THE GEOLOGY OF THE MILTON QUADRANGLE, VERMONT

By

SOLON W. STONE and JOHN G. DENNIS

VERMONT GEOLOGICAL SURVEY

CHARLES G. DOLL, *State Geologist*

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TABLE OF CONTENTS

	PAGE
ABSTRACT	7
INTRODUCTION	8
Location	8
Statement of problem	8
Methods of study	9
Acknowledgments	10
Culture of area	11
Nature of exposures	11
Physiography and glaciation	11
STRATIGRAPHY	14
Historical Introduction	14
Present classification	17
Cambrian (?)	17
Pinnacle Formation	19
Phyllite facies	20
Tibbit Hill volcanics	21
White Brook Dolomite	22
Underhill Formation	23
Fairfield Pond Phyllite	24
West Sutton Slate	25
Lower Cambrian	25
Cheshire Formation	25
Dunham Formation	29
Connor facies	29
Mallett facies	33
Monkton Formation	35
Parker Formation	38
Middle Cambrian	40
Winooski Formation	40
Rugg Brook Formation	42
Woods Corners Group	43
Danby Formation	43
Skeels Corners Formation	45
Rockledge Formation	48
Upper Cambrian or Ordovician	51
Clarendon Springs Formation	51
Lower Ordovician	55

PAGE
Shelburne Formation 55
Cutting Formation 56
Middle Ordovician 57
Igneous Rocks 58
STRUCTURAL RELATIONSHIPS 60
Thrust faults 60
Champlain thrust 60
Hinesburg thrust 62
Muddy Brook thrust 64
Minor thrusts 65
Klippen 65
Cobble Hill Klippen 65
Arrowhead Mountain Klippe 66
Normal faults 69
Folds 69
Hinesburg synclinorium 69
Dead Creek Syncline 73
Georgia Mountain anticline 73
Minor Folds and Drag Folds 74
Cleavage 74
Joints 75
BIBLIOGRAPHY 76

List of Illustrations

PLATE		PAGE
I	Geologic Map of the Milton Quadrangle, Vermont, with Geologic Cross Sections . . .	(In pocket)
II—Figure 1.	Roche moutonnée of Cheshire Quartzite	27
Figure 2.	Pinnacle Formation	27
Figure 3.	Cheshire Formation	27
Figure 4.	Dunham Dolomite	27
III—Figure 1.	Intraformational sharpstone layers developed in Connor facies of Dunham Dolomite	34
IV—Figure 1.	Mallett facies of Dunham Formation	36
Figure 2.	Monkton Formation	36
Figure 3.	Skeels Corners Formation	36
Figure 4.	Bioherms of Skeels Corners Formation	36

PLATE		PAGE
V—Figure 1.	Limestone boulders in Rockledge Formation . .	49
Figure 2.	Rockledge Formation	49
Figure 3.	Mafic dike at Milton power plant	49
Figure 4.	Hinesburg Fault contact showing Cheshire quartzites over Dunham Dolomite	49
VI—Figure 1.	Cheshire—Skeels Corners fault contact along Hinesburg thrust	50
Figure 2.	Contact of Skeels Corners Shale and rock of Arrowhead Klippe at Milton power plant . . .	50
Figure 3.	Panoramic view, Arrowhead Mountain	50

Figures

FIGURE	PAGE
1. Index map showing location of the Milton, Vermont, quadrangle.	13
2. Columnar sections to show the stratigraphic relations of the rocks near Burlington in the south and near Georgia Center in the north	18
3. Graphic presentation of elements observed in spectrographic analysis of Dunham Dolomite	31
4. Graphic presentation of the percentages of insoluble residues of some rocks in the Milton area, Vermont.	47
5. Major structural features of the Milton area, Vermont	61
6. The "celebrated Georgia section" (after Schuchert, 1937). . .	70
7. Geologic map of part of the plane table area mapped by the Harvard Summer School field camp in Georgia township west of Georgia Center	72

Tables

TABLE	PAGE
1. Historical development of stratigraphy.	16
2. Colors observed in Dunham Dolomite	32
3. Mafic dikes of the Milton area	59

THE GEOLOGY OF THE MILTON QUADRANGLE, VERMONT

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ABSTRACT

The Milton quadrangle borders Lake Champlain north of Burlington, Vermont. The bedrock, from west to east, includes a narrow strip of Ordovician foreland rocks which is overridden by a miogeosynclinal Cambrian and Ordovician sequence along the Champlain thrust; this sequence underlies the main central part of the quadrangle. East of the Hinesburg thrust there is transition into the eugeosyncline of lowest Cambrian or earlier age. The Hinesburg synclinorium and the Georgia Mountain anticlinorium are the principal structural features between the two major thrusts. Three klippen are erosional outliers of the Brigham Hill thrust sheet.

