive contact metamorphism. The chemical composition of the minerals have been studied by means of optical and other physical properties, and also by partial chemical analyses. The second part of the chapter deals with the changes that take place in the nature of the mineral assemblages with progressive contact metamorphism. These relationships will be portrayed on quarternary diagrams and ternary projections for specific chemical subsystems, each of which is a partial representation of the chemistry of the rock as a whole. This graphic treatment of phase equilibrium employs the theories and techniques described by Thompson (1955, 1957) and Korzhinskii (1959). It has been widely used by others to show the mutual relationships between minerals of successive regional and contact metamorphic zones. The recent investigations of Green (1963) and Moore (1960) are highly pertinent, as they deal with contact metamorphism of similar rocks in nearby areas; southwest and northeast of the Cupsuptic quadrangle, respectively.

METHOD OF STUDY

Regional mapping of the Cupsuptic quadrangle revealed that the bulk of the rock consisted of phyllite and slate composed mainly of quartz, muscovite, chlorite, and albite. Specific rock units could be traced from the low-grade phyllite and slate to the igneous contact through successive zones consisting of maculose biotite-cordierite-chlorite hornfels, maculose andalusite-biotite-cordierite hornfels and dense, equigranular sillimanite-biotite-cordierite hornfels. The successive changes in the chemistry of specific minerals as well as the changes in mineral assemblages could be related unambiguously to specific igneous bodies of relatively restricted areal distribution. Samples were collected on traverses normal to and parallel to the intrusive contacts. About 250 thin sections of rocks from the contact aureoles around the Cupsuptic and Lincoln Pond plutons were studied.

The phyllite and slate were studied by the combined use of the petrographic microscope and the X-ray diffractometer. Whole rock samples of the phyllite and slate as well as some hornfels samples were X-rayed on a Norelco high-angle Geiger counter diffractometer using CuK_{α} radiation and a Ni filter. The major phases in a rock were identified by comparing the diffractometer chart of the whole rock sample with prepared charts of mineral standards. The technique was identical to that described by Zen (1960, p. 132-133). In addition, some hornfels slabs were stained using the technique described by Laniz and others (1964) to distinguish between potassic feldspar, plagioclase, cordierite, and quartz.

Those phases studied in detail were separated or concentrated using heavy liquids and a Franz magnetic separator.

Specific techniques are described in the discussions of specific minerals.

MINERALOGY

Muscovite

Petrography and association: Muscovite is an ubiquitous phase in the pelitic rocks of the quadrangle. It varies in habit from elongate scales about 50 μ in size in the phyllite and slate to nearly equant plates about 0.5 mm in size in the sillimanite-bearing hornfels. The muscovite flakes in the sillimanite-bearing rocks are markedly coarser than thosein the pelitic rocks of lower metamorphic grade. This fact proved to be a useful guide to sampling and mapping the sillimanite zone in the field.

Muscovite is present in all of the sillimanite-bearing rocks that were studied in thin section; however, in some rocks from local areas closest to the intrusive contact, muscovite appeared to be partially broken down to sillimanite and potassic feldspar. A line bounding a zone in which muscovite was unstable could not be drawn on the map because of limited exposure and the irregular distribution of rocks showing this reaction.

Basal spacing measurements: Eugster and Yoder (1955) pointed out that the basal spacing of muscovite decreases with increasing amounts of Na^+ in solid solution. Similarly, from the work of Yoder and Eugster (1955) on the muscovite-paragonite join, it is apparent that the Na^+ content of muscovite coexisting with paragonite will increase with increasing temperature.

Muscovite was separated from 11 rocks using standard heavy liquid techniques and a Franz magnetic separator. The (0.10) peak of muscovite was measured using Cu $K\alpha$ radiation, Ni filter and a high-angle Geiger counter diffractometer scanning at $1/4^{\circ}$ per minute with the (20.1) peak of quartz as an internal standard. The basal spacings of the 11 muscovite samples from the chlorite, biotite, andalusite, and sillimanite zone are given in Figure 25.

In the chlorite zone the basal spacing indicates that there is virtually no Na^+ in the muscovite. With increasing metamorphic grade the basal spacing decreases to a minimum in the andalusite zone, indicating that the Na^+ content (and possibly, in part, the Ca^{++} content) of the muscovite increases. If the relationship between basal spacing and Na^+ content is linear as proposed by Zen and Albee (1964), the muscovite in the andalusite zone contains about 28 mol percent Na^+. The basal spacing of the muscovite in the sillimanite zone is appreciably greater than that in the andalusite zone, indicating that the Na^+ content is less.

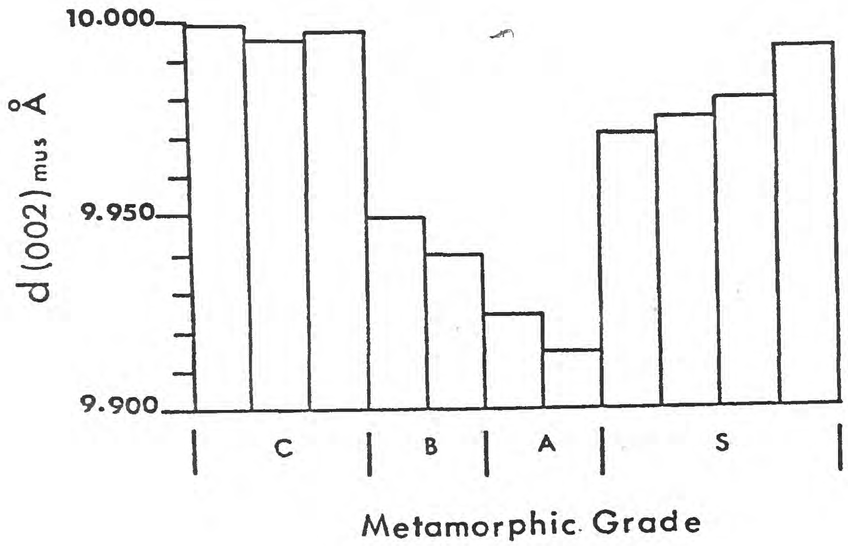


Figure 25: Changes in basal spacing of muscovite with increasing metamorphic grade. C = chlorite; B = biotite; A = andalusite; S = sillimanite. Decrease in basal spacing due to increase of Na^{+} (and Ca^{+}) in muscovite.

Chlorite

Petrography and association: On the basis of microscopic textures, chlorite appears to be a stable produce of prograde metamorphism in all mineral zones except the sillimanite-bearing hornfels zone. In the sillimanite zone, chlorite or chlorite plus ilmenite replaces biotite in what is inferred to represent a retrograde metamorphic assemblage.

Chlorite forms scaly aggregates intermixed with muscovite in the regionally metamorphosed phyllite and slate. The grain boundaries are indistinct; the pleochroism is green to light yellow green, and the interference colors are abnormal blue, or bluish-gray. Chlorite is associated with quartz, muscovite, albite, magnetite, and locally hematite.

In the biotite zone, chlorite forms distinct, euhedral porphyroblasts about 0.2mm in length. Pleochroism is well developed from green to light green or colorless. The interference colors may be either abnormal blue of abnormal brown. In the rocks of the Albee Formation at higher grades of metamorphism, chlorite is generally associated with biotite and cordierite. Locally in the Albee Formation and more commonly in the Dixville Formation, chlorite is associated with biotite and andalusite in the higher grades of metamorphism.

<u>Chemical data</u>: Limited chemical data was obtained for chlorite from the various grades of metamorphism by means of the regression curves given by Albee (1962). Refractive indices for single chlorite grains were determined in standard oils using sodium light. The individual grains were mounted on a spindle stage. The ratio of $\frac{Fe^{+2}+Mn^{+2}+Cr^{+2}}{Fe^{+2}+Mn^{+2}+Cr^{+2}+Mg^{+2}}$ in chlorite, hereafter referred to as F/FM, ranges from about 58 to 65 atomic percent in the phyllite and slate; from about 46 to 53 atomic percent in chlorite-andalusite-biotite assemblages; and about 36-37 atomic percent in chlorite-cordierite-biotite assemblages. Thus chlorite becomes impoverished in iron with progressive contact metamorphism. Changes in the content of alumina were not determined.

Biotite

<u>Petrography and associations</u>: Biotite is the first new mineral to form in response to the changing environmental conditions in the contact aureole. In its early stages of development, biotite is most easily detected in arenaceous beds and adjacent to quartz stringers in the pelitic rocks. It can generally be detected in hand specimen by a slight coarsening of the pelitic material adjacent to quartz stringers. Biotite becomes more abundant and larger in size (up to about 0.5mm)

with increasing metamorphic grade. Biotite is associated with all the minerals found in the pelitic rocks except hematite.

Chemical composition: The first biotite to form in the Albee Formation is pleochroic with the following absorption: Z = olive-brown, X = Y = light tan or Z = brown, X = Y = straw yellow or tan. With progressive metamorphism the pleochroism becomes Z = dark brown, X = Y = light tan. The biotite in the Dixville Formation is generally more red-brown than that in the Albee Formation. Hayama (1959) has correlated the color of biotite with the content of TiO_2 and the ratio FeO/Fe_2O_3. Green interferenece colors are associated with lower values of TiO_2 and the ratio FeO/Fe_2O_3; red-brown interference colors are associated with higher values. Thus the biotite in the Dixville Formation apparently contains more TiO_2 or less Fe_2O_3 than that in the Albee Formation.

The ratio of MgO/MgO+FeO in biotite from the biotite, andalusite, and sillimanite zones of metamorphism is given in Table 13. The ratio was calculated from partial chemical analyses made on the electron probe at Harvard University by Dr. Cornelis Klein. Total iron is reported as FeO. As shown by hand specimen numbers 863, 858, and 1141 in Table 13, total iron in biotite increases with metamorphic grade. In

Table 13. $MgO/_{MgO+FeO}$ ratios of biotite from the biotite, andalusite and sillimanite zones of metamorphism

Formation	Specimen Number	Wt. % Oxide	$MgO/_{MgO+FeO}$ (moles)	Assemblage of major minerals
Albee	863	FeO* 24.9 MgO 12.1 1/	0.48	quartz, muscovite, Na-oligoclase, biotite; cordierite, chlorite, magnetite
Albee	858	FeO* 22.9 MgO 6.1	0.32	quartz, muscovite, oligoclase, biotite, andalusite, cordierite, magnetite
Albee	856	FeO* 20.8 MgO 7.8	0.39	quartz, "muscovite", oligoclase, "biotite", sillimanite, cordierite, magnetite, orthoclase
Dixville	1140	FeO* 25.3	0.29	quartz, (muscovite), oligoclase-andesine, "biotite", sillimanite, cordierite, orthoclase, pyrite, graphite (?)

* Total iron

1/ High value of MgO - analysis questionable the highest grade of metamorphism, number 856 in Table 13, the iron-rich component of biotite breaks down to form sillimanite, orthoclase, and magnetite. The biotite that remains in the rock contains less iron than most biotite in the andalusite zone (c.f. no. 856 and no. 858, Table 13).

Garnet

Petrography and association: Garnet is not a common mineral in the contact metamorphosed pelitic rocks, however, it is found in scattered areas in the biotite, andalusite, and sillimanite zones. In the biotite and andalusite zones, garnet is present in thin, discontinuous garnet-quartz coticules or as euhedral grains in calcareous, "pinstripe" granulite beds of the Albee Formation. The garnet-quartz coticules shown in Figure 26 stand in pronounced relief above the weathered surface. The garnet is very fine- to fine-grained, euhedral to subhedral. It is associated with quartz and minor amounts of biotite. The enclosing hornfels contains quartz, sodic oligoclase, muscovite, biotite and may contain andalusite, or cordierite, or both. Garnet in the calcareous granulite beds is associated with quartz, biotite, actinolite, oligoclase, and apatite.

In the sillimanite zone, garnet is found scattered

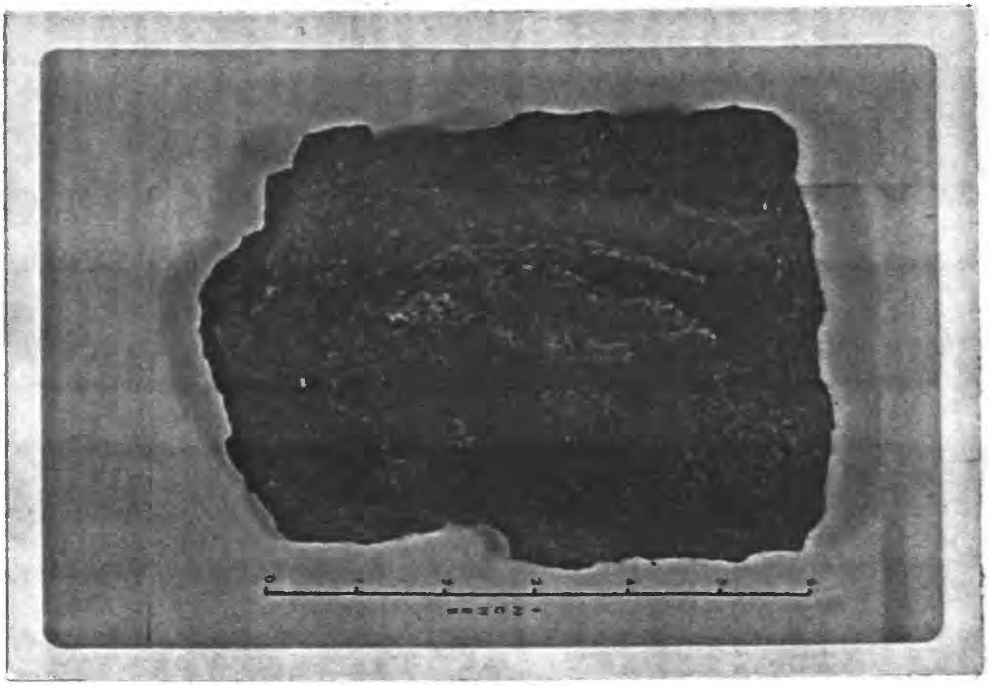


Figure 26: Garnet-quartz coticule in andalusite-bearing maculose hornfels. Garnet composition given in Table 13, no. 930.

in the pelitic rock as well as in garnet-quartz coticules and calcareous granulite beds. Garnet forms euhedral grains about 0.5 mm in size in the equigranular sillimanite-bearing hornfels. The most common associations with quartz and muscovite are andalusite-biotite-garnet, sillimanite-biotite-garnet and sillimanite-biotite-cordierite-garnet.

<u>Chemical composition</u>: The chemistry of the garnets is of interest for two reasons. First, garnet is found in all the contact metamorphic zones, which suggests that its chemical composition may vary greatly within the aureole. Second, as garnet can contain significant amounts of MnO, CaO, and Fe_2O_3 in addition to FeO and MgO, its chemical composition must be known to determine the chemical components required to graphically analyze the garnet-bearing rocks.

Partial chemical analyses of three garnet specimens were made on the electron probe at Harvard University by Mr. Jack Drake. The results are given in Table 14. Garnet in the garnet-quartz coticules is rich in manganese. Similarly, garnet in the assemblage sillimanite-biotite-cordierite-garnet (no. 1024-1, Table 14) contains sufficient manganese to permit the four phases to coexist over a wide range of temperatures and pressures. Garnet from sillimanite-bearing rocks without cordierite, however, appears to be predominantly pyrope-almandine.

Table 14. Partial chemical analyses of garnet specimens. Reported partial analysis

Field Number	#930	#1024-1	#1387
Oxide	Wt. %	Wt. %	Wt. %
MgO	1.7	1.9	3.9
MnO	15.4	15.7	1.4
FeO 1/	24.3	28.4	36.6
CaO	1.7	1.9	0.6
Al_2O_3	20.3	20.4	20.4
N (d)	1.809±0.003	1.812±0.003	1.810±0.003
a_o	11.56Å	11.58Å	11.53Å

1/ Total iron

Calculated formula

(based on X + Y = 5 where X = Mg, Fe^{+2}, Ca, Mn and Y = Al, Fe^{+3})

#930 $(Fe^{+2}_{1.59}Mn_{1.06}Mg_{0.20}Ca_{0.15})_{3.0}(Al_{1.93}Fe^{+3}_{0.06})_{1.99}[SiO_4]_3$

#1024-1 $(Fe^{+2}_{1.62}Mn_{1.01}Mg_{0.20}Ca_{0.16})_{3.0}(Al_{1.82}Fe^{+3}_{0.17})_{1.99}[SiO_4]_3$

#1387 $(Fe^{+2}_{2.38}Mn_{0.10}Mg_{0.47}Ca_{0.05})_{3.0}(Al_{1.93}Fe^{+3}_{0.07})_{2.0}[SiO_4]_3$

Assemblage

#930 quartz-garnet coticule with minor biotite and chlorite

#1024-1 quartz-muscovite-sillimanite-biotite-garnet-cordierite-oligoclase

#1387 quartz-muscovite-sillimanite-biotite-garnet-oligoclase-magnetite

Cordierite

Petrography and association: Cordierite is a common mineral in the contact aureoles surrounding the Cupsuptic and Lincoln Pond plutons. It is present in the biotite, andalusite, and sillimanite zones of metamorphism, but the cordierite is least altered in the andalusite- and sillimanite-bearing rocks. Cordierite can be detected readily in hand specimen by the presence of round, rusty-weathering pits of variable size on the weathered surface of the rock. Commonly black or bluish-black grains of cordierite are visible on the fresh surface of the rock.

In the biotite zone cordierite is generally restricted to the cores of the "spots", the periphery of which is composed of very fine-grained white mica and chlorite. The "spots" are a few tenths of a millimeter in diameter and lighter in color than the matrix of microscopic quartz, plagioclase, muscovite, chlorite and biotite. The cordierite "spots" contain numerous inclusions of extremely fine grained magnetite(?), zircon, muscovite, biotite, and chlorite. In the andalusite zone, porphyroblasts of cordierite commonly attain a maximum diameter of 1.0 mm and show sector twinning and less commonly polysynthetic twinning parallel to (110) under the microscope. These cordierite grains are notably less altered than those in the biotite zone but magnetite(?), zircon, ilmenite, muscovite, and quartz are present as minute inclusions in the porphyroblasts. In plane polarized light the zircon inclusions are surrounded by yellow pleochroic haloes that aid in distinguishing cordierite from quartz and untwinned plagioclase. In the sillimanite zone cordierite forms subhedral grains in an equigranular matrix of quartz, plagioclse, muscovite, and biotite. Opaque rounded "blebs" of magnetite(?), quartz and zircon occur as inclusions. This cordierite is commonly unaltered.

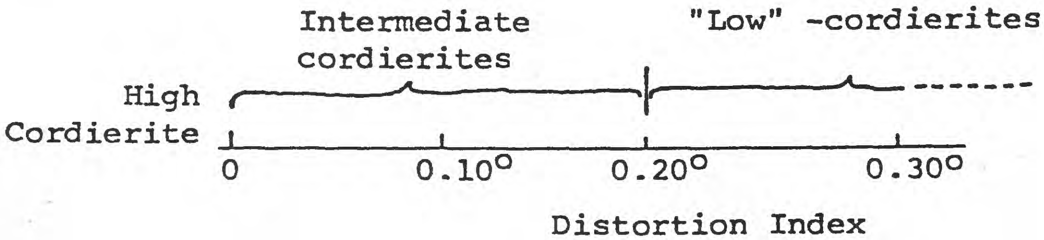
The rounded opaque "blebs", tentatively identified as magnetite(?) inclusions, could possibly be some other mineral of the spinel group exsolved from the cordierite. This would require that there be at least limited solid solution in cordierite along the line $MgAl_2O_4 - SiO_2$. Schreyer and Schairer (1961, p. 348), however, found no variation of this sort in the composition of cordierite in the system $MgO - Al_2O_3 - SiO_2$ at subsolidus temperatures from 1300°C to 800°C. This experimental evidence, coupled with the fact that identical opaque "blebs" are present in minor amounts in andalusite, quartz and plagioclase, suggests the mineral is an inclusion and not an exsolved phase.

<u>Polymorphism, summary of previous work</u>: Rankin and Merwin (1918) distinguished an unstable (μ - form) and a stable (α - form) modification of cordierite in the system MgO-Al_2O_3 - SiO_2 which had different optical properties. Yoder (1952) found that a ternary phase near the ideal 2MgO - $2Al_2O_3$ - $5SiO_2$ composition of cordierite synthesized below 830°C had lower refractive indices than that synthesized above 830°C. Karkhanavala and Hummel (1953) proposed that the two forms synthesized by Yoder were polymorphs related by a high-low inversion analogous to that shown by high and low sanidine. Miyashiro and others (1955) and Miyashiro (1957) proposed an elaborate classification for cordierite polymorphs representing all intermediate structural states between the disordered and ordered end members. Miyashiro (1957) classified the polymorphs on the basis of optical properties and his Δ - index, which is a measure of the separation of three X-ray diffraction peaks (CuKα radiation) in the vicinity of 29° to 30° 2θ, specifically:

$$\Delta = 2\theta_{131} - \frac{(2\theta_{511} + 2\theta_{421})}{2}$$

The high and low varieties of the various distortional polymorphs in Miyashiro's (1957) scheme were distinguished on optical properties. Subsequent work at the Geophysical Laboratory by Schreyer and Schairer (1961) and Schreyer and

Yoder (1964) has shown that the supposed high-low inversion reported by Karkhanovala and Hummel (1953) and Miyashiro (1957) based on optical properties was at least in part related to variable amounts of water in the cordierite structure and was thus non-polymorphic. Schreyer and Schairer (1961) found, however, that anhydrous cordierite of composition $2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$ did exist in different structural states which they distinguished on the basis of Miyashiro's Δ - index as follows:



Schreyer and Schairer (1961) discovered that high cordierite ($\Delta = 0$) was the first cordierite polymorph to crystallize from a melt of appropriate bulk composition. There is a stable transformation from high cordierite through intermediate cordierites to low cordierite at subsolidus temperatures in aluminous bulk compositions. In less aluminous bulk compositions they found that the first-formed high cordierite was metastable. Schreyer and Schairer found that the distortion index (Δ) of high cordierite became greater with a higher temperature and greater time of heating. They suggested that Al/Si ordering was a probable cause of the transformation and proposed that cordierite polymorphs might be used as "geologic timers" to indicate the crystallization history of cordierite-bearing rock.

The work of Meagher and Gibbs (1965) and Gibbs (unpublished manuscript) has shown that cordierite has a framework structure of Al-rich and Si-rich tetrahedra within which six-membered rings may be outlined. The basic framework has an $Al_4Si_5O_{18}$ composition. Gibbs (unpublished manuscript) has indicated that the high and low structural states of cordierite result from a disorder-order transformation related to the distribution of four Al- and five Si- atoms in the $Al_4Si_5O_{18}$ framework. Meagher and Gibbs (1965) report that cordierite from the Bokaro coal field in India ($\Delta = 0.0$) is only partly ordered and that cordierite from Haddam, Connecticut, ($\Delta = 0.12$) has a completely ordered framework structure. Meagher and Gibbs concluded that the distortion index (Δ) is not a reliable measure of the degree of order in cordierite. Variations in the chemical composition of natural cordierite affect the Δ - index.

John Moore (1960, unpublished Ph.D. Thesis, Mass. Inst. Technology) investigated the phase equilibria in a contact aureole in northwestern Maine. Moore reported that the distortion index (Δ) for cordierite from this sillimanite -

potassic feldspar zone averaged 0.27° (8 specimens), whereas that from the sillimanite zone averaged 0.24° (3 specimens). This represents the only previous work known to the writer on the progressive changes in the Δ - index of cordierite in contact metamorphosed rocks.

<u>Polymorphism, work in the Cupsuptic area</u>: The Δ- index as defined by Miyashiro (1957) was determined for 52 cordierite samples from the contact aureole surrounding the Cupsuptic quartz monzonite body. In each case the whole rock was ground to -80 +100 mesh or -100 +200 mesh size. The quartz, feldspar, and muscovite in the crushed rock were separated from cordierite, biotite, and opaque minerals by using a mixture of bromoform and acetone and standard heavy liquid techniques. Cordierite was further concentrated in the "sink fraction" of the heavy liquid separate by means of a Franz magnetic separator. In this manner, cordierite was concentrated sufficiently to give sharp peaks on the X-ray diffractometer chart. Scale factor, multiplier and time constant settings of 4, 1, 4 respectively were used with CuK_{α} radiation. A scanning speed of 1/4 degree per minute and a chart speed of one degree per minute were used. The Geiger tube detector was set in oscillating mode and the region between 28.5° 2θ and 30.5° 2θ was scanned an average of 6 times. The Δ - index

from the forward and backward scans was measured and an average value was taken.

The distribution of the Δ- index determinations in the contact aureole around the Cupsuptic quartz monzonite is shown in Figure 27. The distribution of the Δ- index determinations among the mappable metamorphic zones is as follows:

Number of Determinations	Metamorphic index mineral(s)	Δ- index range	Δ- index average
28	Sillimanite + muscovite ± K feldspar	0.238° - 0.293°	0.261°
20	Andalusite	0.217° - 0.254°	0.237°
4	Biotite ± chlorite	0.232° - 0.249°	0.238°

The above data shows a definite increase in the Δ- index of cordierite from the outer margin of the contact aureole toward the igneous body. There appears to be little difference between the Δ- index of cordierite from the rocks of the Albee Formation and those from corresponding metamorphic grades in the Dixie Brook member of the Dixville Formation. For example, in the sillimanite zone the average Δ- index of the cordierite in the Albee Formation is 0.259 (15 determinations) whereas the Δ- index is 0.262 (13 determinations) for the cordierite from the Dixie Brook member. The value of the

Figure 27: Distribution of Δ- index values of cordierite around the Cupsuptic quartz-monzonite stock (shaded)

Odd = Dixie Brook member of Dixville Formation.