In the past century a number of geologists have worked in the area because of the interesting stratigraphy and the complicated structure. Very few have spent sufficient time for detailed study and have correlated stratigraphic units on the basis of similar lithology. Walcott's type locality of the Lower Cambrian series of North America, the Georgian series, is located in the northern part of the area. As a result of recent investigations, this series is known to contain formations as young as the Upper Cambrian and to be considerably thinner than the 10,000 feet supposed by Walcott. Schuchert and Keith have published extensively concerning the geology of this section of Vermont. Much of their work is now known to be in error.

The Milton area is underlain by rocks of Cambrian and Lower Ordovician age. The stratigraphic column is notable for facies change. To the south in west-central Vermont the rocks are predominantly calcareous; to the north in the St. Albans area the formations are mainly argillaceous and arenaceous. It is in the Milton area that these two contrasting facies interfinger. The formations used in mapping closely follow the stratigraphic column as proposed by Cady in west-central Vermont. The term *Milton* should be dropped from the literature as a formation name because of the complexities and misunderstandings in its meaning.

The type locality of the "Milton" as defined by Schuchert is included in the Clarendon Springs Dolomite of Cambrian and Ordovician age.

INTRODUCTION

Location

The Milton quadrangle is situated between latitudes 44°30′ and 44°45′ north and longitudes 73°00′ and 73°15′ west. It borders the eastern shore of Lake Champlain north of the city of Burlington, Vermont, and its northern border is less than twenty miles south of the international boundary line.

Statement of Problem

The investigation of the geology in the Milton area was undertaken more specifically in order to solve certain problems:

1. Although the general stratigraphy and structure of the Cambrian and Ordovician rocks of west-central and northwestern Vermont has been known for many years, many of the details have remained obscure. In west-central Vermont, Cady (1945) has brought order to the chaotic concepts of stratigraphy and structure that had existed there. In the St. Albans area, Shaw (1949 and 1958) has even more recently rationalized the stratigraphic relations. However, the rocks in west-central Vermont are dominantly calcareous, whereas those in the St. Albans area contain extensive argillaceous and arenacous beds. It is in the Milton quadrangle that the transition between these two contrasting facies of similar age is seen. Therefore, one problem has been to attempt a correlation between the stratigraphy of west-central Vermont and that of the St. Albans area. For the most part, the results of this phase of the investigation have been satisfactory. However, the contacts between the thick Cambrian dolomites in the northwest part of the Milton quadrangle cannot be drawn with complete satisfaction because of the amazingly similar lithologic characteristics in several formations and the paucity of paleontological evidence.

2. The "celebrated Georgia section" (Fig. 6) as drawn by Schuchert (1937, p. 1024) is located in the Milton area. In 1893 Walcott proposed that this section be designated the type locality for the Lower Cambrian series of North America. As a result of plane table work (Fig. 7) on a scale of 400 feet to the inch by members of the Harvard Summer Field School west of Georgia Center in 1942, it became evident that previous workers had misinterpreted the stratigraphy and structure of this area.

The Georgia section as drawn by Schuchert is not correct. It was the problem of the author to extend the results of the plane table work throughout the Milton area.

3. The work of the Geological Survey of Canada from 1921–1931 in southern Quebec suggested the presence of a series of thrust sheets along the international boundary, as had been earlier suggested by Keith. One of the thrusts has been named the Oak Hill thrust by Clark (1934, p. 4) and he shows that it extends for at least a few miles into northwestern Vermont. Booth (1938, p. 1869) traced the rocks east of this thrust, Clark's "Oak Hill slice," into northwestern Vermont. He did not find an eastern fault contact for the Oak Hill series which corresponded to Clark's Brome fault, but followed Clark by delimiting the western extension of the Oak Hill series by the Oak Hill thrust.

In a later paper, Booth reversed his earlier opinion and states (Booth, 1950) that, "the Oak Hill Thrust cannot be recognized with certainty in Vermont." However, he introduced the term Oak Hill escarpment for the southern extension of this fault (Booth, 1950, p. 1160). Thus he did not eliminate entirely the confusion regarding this structural feature.

The evidence for the Oak Hill fault and the accompanying "Oak Hill slice" in the Milton area has been studied by the authors. It appears unjustifiable to extend this fault and certain formations of the Oak Hill series into the area of this report.