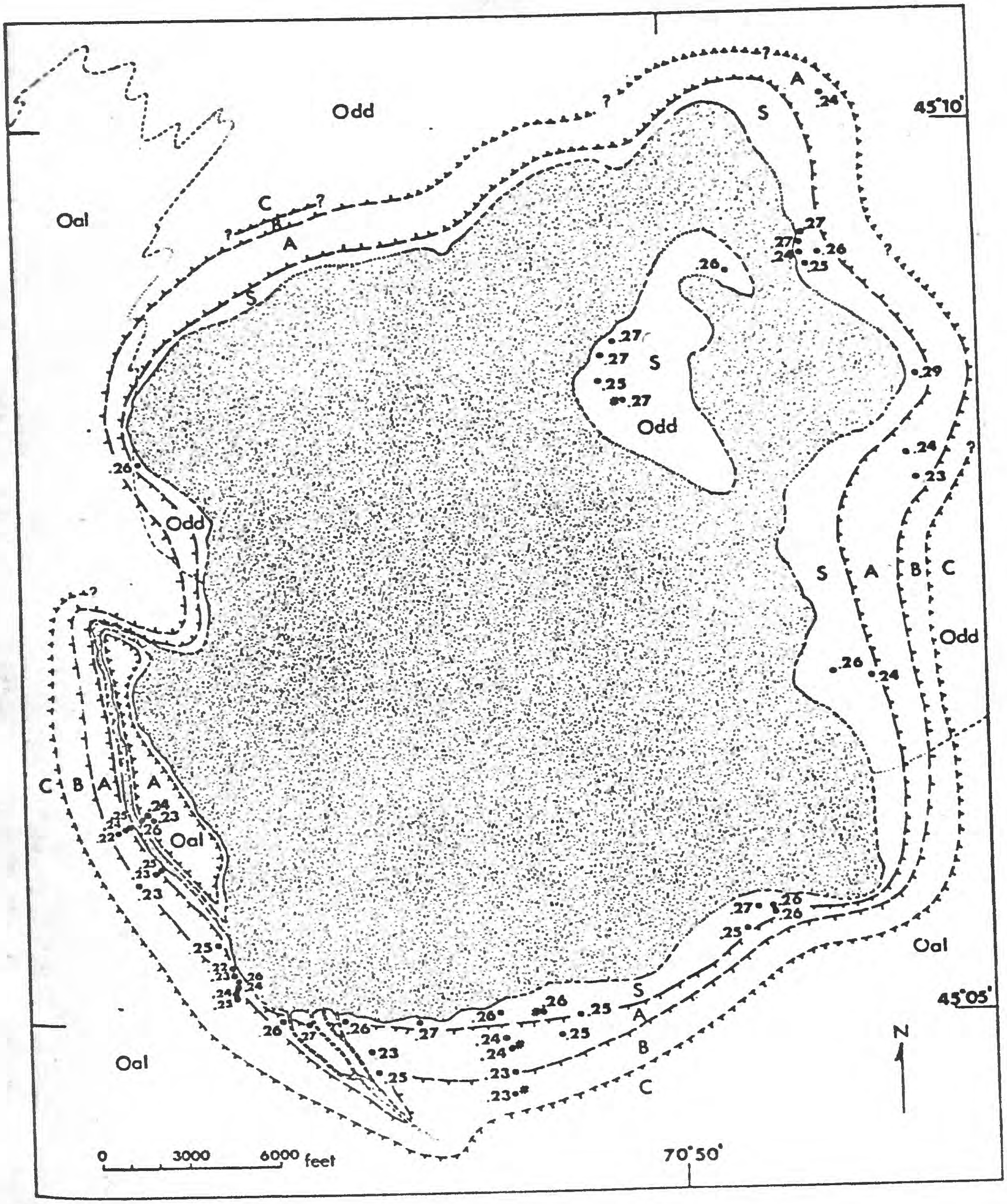
Oal = Albee Formation

S = sillimanite zone

A = andalusite zone

B = biotite zone

C = chlorite zone



Odd
Oal
45°10'
45°05'
70°50'
S
A
B
C
N
0 3000 6000 feet

Δ- index shows considerable variation within a relatively small area of a given metamorphic zone. Thus the problems presented by this work appear to be the explanation of a general increase in the Δ- index with increasing metamorphic grade and local variations in the Δ- index within a given metamorphic grade.

Four cordierite specimens were analyzed for FeO and MgO to determine if any relationship existed between the amount of these components, Δ- index, and metamorphic grade. The cordierite specimens contained variable amounts of inclusions so that a complete wet chemical analysis was impossible. The specimens were analyzed in thin section on the electron micro-probe at Harvard University by Dr. Cornelis Klein. The results are given in Table 15.

The variation in the ratio MgO/MgO+FeO indicates a general increase in FeO (total iron) with increasing grade of metamorphism; however specimen no. 856 is anomalous.

The progressive increase in FeO in cordierite with increasing grade of metamorphism was also detected by Moore (1960). This increase in FeO probably is the main cause for the general progressive increase in the Δ- index in cordierite with increasing metamorphism. Local variations in MgO/MgO+FeO ratio may account for local variations in the Δ- index. However, as pointed out by Folinsbee (1941), cordierite

Table 15. $MgO/_{MgO+FeO}$ ratios of cordierite from the biotite, andalusite, and sillimanite zones of metamorphism

Formation	Specimen Number	Wt. % Oxide	MgO/ MgO+FeO (moles)	Assemblage of major minerals
Albee	863	FeO* 7.8 MgO 7.4	0.63 $\Delta = 0.233^{\circ}$	quartz, muscovite, Na-oligoclase, <u>biotite</u>, <u>cordierite</u>, <u>chlorite</u>, magnetite
Albee	858	FeO* 9.3 MgO 6.3	0.54 $\Delta = 0.238^{\circ}$	quartz, muscovite, oligoclase, <u>biotite</u>, <u>andalusite</u>, <u>cordierite</u>, magnetite
Albee	856	FeO* 8.5 MgO 7.4	0.60 $\Delta = 0.264^{\circ}$	quartz, muscovite, oligoclase, <u>biotite</u>, <u>sillimanite</u>, <u>cordierite</u>, magnetite
Dixville	1141	FeO* 12.2 MgO 6.5	0.48 $\Delta = 0.274^{\circ}$	quartz, (muscovite), oligoclase-andesine, <u>biotite</u>, <u>sillimanite</u>, <u>cordierite</u>, <u>orthoclase</u>, pyrite, graphite (?)

* Total iron

$$\Delta = 2\theta_{131} - \frac{(2\theta_{511} + 2\theta_{421})}{2}$$

generally contains variable amounts of Li, K, Na, Cs, Rb, and indeed some of the local variation in the Δ- index may be due to the presence of variable amounts of these elements independent of temperature. Furthermore, it has been shown by Schreyer and Yoder (1959) that increasing amounts of water in cordierite increase the mean refractive index, but the effect of water on the Δ-index of cordierite is unknown. Variable water content in cordierite might have significant effect on the Δ- index. Also, it has been shown by Schreyer and Schairer (1960) that in rigidly controlled chemical systems the Δ- index is also a measure of cordierite polymorphism. Thus the Δ- index must be influenced by Al-, Si-distribution as well as chemical composition as pointed out by Meagher and Gibbs (1965).

In conclusion it can be stated that the major progressive change in the Δ- index of cordierite with progressive contact metamorphism is probably most closely related to a decreasing $^{MgO}/_{MgO+FeO}$ ratio in the phase. Local variations in the Δ- index may be due to local variations in either the Mg or Fe content, from different assemblages, variable amounts of minor elements including H_2O, or variations in the Al-, Si-distribution.

Andalusite - Sillimanite

Petrography and association: Andalusite is the more widespread of these Al_2SiO_5 polymorphs. Andalusite persists in the rocks of the sillimanite zone; but in such occurrences it is rimmed by quartz, quartz and sillimanite, sillimanite, or less commonly muscovite. Microscopically, the first andalusite to form in the rocks of the Albee Formation appears as subhedral to anhedral "network-like" grains surrounding quartz and plagioclase. With increasing metamorphic grade, andalusite forms euhedral laths up to 1 inch maximum length. Andalusite is always associated with biotite, quartz and muscovite. In the rocks of the Dixville Formation and locally in the rocks of the Albee Formation, the first appearance of andalusite is in association with chlorite and biotite. In most rocks of the Albee Formation, however, the first andalusite to form is associated with cordierite and biotite. The first appearance of andalusite is thus dependent in part on the bulk chemical composition of the rock.

Sillimanite is difficult to see in hand specimen. Its presence is indicated by irregular, bluish-white patches in an equigranular hornfels that contains relatively large muscovite grains. Microscopically, sillimanite appears as fibrous mats commonly replacing muscovite, biotite, or both. Less commonly sillimanite forms thin, fibrous rims around andalusite laths.

Feldspar

Potassic feldspar and plagioclase are present in the metamorphosed pelitic rocks of the Cupsuptic area. Plagioclase is the more common variety and ranges in composition from albite (An_{0-5}) in the phyllite and slate to oligoclase (An_{25-28}) in the sillimanite-bearing hornfels. The composition of the plagioclase was estimated by means of relief in thin section, by the Michel-Levy method of extinction angles of polysynthetic twins, and by the separation of the (131) and ($1\bar{3}1$) x-ray reflections described by Smith (1956). No major gap in composition between An_0 and An_{28} could be detected by these methods; therefore, it is inferred that plagioclase exhibits a continuous change in composition within these limits in the Cupsuptic area. The potassium content of the albite in the phyllite was estimated to be negligible by means of a regression curve given in Smith (1956), based on the separation of the ($\bar{2}01$) reflection of feldspar and the ($10\bar{1}0$) reflection of quartz.

Plagioclase is untwinned in the phyllite and biotite hornfels but its presence was easily detected by x-ray diffractometer studies. Plagioclase in the andalusite- and sillimanite-bearing rocks is commonly twinned and may show a diffuse zonal pattern from a sodic core to a relatively calcic rim.

Potassic feldspar was positively identified in some sillimanite-bearing hornfels by its strong x-ray reflection at about 27.5° 2θ. Microscopically the potassic feldspar is untwinned and optically monoclinic. Potassic feldspar was tentatively identified in one specimen of black phyllite in the Aziscohos member found at 1530' elevation in the south branch of Cold Brook. Identification was made by a weak x-ray reflection at about 27.5° 2θ; however, the most intense x-ray reflection for rutile also occurs in this position. No potassic feldspar or rutile could be positively identified in thin section. Rutile is visible in other sections, so it is tentatively assumed that the observed x-ray peak is that of potassic feldspar. No attempt was made to determine the compositions of the potassic feldspars because of the small amounts present in the rocks.

Magnetite and Hematite

Magnetite is the most common iron oxide in the Cupsuptic area. It is most abundant in the green phyllite of the Albee Formation where it is associated with chlorite, sericite, quartz, and albite. Magnetite octahedra, up to 0.5 mm in diameter commonly stud the weathered surface of the phyllite in the southern and southwestern part of the map area.

Hematite is the most abundant iron oxide in the purple slate and phyllite of the Kennebago member of the Albee Formation. It commonly occurs as minute, blood-red plates about 50 μ in size associated with quartz, sericite, chlorite, and albite. The plates are translucent and some show a crude hexagonal outline. Thin bands and patches of green slate in the purple slate contain magnetite and no hematite.

Locally in the outer margins of the contact aureoles around the Cupsuptic and Lincoln Pond stocks, the purple phyllite of the Kennebago member contains minute plates of hematite and very fine-grained magnetite octahedra. The magnetite octahedra are visible in hand specimen. With increased metamorphic grade, the hematite disappears from the rock and magnetite is the only iron oxide present. Magnetite and hematite coexist with quartz, albite, sericite, and chlorite.

Other Minerals

Staurolite: Staurolite was found in two thin sections of the Albee Formation from the 2217 foot summit of Big Buck Mountain immediately west of Lincoln Pond. This was the only staurolite found in the map area. Staurolite is present as widely scattered grains associated with quartz, muscovite, biotite, and chlorite in one specimen, and with quartz, muscovite, biotite, andalusite and chlorite in the other specimen.

Chloritoid: Chloritoid was found in one thin section collected from the Albee Formation at 1900 feet elevation on the north side of the 1920 foot knob due south of Big Buck Mountain. It was distinguished from chlorite by higher refractive index and from andalusite by light green pleochroism, polysynthetic twinning, and anomalous blue interference color. A positive identification of the chloritoid was made by means of an x-ray powder photograph on a separated sample.

The chloritoid is present only in the fine-grained white mica alteration rims surrounding large andalusite crystals as shown in Figure 28. The formation of the chloritoid is thus definitely retrograde after that of andalusite.

Tourmaline: Euhedral to subhedral grains of tourmaline of variable size are present in the rocks of the Albee Formation in all metamorphic zones. Pleochroic, doubly terminated crystals of tourmaline about 30 μ in length, are common in the slate and phyllite of the Albee. With increased metamorphic grade, the tourmaline increases in size to about 0.1 mm in length and becomes subhedral or anhedral in crystal habit.

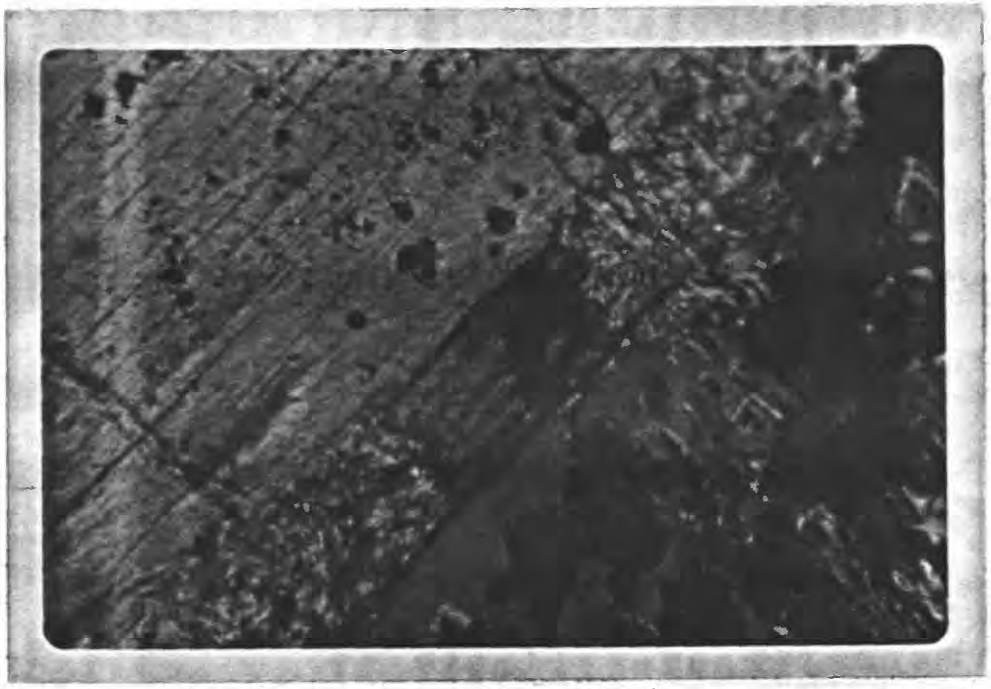


Figure 28: Chloritoid in white mica alteration rim around andalusite. Matrix in lower r.h. corner contains fine-grained quartz, feldspar, muscovite, biotite. Sillimanite and garnet are also present in the thin section.

It is a common accessory mineral in the higher grade rocks of the Dixie Brook member of the Dixville Formation and it is undoubtedly present in the lower grade black phyllite, but it cannot be seen microscopically.

Rutile, ilmenite: Rutile is an accessory mineral that is most commonly present in the lowest grade phyllites and slates of the Albee Formation. Ilmenite is present in the middle- and high-grade metamorphic rocks. Ilmenite most commonly occurs as skeletal crystals in biotite that has been altered to chlorite. Rutile forms as euhedral, doubly terminated or twinned crystals in the low grade slates and phyllites. Rutile needles are common in detrital quartz grains in the Magalloway member of the Dixville Formation.

Zircon: Zircon is ubiquitous in the pelitic rocks of the Cupsuptic area. It occurs as rounded grains about 50 μ in size. It forms dark pleochroic haloes in biotite, and yellow pleochroic haloes in cordierite. It is the only detrital "heavy mineral" positively identified as such in rocks of the quadrangle.

PETROLOGY

Mineral assemblages in the pelitic rocks

The analysis of the mutual relationships between minerals with progressive metamorphism depends on the determination of mineral assemblages for rocks of different bulk composition within the successive zones. To a certain extent the stable mineral assemblages in both the low grade phyllite and the sillimanite-bearing hornfels were difficult to determine. The phyllite is very fine-grained; thus optical methods did not always yield unequivocal mineral determinations. Phases present in minor amounts in the phyllites may not give definitive x-ray diffractometer peaks if the whole rock sample is studied. Diagnostic x-ray diffractograms of questionable phases were obtained by separating the heavy fraction from the light fraction of ground phyllite samples (-200+300 mesh) using heavy liquids in a centrifuge.

In the sillimanite hornfels the problem is of a different nature. Minerals or assemblages of minerals apparently not stable at conditions required for the formation of sillimanite generally persist in sillimanite-bearing rocks. The metamorphism was a thermal shock of relatively short duration, compared to regional metamorphism. Thus, assemblages characteristic of middle- and high-grade metamorphism are superimposed in the high-grade rocks. This offers evidence of the path followed during metamorphism if the complicated textures which result can be deciphered.

Table 16 lists the assemblages observed in the pelitic rocks in low grade phyllites and in the successive zones of the contact aueroles around the Cupsuptic and Lincoln Pond plutons. In general, a maximum of three phases were observed in mutual contact; however, any phase can be found in contact with any other phase listed in a given assemblage.

Graphical Analysis of Mineral Assemblages

To discuss the total chemistry of the rocks would require that at least SiO_2, Al_2O_3, FeO, MgO, MnO, Fe_2O_3, Na_2O, K_2O, CaO, TiO_2, ZrO_2, B_2O_3, P_2O_5, S, CO_2, H_2O be considered as chemical components. It would be impossible to show the mutual relationship of all the phases graphically, but this in fact is not necessary. Those phases that occur in abundance and serve as indicators of the contact metamorphic grade are composed predominantly of SiO_2, Al_2O_3, FeO, MgO, MnO, Fe_2O_3, Na_2O, K_2O, CaO, and H_2O. Certain components, namely ZrO_2, B_2O_3, P_2O_5, and S are found in measurable amounts in the minerals zircon, tourmaline, apatite, and pyrite. We may ignore these components in the graphical analysis if we ignore the minerals containing them. Even so, the pelitic rocks contain

Table 16. Assemblages of minerals in the pelitic rocks

<u>phyllite and slate</u>:

quartz-muscovite-albite-chlorite-magnetite-tourmaline-zircon
" " " chlorite-hematite-tourmaline-zircon
" " " chlorite-zoisite-hematite-magnetite-rutile-tourmaline-zircon
" " " potash feldspar-chlorite-magnetite-tourmaline-zircon
" " " chlorite-pyrite-carbonaceous material
" " " chlorite-calcite

<u>biotite zone</u>:

quartz-muscovite-albite-biotite-chlorite-magnetite-tourmaline-zircon
" " " biotite-chlotite-cordierite-magnetite-tourmaline-zircon
" " " biotite-chlorite-garnet-magnetite
" " " biotite-cordierite-magnetite-ilmenite
" " " biotite-chlorite-pyrite-carbonaceous material

<u>andalusite zone</u>:

quartz-muscovite-sodic plagioclase-biotite-cordierite-andalusite-magnetite-zircon-tourmaline
" " sodic plagioclase-biotite-cordierite-magnetite-ilmenite
" " sodic plagioclase-biotite-chlorite-andalusite-pyrite-carbonaceous material
" " sodic plagioclase-biotite-staurolite-andalusite-magnetite
" " sodic plagioclase-biotite-staurolite-magnetite

quartz-muscovite-biotite

andalusite zone: (Cont'd.)

quartz-muscovite-sodic plagioclase-biotite-garnet-andalusite-magnetite-tourmaline-zircon

" " sodic plagioclase-biotite-garnet-magnetite

" " " " cordierite-andalusite-pyrite-carbonaceous material

sillimanite zone:

quartz-muscovite-sodic oligoclase-(andalusite)-biotite-cordierite-sillimanite-magnetite-ilmenite-tourmaline-zircon

" " sodic oligoclase-biotite-garnet-magnetite-apatite-zircon

" " sodic oligoclase-(andalusite)-biotite-cordierite-garnet-sillimanite-magnetite-tourmaline-zircon

" " sodic oligoclase-biotite-garnet-sillimanite-magnetite-zircon

" " sodic oligoclase-cordierite-biotite-sillimanite-pyrrhotite(?)-graphite(?)

quartz-oligoclase-biotite-cordierite-sillimanite-orthoclase-magnetite-zircon-tourmaline-(muscovite)-(andalusite)

quartz-oligoclase-cordierite-sillimanite-orthoclase-magnetite-ilmenite-(muscovite)-(biotite)-(andalusite)-(chlorite) more essential components than can be shown graphically on one diagram; therefore, the analysis will be done by means of diagrams that show the mutual relationships between minerals in specific chemical subsystems. The methods and diagrams used have been discussed by Thompson (1957), Korzhinskii (1959), Zen (1960) and Guidotti (1963).

The Subsystem SiO_2 - Al_2O_3 - K_2O - Na_2O - CaO - H_2O

<u>Components</u>: Six components cannot be represented graphically. However, by following the methods outlined below and discussed fully by Thompson (1957) and Korzhinskii (1959), the number of components needed to represent the subsystem graphically can be reduced. If we consider only those assemblages in which quartz is present, then any reaction between phases that uses or produces SiO_2 will be reflected by a decrease or increase in the relative amount of quartz in the rock. As quartz is essentially pure SiO_2 and is considered here to be a saturating phase, SiO_2 need not appear as a component in the graphical analysis. Similarly, following Thompson (1957) and Korzhinskii (1959), the rocks will be considered as a system open to H_2O. Thus the tendency for a rock at a specific temperature and pressure to gain or lose H_2O depends on the activity of H_2O (aH_2O) in that rock with

respect to the activity of H_2O in the surrounding rocks. The activity of a mobile component in a rock is an externally controlled, intensive variable much like temperature and pressure and though all assemblages must be consistent with a particular activity of H_2O, that component need not appear in the graphical representation.

The mineral assemblages in Table 16 indicate that hydrous minerals such as muscovite and biotite break down to anhydrous phases such as sillimanite, orthoclase, and magnetite as the intrusive rock is approached. On cooling, the relatively anhydrous hornfels appears to have acted as a "sink" for H_2O. Microscopic textures support this hypothesis. Cordierite in the biotite zone is present only in the core of "spots", the outer margin of which is white mica and chlorite. Similarly, andalusite and cordierite are commonly altered in the same way, but to a lesser degree in the outer part of the andalusite zone. Retrograde alteration is not common in the equigranular sillimanite hornfels, suggesting that the permeability of the rocks may have been too low to permit retrograde alteration.

<u>Phases</u>: This subsystem includes the major components of quartz, muscovite, alkali feldspars, plagioclase feldspars, and the aluminum silicates. None of these phases have been analyzed

chemically, but approximate changes in their compositions have been determined by optical and x-ray methods.

Equilibrium: Phase equilibrium in this subsystem can be represented in terms of the components Al_2O_3 - K_2O - Na_2O CaO at the apices of a tetrahedron. All of the above mineral phases have a gram formula ratio of alumina to alkalis plus calcium equal to or greater than unit, so that the following end-member components, forming a tetrahedral volume within the Al_2O_3 - K_2O - Na_2O - CaO tetrahedron wiil be used in graphical analysis:

"A" = Al_2O_3, "K" = $KAlO_2$, "N" = $NaAlO_2$, "C" = $CaAl_2O_4$.

No assemblages more aluminous than muscovite-albite were found in the low-grade phyllite and slate although paragonite, pyrophyllite, and kaolinite are minerals that might be expected in such rocks. White mica was separated from 16 specimens of phyllite that were known to contain albite and muscovite but no detectable potassic feldspar. The white mica concentrate was scanned on the diffractometer at 1/4 degree per minute in the vicinity of 45° to 47° 2θ in search of the (0010) peak of paragonite. No paragonite was found, hence the bulk composition of the rocks examined was assumed to be too low in alumina for paragonite to form, and thus much too low in alumina to expect pyrophyllite or kaolinite.

Most changes in the phase relationships in this subsystem are of a continuous nature, though some discontinuities are present that result in the appearance of a new phase or in different compatibilities between phases. As noted in the section on mineralogy the muscovite, potassic feldspar, and albite in the phyllite have very nearly the end-member compositions. That part of the bulk composition of the rock that is made up by phases in this subsystem would lie close to the AKN face of the tetrahedron either in the two phase field muscovite-albite or slightly out of that field toward potassic feldspar. Compatible mineral assemblages in the phyllite are shown in Figure 29a. With increasing metamorphic grade the maximum Na^+ content of muscovite increases and andalusite appears in the rocks, shown in Figure 29b. Andalusite could have formed either from the dehydration of pyrophyllite or from a reaction between aluminous chlorite and muscovite discussed in the following subsystem.

Textural evidence indicates that sillimanite formed in some rocks by the inversion of andalusite representing the univariant reaction; (andalusite $\longrightarrow$ sillimanite). This discontinuous change results in the assemblage shown in Figure 29c. The mutual solubility of $KAlSi_3O_8$ in albite and $NaAlSi_3O_8$ in potassic feldspar presumably increases with

Figure 29: Compatibilities in the subsystem Al_2O_3-K_2O-Na_2O-CaO for quartz-bearing rocks, H_2O mobile. A = Al_2O_3, K = $KAlO_2$, N = $NaAlO_2$, C = $CaAl_2O_4$. (mol proportions)

Pyp? = pyrophyllite

Mus = muscovite

Par? = paragonite?