Cady has summarized the geotetonics in this area in a recent publication (Cady, 1960).

4. Hager (1862, p. 167) noted a series of hills between the shores of Lake Champlain and the Green Mountain front. Cady's (1945) map was the first to illustrate Cobble Hill as a klippe, following the interpretation of Keith (1932) and Schuchert (1937). This interpretation leads to the question of whether the other hills paralleling the Green Mountain front might also be klippen. If these are all klippen, then the problem arises as to the nature and extent of their displacement.

Additional problems inevitably arose during the field work. One of these was an interpretation of a number of thrust blocks in the vicinity of Colchester Pond, and of the continuation northward of the Hinesburg thrust.

Methods of Study

The field work for this report consisted of approximately 33 weeks during the summers of 1946, 1948 and 1949 by Stone, and a few weeks in the summer of 1959 by Dennis. Rock units were plotted on photostatic enlargements of the United States Geological Survey topographic map of the Milton quadrangle at one inch = one mile, published in 1915 (Stone) and on the two inches = one mile maps published in 1948 (Dennis). Outcrops were located as closely as possible on these base maps with reference to culture and topography. In areas of little relief or where the contours were not drawn accurately, pace and compass traverses were made on scales of 50 to 200 feet to the inch. These traverses were made also in areas of complex structures where details could not be shown on the scale of the base map. Dennis' task was to extend Stone's work to the eastern boundary of the quadrangle, and to revise the pre-Cheshire stratigraphy and related major structures in the light of his recent work to the north (Dennis, 1964). The Trentonian stratigraphy west of the Champlain fault has been mapped by Hawley (1957), and details of this are not included in this report.

Laboratory studies were conducted in order to understand more clearly and to describe in more detail the variations in the different lithologic units. These studies consisted of analyses of the insoluble residues of some of the carbonate rocks, a brief petrographic study of some formations, and a spectrographic analysis of the Dunham Dolomite. Fossils were scarce and the few specimens collected were studied by Alan B. Shaw, who recently described the Cambrian faunas of northwestern Vermont (Shaw, 1951, 1954, 1958).

Emphasis is placed on the structural and stratigraphic relations of the formations in this report.

Acknowledgements

The writers are especially indebted to M. P. Billings, who suggested the problem, and who guided the progress of Stone's field work and the preparation of this report. Helpful suggestions and criticisms have also been given in the field by P. E. Raymond, W. M. Cady, C. G. Doll and V. H. Booth.

The field assistance of R. D. Allen, G. A. Sanderson, and R. P. Flebeau is deeply appreciated. R. D. Allen has also made the spectrographic analysis of the Dunham Dolomite which accompanies this report.

Alan B. Shaw, who mapped the St. Albans area to the north, has aided greatly in the completion of this work, especially in regard to paleontological problems.

David Hawley kindly made available to the authors a field notebook with recorded observations of the rocks in the lower course of the Lamoille River. These were made by him while he was a student at the University

of Vermont prior to the construction of the new hydro-electric dam, the waters of which now cover many fine exposures.

To other members on the staff of the Division of Geological Sciences at Harvard University and to fellow students, the writers express appreciation for their suggestions and criticisms. Dr. H. B. Whittington has read the manuscript and has made many helpful suggestions.

The people of the town of Milton have been exceptionally helpful in all ways. Appreciation is expressed especially to Ralph Wells, Wilbur Patten and Harry Berry.

Culture of area

The village of Milton, with a population of approximately 800, is the largest community in the area. It is located along the Lamoille River within a mile of the center of the quadrangle. The principal industries are dairy farming, catering to the summer tourists, development of hydro-electric power, and small logging operations.

U. S. Routes 2 and 7 afford travel north and south through the area. Vermont Routes 2a, 15, 104, 104a, 127 and 128 also traverse parts of the area. No entirely new public roads have been added since the area was resurveyed in 1948 but an Interstate System right of way is planned to pass through Georgia. On the other hand, roads shown on the map are now incorporated in pastures or are overgrown with brush. No point in the area is over two miles from a road.

The main line of the Central Vermont railway crosses the area in a north-south direction approximately in the center of the quadrangle.

Nature of exposures

Farming in this region has resulted in clearing of much of the forest cover. The best exposures are on ridges of this cleared land. In the eastern part of the area, where the greatest relief is found, many farms have been abandoned and secondary growth is common. Rocks in this eastern area are not well exposed, as they are covered by thick growths of moss or buried under numerous seasonal falls of leaves. The thickness of the secondary growth in many places also limits one's ability to see outcrops from any great distance. Excellent exposures are found locally along the numerous stream channels which have become superimposed from a thick mantle of glacial drift.