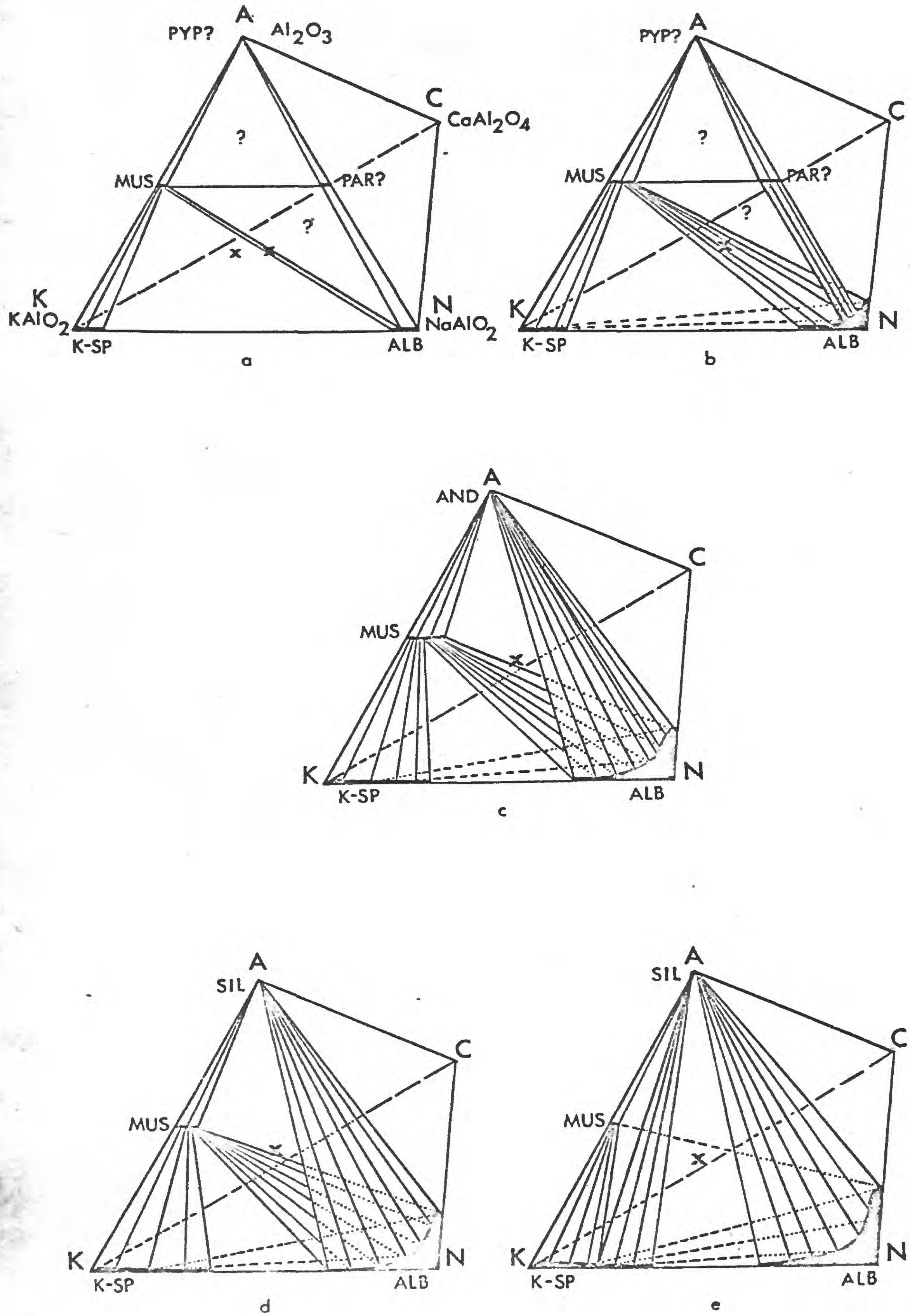
K-sp = potassic feldspar

Alb = albite

And = andalusite

Sil = sillimanite

X = observed assemblage


A
PYP?
Al_2O_3
C
$CaAl_2O_4$
?
MUS
PAR?
?
x
K
$KAlO_2$
K-SP
N
$NaAlO_2$
ALB
a
PYP?
A
C
?
MUS
PAR?
?
K
K-SP
ALB
N
b
A
AND
C
MUS
x
K
K-SP
ALB
N
c
A
SIL
C
MUS
K
K-SP
ALB
N
d
A
SIL
C
MUS
x
K
K-SP
ALB
N
e

increasing metamorphic grade. In contrast, the sodium content of muscovite coexisting with quartz, aluminum silicate and plagioclase is appreciably less in the sillimanite zone than in the andalusite zone as shown in Figure 25. In the highest grade of metamorphism muscovite is not compatible with sodic plagioclase, and the muscovite-albite pair is replaced by the pair sillimanite-potassic feldspar as shown in Figure 29. Sillimanite- potassic feldspar-plagioclase (An_{10-20}) is the common assemblage found in the innermost aureole in the Cupsuptic area.

The subsystem SiO_2-Al_2O_3-K_2O-FeO-MgO-H_2O

To facilitate graphical representation in this subsystem, only quartz-bearing rocks will be considered and H_2O will be treated as above. Following Thompson (1957), the components Al_2O_3 - K_2O - FeO - MgO are taken as the apices of a tetrahedron and designated A-K-F-M respectively. Those phases associated with muscovite that lie within the AKFM tetrahedron are projected from muscovite to a plane coincident with the AFM face.

Thompson (1957) has discussed the effects of neglecting components such as Na_2O, MnO, CaO, TiO_2 and Fe_2O_3 in phases represented on the AKFM projection. In the Cupsuptic area, garnet in some rocks from the biotite zone and the outer part of the andalusite zone contains sufficient amounts of MnO, CaO, and Fe_2O_3 to enable assemblages such as quartz-muscovite-andalusite-cordierite-biotite-garnet to coexist. These phases, if wholly within the subsystem, constitute a univariant assemblage but would not if there were a large amount of MnO in the garnet (see Table 13, no. 930 and no. 1024-1). Garnet in the sillimanite-bearing rocks, and possibly in some andalusite-bearing rocks that do not contain cordierite, is essentially an almandite-pyrope solid solution and thus appropriate to this subsystem.

Iron-magnesium distribution in coexisting minerals: Before discussing the mutual relationships between all the phases in this subsystem, it is pertinent to examine the chemical changes in chlorite and coexisting cordierite-biotite pairs with increasing metamorphic grade. As shown in Figure 30, the ratio MgO/MgO+FeO (M/MF) in cordierite and biotite co-existing with andalusite or sillimanite decreases with progressive metamorphism. In all grades of metamorphism, biotite has a lower ratio M/MF than the coexisting cordierite, and chlorite has a higher ratio M/MF than either the cordierite or biotite with which it coexists. These data, though incomplete and preliminary, have been used in the following

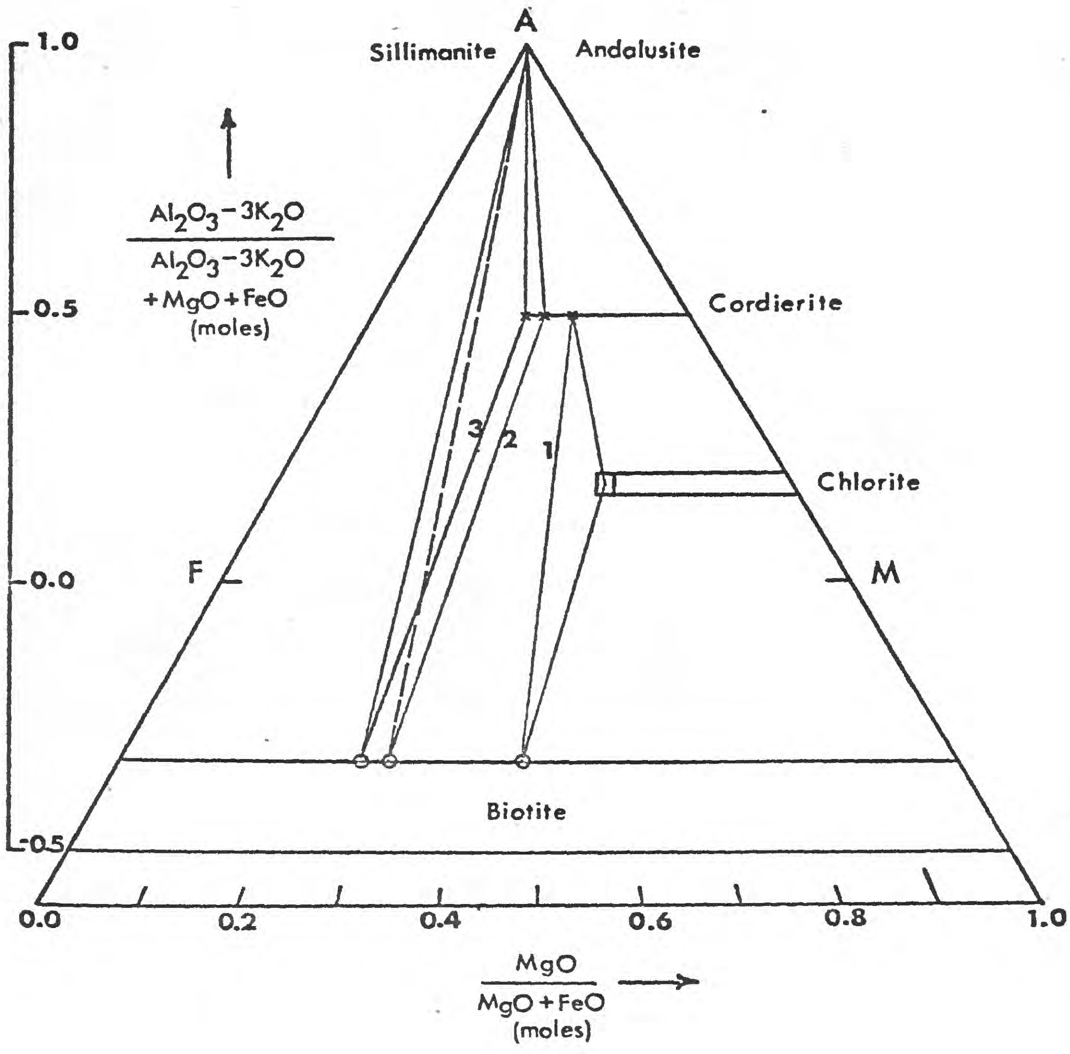


Figure 30: Iron-magnesium distribution between coexisting cordierite-biotite pairs, with chlorite (1); with andalusite (2); and with sillimanite (3).

section to determine the topology of some of the diagrams representing the progressive changes in the ferromagnesian minerals.

Graphical analysis: The phyllite and slate in the chlorite zone have a remarkably simple mineralogy. Chlorite, and less commonly chlorite plus potassic feldspar, are associated with quartz, muscovite, and albite to form the bulk of the rocks. Pyrophyllite, though not detected in the Cupsuptic area, is a mineral that might be expected in low-grade rocks of appropriate bulk composition. The assemblages observed in the phyllite and slate are shown in Figure 31(a).

In the outer margins of the contact aureoles, the pair biotite-chlorite is found instead of the pair chlorite-potassic feldspar. The first appearance of biotite in a given rock probably represents a shift of the projected three phase field, chlorite-potassic feldspar-biotite, across the projected bulk composition in response to changes in the externally controlled variables P, T, and aH_2O. The reaction would be of the type:

$$\text{chlorite} + \text{potassic feldspar} \longrightarrow \text{biotite} + \text{muscovite} + \text{quartz} + H_2O$$

$$3(FM)_7Al_4Si_4O_{15}(OH)_{12} + 13KAlSi_3O_8 \longrightarrow 7K(FM)_3(AlSi_3O_{10})(OH)_2 + 6KAl_2(AlSi_3O_{10})(OH)_2 + 12SiO_2 + 23H_2O$$

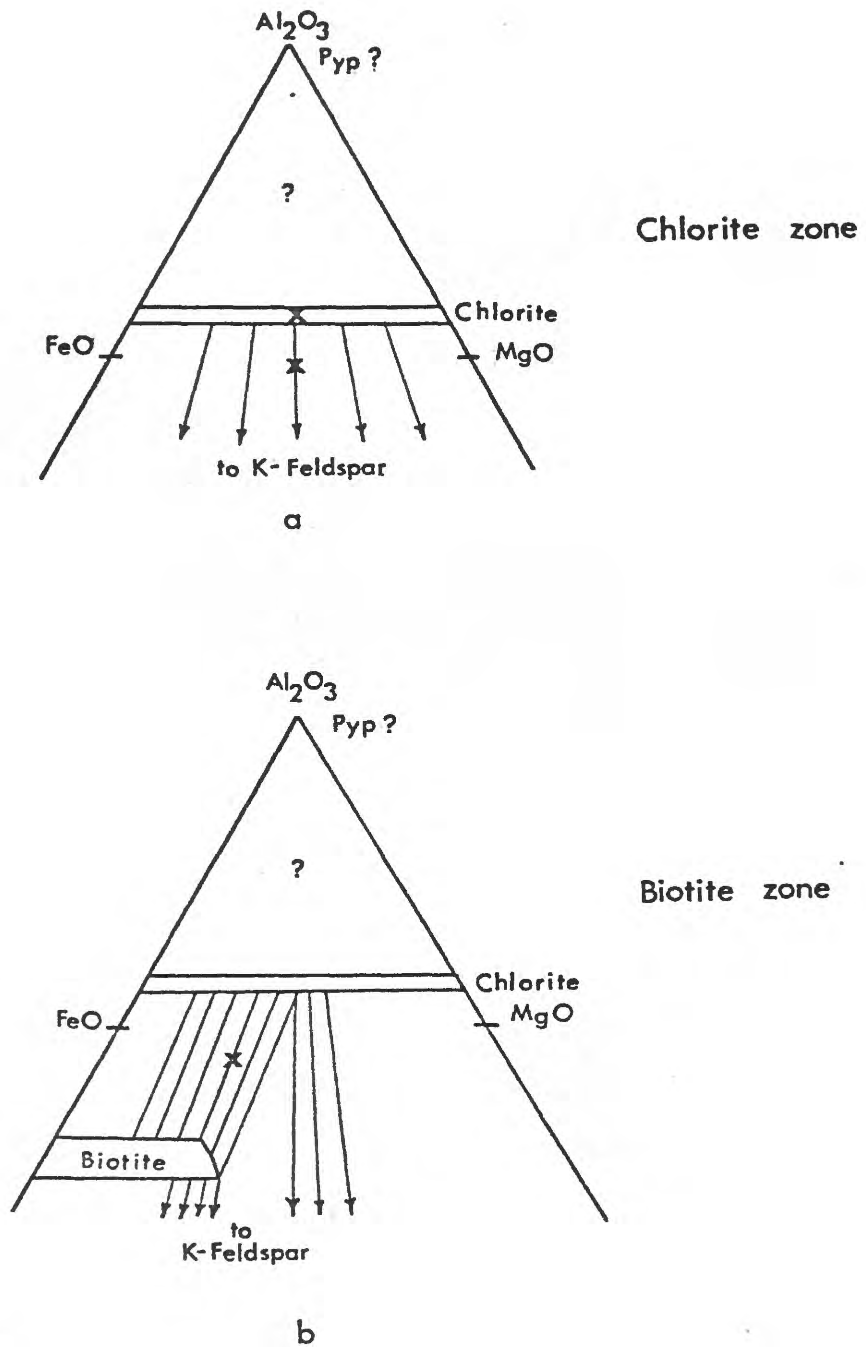


Figure 31: Mineral assemblages with quartz and muscovite in the AFM projection from the chlorite and biotite zones.

where the calanced equation would apply specifically to the idealized mineral compositions shown. Biotite first appears adjacent to quartz stringers in the pelitic rocks or in quartz-feldspar granulite beds, consistent with the above reaction producing free quartz. The assemblage, chlorite-potassic feldspar-biotite, was not observed in the Cupsuptic area, but it may be found with additional sampling. Biotite-chlorite-muscovite is the common assemblage in the biotite zone as shown in Figure 31(b).

The first appearance of andalusite, like that of biotite, is dependent on the bulk composition of the rocks as well as changes in the externally controlled variables P, T, and aH_2O. The rocks involved in the contact metamorphism apparently have a limited range of bulk compositions; therefore, the path or paths followed from the biotite zone to the andalusite zone are not completely known. The assemblages staurolite-chlorite-biotite and staurolite-andalusite-biotite, however, suggest that the first appearance of andalusite in some rocks, at least, results from a reaction of the type:

$$\text{staurolite + chlorite + muscovite} \longrightarrow \text{andalusite + biotite} + H_2O$$

This reaction produces a discontinuous change in the topology of the AFM projection shown by diagrams (a) and (b) of Figure 32. Garnet, though not observed in the staurolite-bearing rocks, is tentatively included in Figure 32(a) because Green (1963) reported its appearance prior to that of staurolite in similar rocks immediately southwest of the map area.

In the Dixville Formation andalusite first appears associated with chlorite and biotite. As staurolite was not observed in these rocks it is believed that andalusite appears first in the Dixville Formation by a reaction of the type:

$$\text{chlorite} + \text{muscovite} + \text{quartz} \longrightarrow \text{andalusite} + \text{biotite} + H_2O$$

$$3(FM)_7Al_4Si_4O_{15}(OH)_{12} + 7KAl_2(AlSi_3O_{10})(OH)_2 + SiO_2 \longrightarrow$$

$$13Al_2SiO_5 + 7K(FM)_3(AlSi_3O_{10})(OH)_2 + 18H_2O$$

where the balanced equation holds for the idealized mineral compositions. Graphically, andalusite appears in this manner if the compositions of biotite and chlorite coexisting with andalusite change continuously with changing environmental conditions, such that the projected three phase field moves across the projected bulk composition of the Dixville Formation. The configuration is that shown in Figure 33(b).

Cordierite is commonly found in the andalusite-bearing rocks associated with andalusite and biotite, chlorite and biotite, or andalusite-chlorite-biotite. It is impossible to determine a unique configuration for the first appearance of cordierite from these assemblages and the limited data on the iron-magnesium distribution in coexisting chlorite and cordierite presented on Figure 30. It can determined, however, that the configuration representing the first appearance of cordierite must follow that showing the assemblage andalusite-chlorite-biotite (Figure 32b) and that the appearance of cordierite results in a discontinuous change in the topology of the AFM projection. If the first cordierite to appear is more siderophile than the coexisting chlorite, as suggested by Figure 30, then cordierite would form by a terminal reaction of the type:

andalusite + chlorite + biotite + quartz ⟶ cordierite + muscovite + H_2O

A reaction of this type would correspond to the path shown between Figure 32(b), (c) and (e). If the first cordierite to appear is more magnesian than the coexisting chlorite, then it would appear in the rocks by a reaction of the type:

andalusite + chlorite + muscovite + quartz ⟶ cordierite + biotite + H_2O

The configuration representing the above reaction is that shown in Figure 32(d).

Staurolite was not observed in sillimanite-bearing rocks. Instead, almandine-rich garnet associated with sillimanite and biotite is found in rocks of appropriate bulk composition. Staurolite, in fact, may disappear in the inner part of the andalusite zone, but this cannot be unequivocally determined due to its limited occurrence. The assemblages andalusite-staurolite-biotite and sillimanite-garnet-biotite suggest that staurolite disappears by a terminal reaction of the type:

$$\text{staurolite} + \text{muscovite} + \text{quartz} \longrightarrow \text{alumino-silicate} + \text{garnet} + \text{biotite} + H_2O \; .$$

If staurolite disappears in the andalusite zone, the path followed would be that between figure 32(e) and (f); but if the terminal reaction for staurolite produced sillimanite, the path would be that shown between Figure 32(g) and (h).

Reactions analogous to those mentioned above producing andalusite may also account for some of the sillimanite, but textural evidence indicates that the bulk of it forms from the direct inversion of andalusite. This corresponds to the paths shown between Figure 32(f) and (h), or Figure 32(e) and (g).

Iron and Titanium Oxides

In considering the equilibrium relationships in the AKFM tetrahedron, FeO and Fe_2O_3 were treated as separate inert components. Furthermore, Fe_2O_3 was essentially ignored in the graphical representation except in its effect to stabilize a phase, such as garnet, in certain otherwise anomalous assemblages. This treatment implied that oxygen

Figure 32: Assemblages with quartz and muscovite (H_2O mobile) in the AFM projection showing possible paths followed in the andalusite and sillimanite zones of metamorphism. Solid arrows = preferred sequence; broken arrows = alternative configurations.

X = observed assemblages

A = Al_2O_3; F = FeO; M = MgO

AND = andalusite

ALM = almandine garnet

BIO = biotite

CHL = chlorite

CRD = cordierite

SIL = sillimanite

STR = staurolite

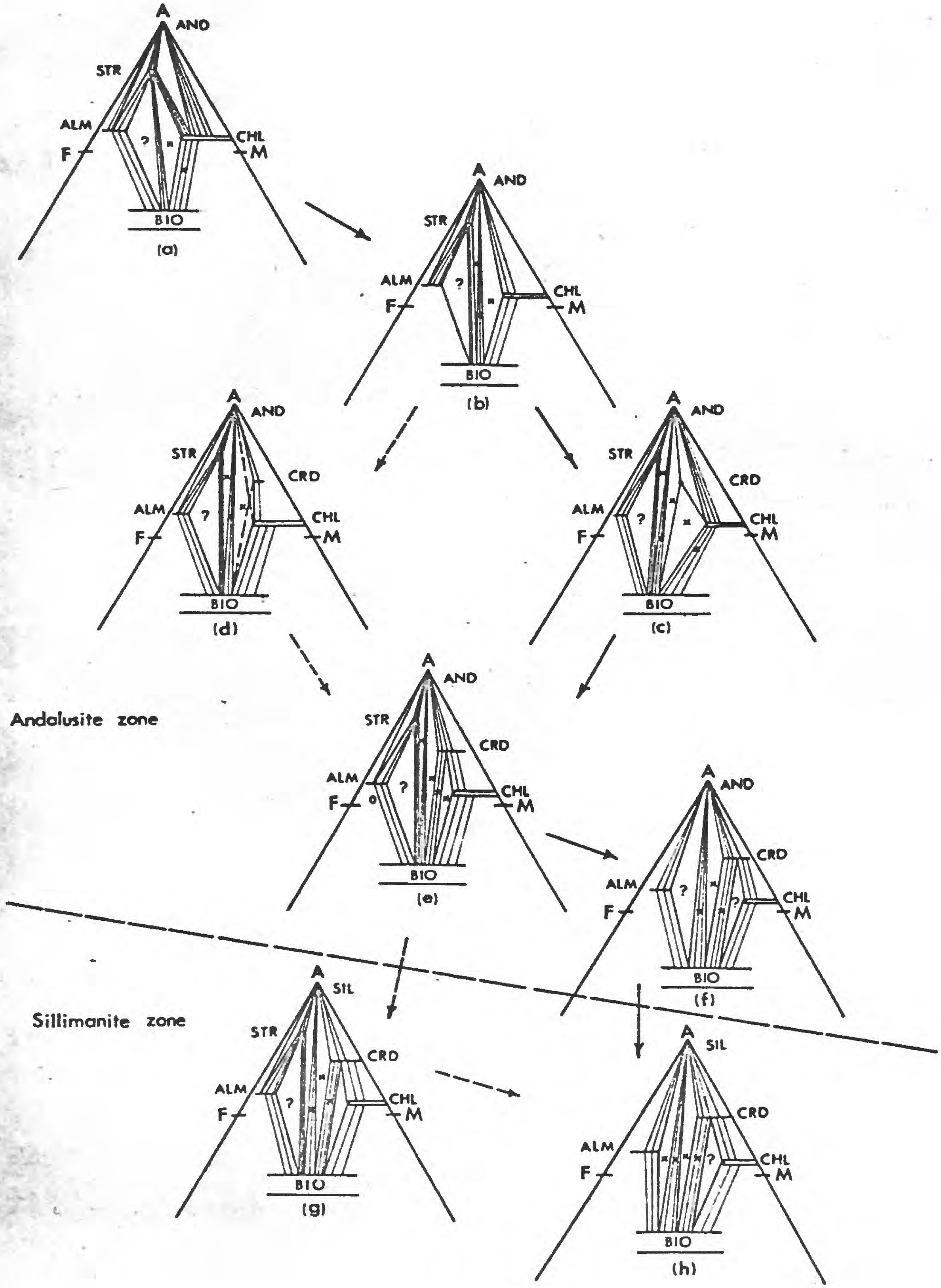

A
AND
STR
ALM
CHL
F
M
?
BIO
(a)
(b)
CRD
(c)
(d)
Andalusite zone
(e)
(f)
Sillimanite zone
SIL
(g)
(h)

FIGURE 32

was not a mobile component. If oxygen were considered a mobile component, then Fe_2O_3, being colinear with FeO and oxygen, would be treated graphically as FeO; and as discussed by Thompson (1957, p. 588), magnetite and hematite would plot at the "F" corner of the AKFM tetrahedron.

There is evidence in the Cupsuptic area to indicate that oxygen was not a mobile component in the low grade rocks. The green phyllite of the Albee Formation contains magnetite as the only iron oxide phase. Purple phyllite of the same formation contains hematite, or hematite and magnetite. Localities in which hematite and magnetite coexist are known in areas of predominantly magnetite-bearing green phyllite, all of which are well removed from known intrusive bodies. The sporadic occurrence of magnetite with hematite is inconsistent with an externally controlled activity of oxygen. James and Howland (1955) have reported the assemblage hematite-magnetite from high-grade metamorphic rocks. This agrees with the evidence in the Cupsuptic quadrangle and supports the graphical treatment used in the AKFM tetrahedron.