Physiography and glaciation

Relief in the area ranges from the Lake Champlain shore line at approximately 95 feet above sea level to Georgia Mountain, with an altitude of 1,500 feet. Two of the physiographic divisions of Vermont, as outlined by Jacobs (1937, 1950), are represented in the area. The western two-thirds lie in the Vermont Lowland, a sub-division of the Champlain Valley, whereas the eastern third is part of the Green Mountains.

The Vermont Lowland is a region of relatively low relief, approximately 400 to 500 feet, if one omits such isolated hills as Arrowhead Mountain and Cobble Hill. The Lowland is a maturely dissected region which has been covered recently by continental glaciers. As the ice sheets retreated to the north, the Lowland held large stagnant ice blocks trapped between the Adirondacks to the west and the Green Mountains to the east. The melt waters of the glacier produced a large glacial lake between the ice on the north and a topographic barrier to the south. Levels of this lake varied as new and lower outlets were uncovered. At the end of the Pleistocene and before the isostatic rise of the land following removal of the ice, the Vermont Lowland was invaded by marine waters from the Atlantic. Large deltas, wave-cut and wave-built terraces, beaches, marine and varved clays, kame terraces, and kettles all have been formed during and shortly after the glaciation of the region. Chapman (1937) presents an excellent account of the details of the late-glacial and post-glacial conditions in this region.

East of Milton the western foothills of the Green Mountains rise abruptly to an altitude of 1,500 feet. Mt. Mansfield (4,393 feet), the highest point in Vermont, is located approximately 12 miles to the east of this area. The foothills of the Green Mountains are also maturely dissected, but because of the more resistant nature of the rocks and the relief, the features are not covered by glacial deposits to the same extent as in the Lowland. Erratic boulders, striated surfaces, and *roches moutonnées* are the obvious results of glaciation in the Green Mountain section (Plate II, Figure 1).

Drainage in the Milton quadrangle is controlled largely by the Lamoille and Winooski rivers. The courses in the Green Mountain section are apparently superimposed from a former peneplained surface. In the Vermont Lowland the lower courses of these rivers developed as extended consequent streams across lake beds as levels of the glacial lakes were lowered. The rivers have cut through these glacial deposits and are now superimposed on the underlying rocks.

Much of the Lowland is drained also by Malletts Creek and Indian Brook, both of which empty into Lake Champlain at Malletts Bay. Other small streams drain the northwest section of the Lowland through