<u>Assemblages with hematite and magnetite</u>: The following assemblages with quartz, muscovite, chlorite, and albite have been observed in the low-grade phyllite of the Albee Formation:

magnetite

hematite

magnetite-hematite-rutile

With progressive contact metamorphism the pertinent assemblages are:

magnetite-hematite-ilmenite	(chlorite zone)
magnetite	(biotite,
magnetite-ilmenite	andalusite, and sillimanite zones)

One specimen of spotted purplish-gray, chlorite-bearing phyllite was found that contained the assemblage magnetite-hematite-ilmenite. Hematite was present as ragged hexagonal plates, or as intergrowths of hematite and ilmenite with coplanar (0001) surfaces, or as ragged cores surrounded by rims of ilmenite. The ilmenite and hematite occur as translucent plates about 50 μ or less in size. Magnetite forms subhedral grains. The important change in the compatibilities between these phases within the chlorite zone is shown by Figure 33 and apparently represents a reaction of the type:

$$\text{magnetite} + \text{rutile} \longrightarrow \text{ilmenite} + \text{hematite}$$

From the above reaction it would appear that hematite should be a common phase in the higher grade rocks. Magnetite, however, was the only iron oxide phase observed in the biotite,

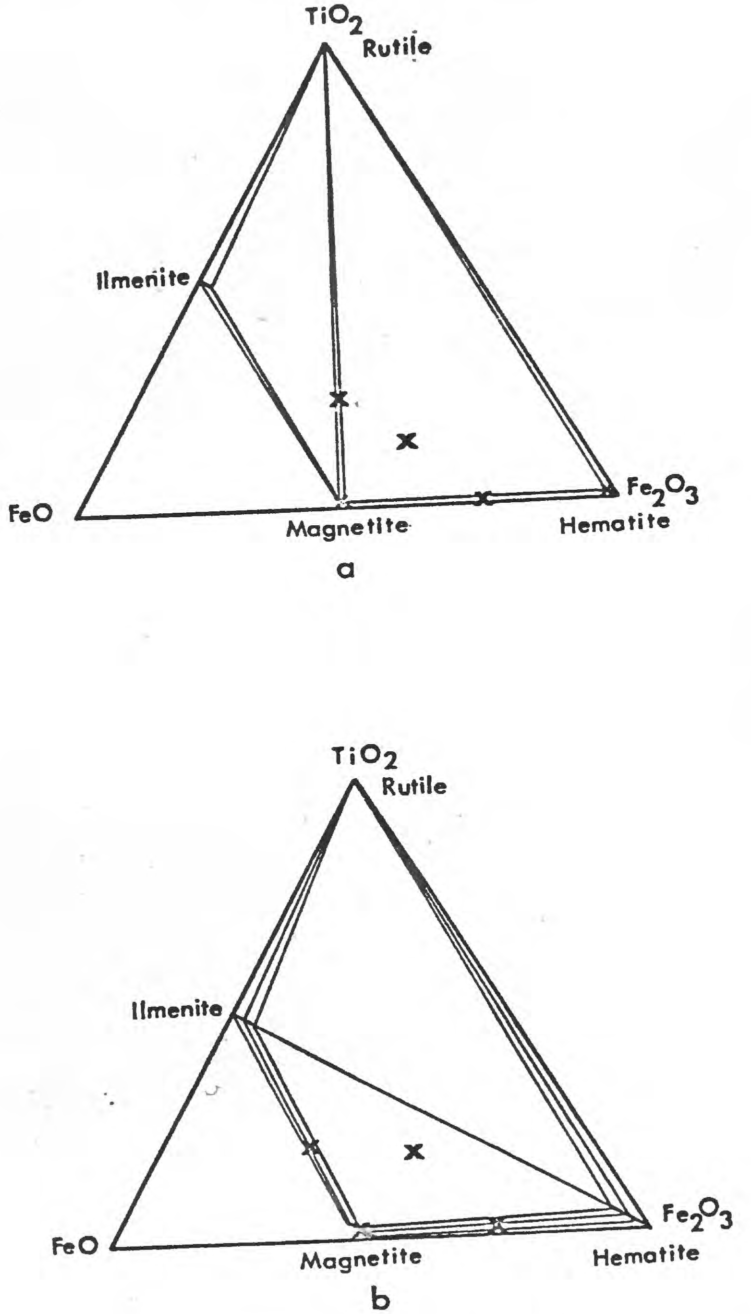


Figure 33: Mineral compatibilities in the system TiO_2-FeO-Fe_2O_3 for low chlorite zone (a) and high chlorite, biotite, andalusite and sillimanite zones (b).

andalusite, and sillimanite zones. There are two possible explanations for this: one requires an oxygen loss or reduction of hematite to magnetite; the second requires an effective iron gain in the hematite through successive reactions with the ferrous end members of various ferromagnesian silicates. As there is evidence to suggest that oxygen was not a mobile component, the second alternative, suggested by Thompson (1964, lecture notes) is preferred. With increasing metamorphic grade, hematite may be removed from the rocks by a series of reactions of the type:

chlorite zone:

hematite + Fe-chlorite + potassic feldspar $\longrightarrow$

magnetite + muscovite + quartz + H_2O

$$7Fe_2O_3 + 7Fe_7Al_4Si_4O_{15}(OH)_2 + 14KAlSi_3O_8 \longrightarrow Fe_3O_4 + 14KAl_2(AlSi_2O_{10})(OH)_2 + 28SiO_2 + 28H_2O$$

biotite zone:

hematite + Fe-chlorite + Fe-biotite $\longrightarrow$ magnetite +

muscovite + quartz + H_2O

$$10Fe_2O_3 + Fe_7Al_4Si_4O_{15}(OH)_2 + K(Fe)_3(AlSi_3O_{10})(OH)_2 \longrightarrow 10Fe_3O_4 + 2KAl_2(AlSi_3O_{10})(OH)_2 + 14SiO_2 + 6H_2O$$

andalusite zone:

hematite + Fe-chlorite $\longrightarrow$ magnetite + andalusite

+ quartz + H_2O

$$7Fe_2O_3 + Fe_7Al_4Si_4O_{15}(OH)_{12} \longrightarrow 7Fe_3O_4 + 2Al_2SiO_5 + 2SiO_2 + 6H_2O$$

The balanced equations apply only to the idealized compositions. Magnetite becomes associated with a wider variety of minerals as the projected three phase fields shift across projected bulk compositions and new phases appear by discontinuous changes in the topology of the AFM projection as shown in Figure 32. Hematite, if present in the higher grade rocks, must be associated with bulk compositions that are more magnesian than those observed.

CONDITIONS OF METAMORPHISM

Specific temperatures and pressures cannot be ascribed to the reactions proposed for the mineralogical changes, even though experimental work has been done on closely related systems. The uncertainty arises because experimental work has been conducted in relatively "clean" chemical systems generally restricted to either the magnesium or iron end-members of the iron-magnesium solid solutions. In addition, minor amounts of extraneous components are the exception in experimental systems, whereas they are the rule in natural assemblages. Whether the experimentally determined curves would shift to lower or higher temperatures by the addition of extraneous components would depend on whether the components preferentially entered the products or reactants respectively. Most changes observed in the Cupsuptic area involve dehydrating reactions that are strongly dependent on an unknown value of the activity of water. Most experiments, however, are conducted with an aqueous phase present corresponding to an activity of water near unity; hence naturally occurring reactions must coincide with or lie on the low temperature side of the experimental curves.

The experimental curves of univariant equilibrium separating the stability fields of the aluminum silicates can be applied directly to field observations. Unfortunately, the position of the triple point and the slope of the univariant curves is still in question. Recently Newton (1966) determined the triple point at 4.1 ± 0.4 kb and 470°C which is significantly different than the values of 8.0 ± 5 kb and 300° ± 50°C determined by Bell (1963). The position of the triple point would set a maximum pressure limit for the metamorphism in the Cupsuptic area. If Newton's work is correct the maximum pressure limit is about 4.1 kb, but if Bell's work is correct the maximum limit is about 8.0 kb.

As shown on Figure 34 the experimental curve for the breakdown of muscovite + quartz to potassic feldspar + sillimanite + vapor (Eugster and Yoder, 1955) intersects the sillimanite-andalusite curve at about 2.3 kb and about 670°C. This curve represents the maximum stability of muscovite and must lie at temperatures higher than ~~an~~ are realized in the contact aureoles of the Cupsuptic area. A maximum temperature limit of about 650°C and a minimum pressure limit of about 2.3 kb is suggested by the intersection of these curves. This is not unreasonable in view of the fact that the intrusive rock is essentially a subsolvus "granite" in the terms of Bowen and Tuttle (1958) that contains muscovite, microcline perthite, and plagioclase. The lower temperature limit is more difficult to determine at present, but chemical analyses of coexisting phases in the system Fe-Ti-O may provide better information in the future. If we consider the solid solution of in magnetite and hematite in ilmenite to be slight, then an extrapolation of Lindsley's work (1963, p. 64) suggests a minimum temperature limit of 350° to 400°C for the biotite zone.

In summary, then, a pressure greater than about 2.3kb but less than about 8.0 kb and possibly less than about 4.0kb can be inferred for the metamorphism. A temperature range

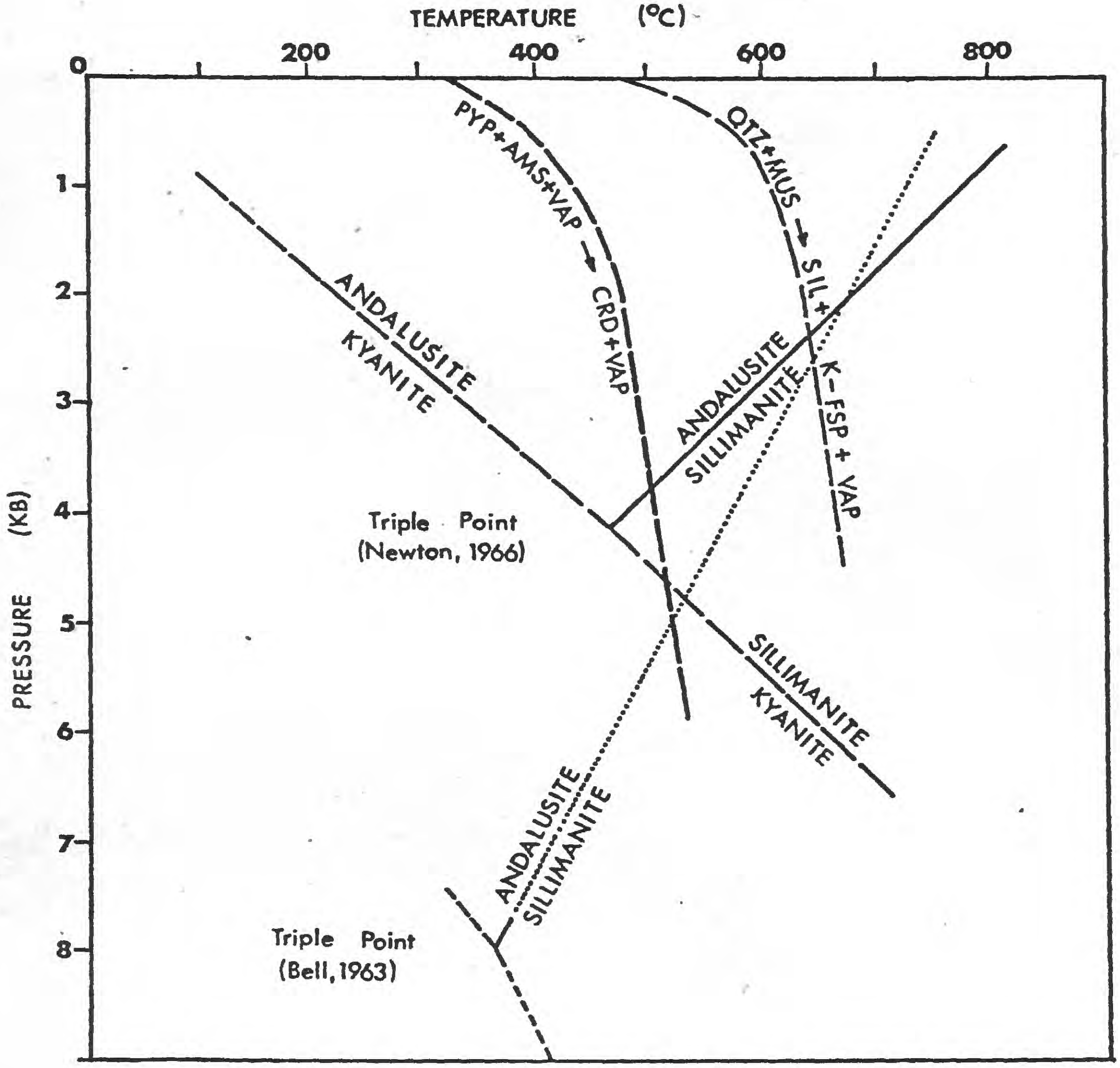


Figure 34: Experimentally determined stability fields for minerals pertinent to the metamorphism in the Cupsuptic quadrangle

AMS = amesite
CRO = cordierite
K-FSP = potassic feldspar
MUS = muscovite
QTZ = quartz
PYP = pyrophyllite
SIL = sillimanite
VAP = vapor

from about 350°-400°C to about 650°C appears to be consistent with the assemblages observed in the Cupsuptic quadrangle.

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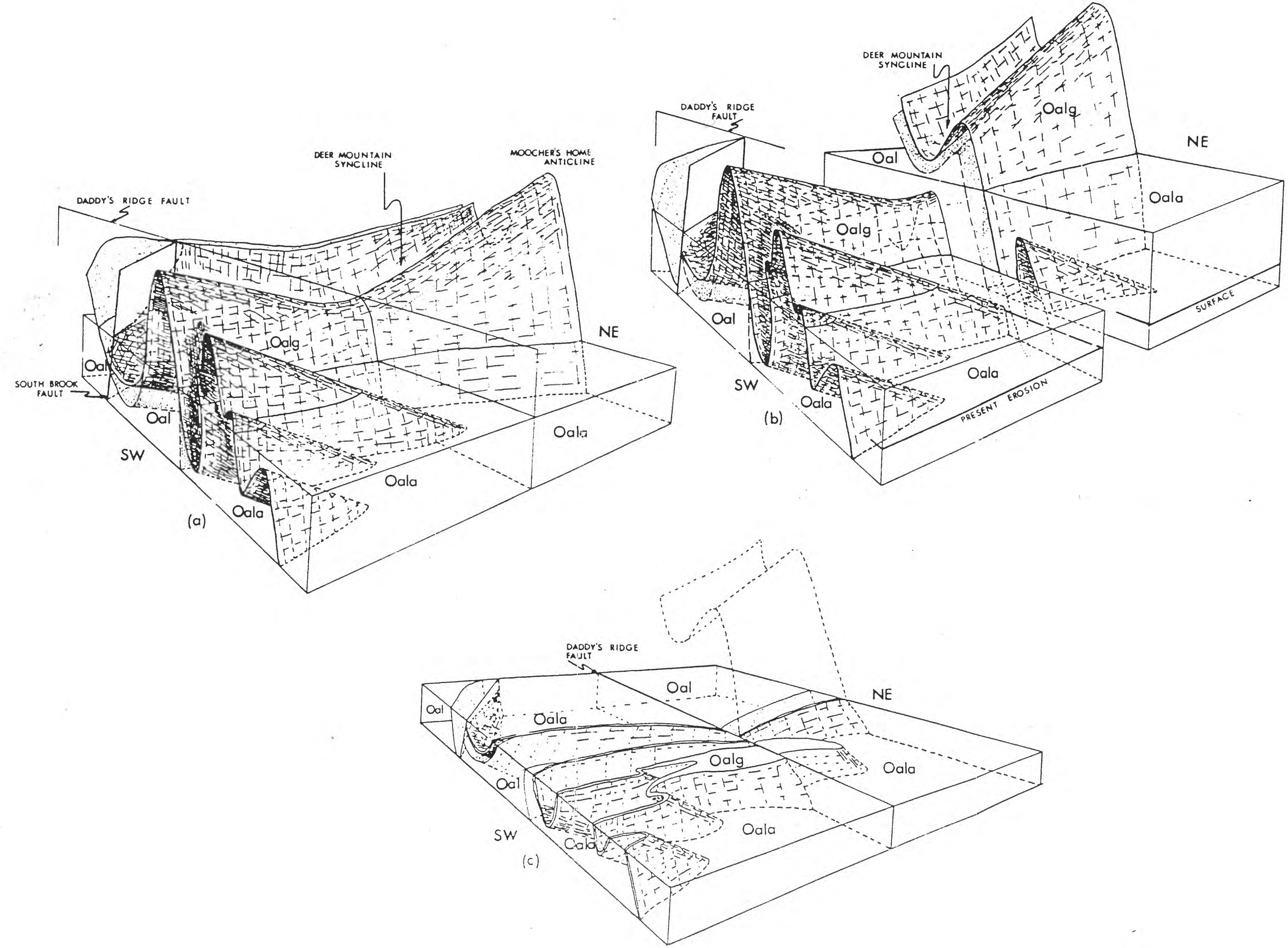
DADDY'S RIDGE FAULT
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DADDY'S RIDGE FAULT
DEER MOUNTAIN SYNCLINE
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SURFACE
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(b)
PRESENT EROSION
DADDY'S RIDGE FAULT
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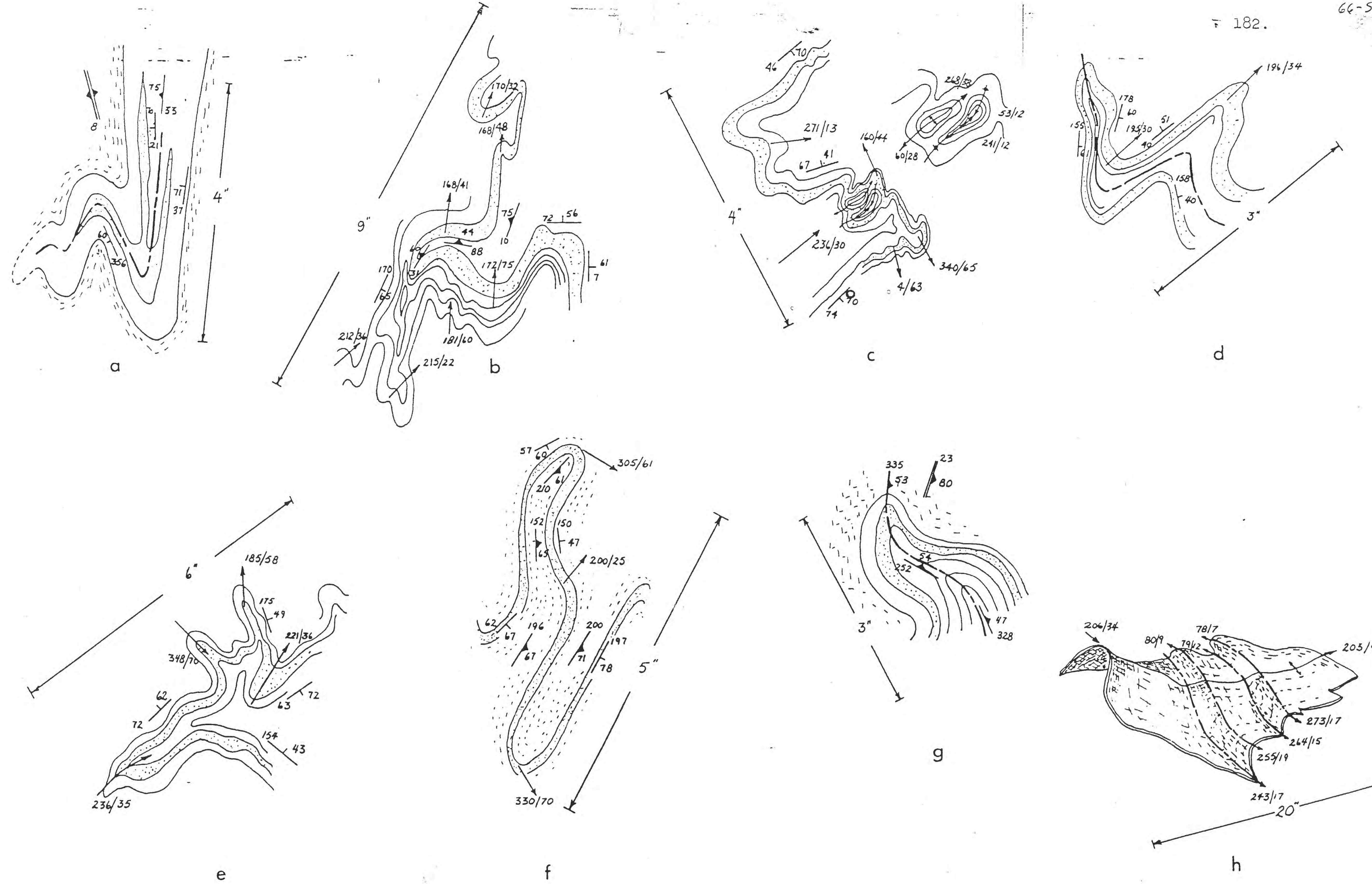
FIGURE 17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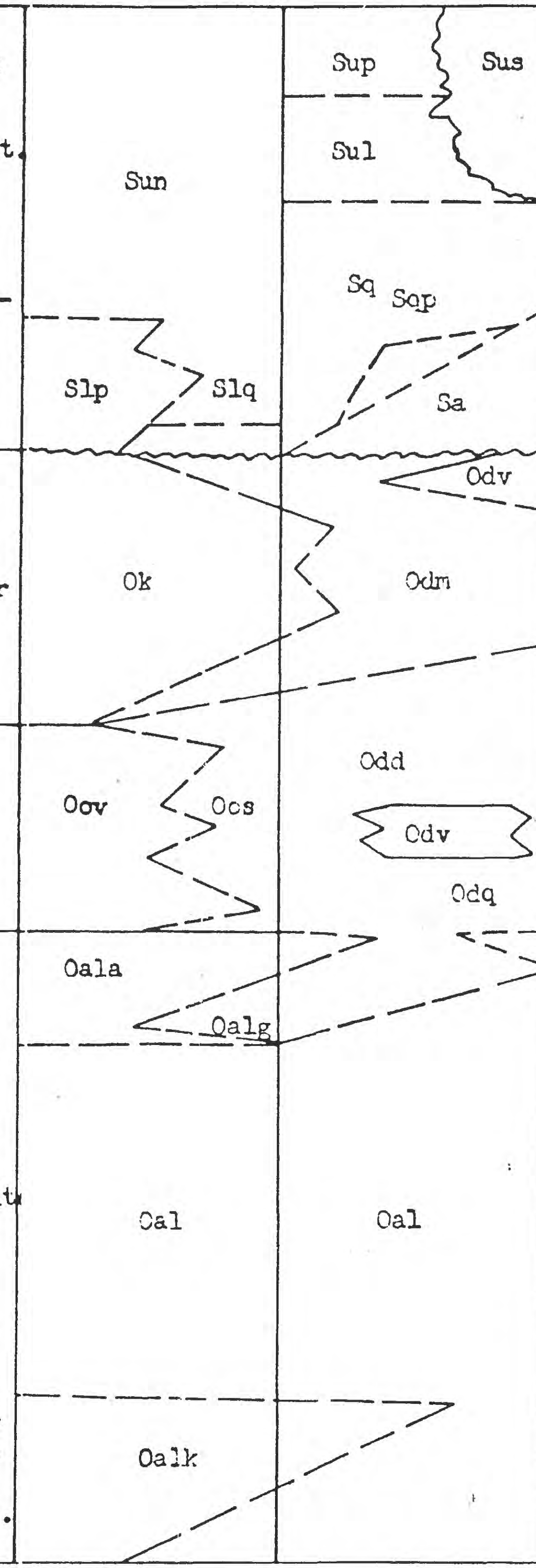
196/34
185/58
305/61
330/70
236/35
200/25
206/34
203/9
243/17

FIGURE 22

Southeast part of the quadrangle

System	Series	NAME	THICKNESS	LITHOLOGY
SILURIAN	Lower to Upper	(unnamed) Sun	2600'	Sun: Dark-gray, white to light-gray weathering slate with interbedded dark-gray, fine-grained, quartz-feldspar granulite. Granulite calcareous near the base of unit.
		Slp	0 - 1,000'	Slp: Dark-gray, boulder to cobble polymict conglomerate. Medium- to coarse-grained sand matrix.
		Slq	0 - 450'	Slq: White to light-gray quartz pebble conglomerate. Yellow-green chlorite-sericite matrix, locally silicified.
				UNCONFORMITY
ORDOVICIAN	Middle	Kamankeag Formation	(Top not exposed) 6,000'	Ok: Rusty weathering black slate; minor calcareous lithic graywacke, and greenstone. Thin-bedded, fine-grained, dark-gray quartzite increases in abundance near top of unit. Late Middle Ordovician graptolites near the base.
		Oquossoc Formation	5,500'	Oos: Rusty-weathering black slate with minor thin-bedded, fine-grained, pyritic quartzite. Oov: Massive to crudely foliated greenstone.
	Middle -?-?- Lower	Albee Formation	4,500 - 13,000' (base not exposed)	Oal: Principal member: Green to gray-green slate and phyllite with gray-green, "pinstripe" quartzite and quartz-feldspar granulite beds common. Minor amounts of greenstone scattered in the unit. Oala: Aziscohos member: Green to purplish-gray slate and phyllite; locally chlorite-muscovite schist. Quartz-feldspar granulite beds present locally but not characteristic of unit. Quartz pods and stringers abundant. Oalg: Black phyllite with discontinuous patches of greenstone present at contact with Oala. Oalk: Kennebago member: Purple to purplish-gray slate and phyllite. "Pinstripe" granulite beds common. Minor greenstone. Local patches of black slate at contact with Oal.



Northwest part of the quadrangle

NAME	THICKNESS	LITHOLOGY
(unnamed) Sus	?	Sus: Dark-gray, well-bedded, slate and feldspathic quartzite
Sup	450'	Sup: Gray-green to tan, arenaceous limestone. Pronounced "pit-weathering" of limestone or shelly beds. Upper Silurian (Ludlow) fauna.
Sul	250'	Sul: Light-gray, tan-weathering, silty limestone.
Sq	0 - 1100'	Sq: Pebble to cobble quartz and quartzite conglomerate; coarse-grained quartzite; minor gray slate. Sqp: Local polymict cgl.
Sa	500'	Sa: Dark gray or green argillite and tuff(?).
		UNCONFORMITY
Dixville Formation	5500'	Odm: Magalloway member: Dark-gray to gray-green feldspathic graywacke; green to purplish-gray slate; schistose felsic volcanic rocks. Patches of quartz-feldspar granule conglomerate and black slate. Odd: Dixie Brook member: Rusty-weathering black slate and phyllite. Thin- to thick-bedded gray quartzite (Odq) present locally near the base of unit. Odv: Massive to foliated greenstone; minor felsic volcanic rocks. Pillow structures and agglomerate beds common in volcanic rocks in the Magalloway member.
Albee Formation	4500 - 13,000'	Lithology the same as that in the southeast except that the Aziscohos member cannot be recognized.

Figure 3: Columnar section of the stratified