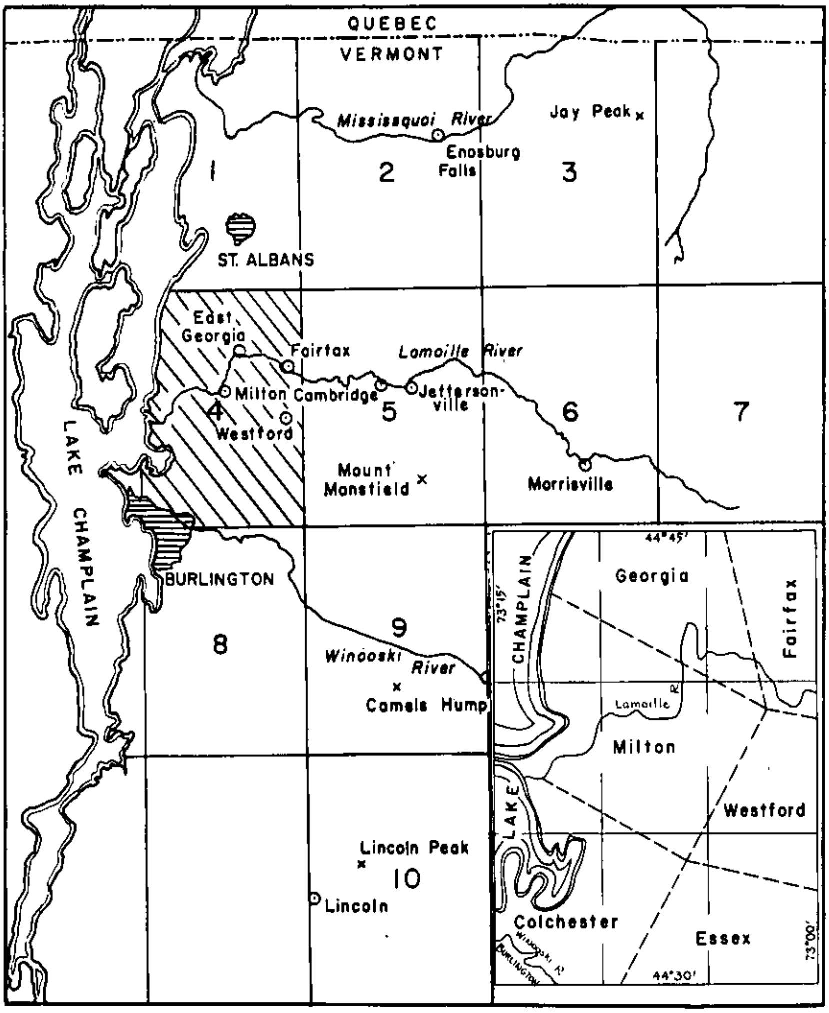

Figure 1. Index map of northwestern Vermont. Milton quadrangle is shaded. (Insert shows enlargement of Milton quadrangle and townships). The quadrangles are numbered as follows:

1. St. Albans	4. Milton	8. Burlington
2. Enosburg Falls	5. Mt. Mansfield	9. Camels Hump
3. Jay Peak	6. Hyde Park	10. Lincoln Mountain
	7. Hardwick	

northeast-southwest valleys. Several examples of stream capture can be noted along these small streams.

STRATIGRAPHY

Historical Introduction

In his opening remarks on the structure and stratigraphy of northwestern Vermont, Schuchert (1937, p. 1003) states that "no Cambrian area in Eastern North America is more interesting stratigraphically, or shows more complicated structure." During the past century many geologists have been attracted to the area, but, since few have spent sufficient time for detailed study, stratigraphic units have been correlated on the basis of lithologic similarity.

It is not the purpose of this report to present a detailed account of the historical development of the concepts of the stratigraphy and structure of the area. However, the works of a few of the leading contributors will be mentioned.

Hitchcock (1861) attempted the first extensive study of the geology of Vermont. His stratigraphy is known to be in error because his correlations were made on lithologic similarity, and because he was reluctant to accept thrust faulting as a structural possibility. The rock units, in the area of this report, were assigned names and designated age relationships by Hitchcock (Table 1, p. 9).

Logan and E. Billings made fossil collections in the Red Sandrock above Hitchcock's Hudson River group. The fauna was considered by them to be "Primordial," or very nearly the equivalent of the Potsdam Sandstone in New York. The "Primordial" age was confirmed by J. Barrande, noted paleontologist of Bohemia. In Sweden an *Olenellus* fauna was known to underlie the *Paradoxides* beds or the "Primordial" of Barrande. It was not until Walcott (1888) confirmed such a succession in Newfoundland that the Lower Cambrian age of the *Olenellus* beds was established in North America.

On the basis of the "Primordial" age, Logan (1863) placed a great fault along the eastern shores of Lake Champlain to explain the reverse stratigraphic relations. This fault is now known as the Champlain thrust or "Logan's Line."

As the leading student of Cambrian faunas, Walcott visited the area and wrote many papers on the paleontology. The Lower Cambrian fossils on the Noah Parker farm 2.1 miles N.60°W. of Georgia Center became well known to paleontologists. In addition to the shales at the Parker farm, Walcott (1891) included many more rocks to the east as the type locality for the Lower Cambrian of North America. Walcott assigned to this series of rocks the name *Georgian* and assumed the thickness to be about 10,000 feet. As a result of recent investigations, however, this section is known to contain formations as young as the Upper Cambrian and to be considerably thinner.

About 1920 Arthur Keith, who had done extensive work in the Southern Appalachians, directed his efforts toward the solution of the structure and stratigraphy of northwestern Vermont. Keith's reports lack sufficient diagrams and structure sections to explain fully the relationships. However, the results of his work were taken as standard for this section and quoted frequently in succeeding publications. Keith's formations are shown in Table 1. The identification of Upper Cambrian fossils at this time, and the description of them by Raymond (1924), reduced the apparent tremendous thickness of Walcott's Lower Cambrian. Keith unfortunately used the name Georgia slate for one of these new Upper Cambrian formations, thus causing confusion with Walcott's Georgian series.

Keith (1932) revised his stratigraphy after Howell's (1926, 1929) announcement of finding Middle Cambrian beds in the St. Albans area. Keith's early omission of Middle Cambrian was the result of an assumption that limestone conglomerates of similar lithology were of the same age. His revised stratigraphy is listed in Table 1.

Schuchert (1933, 1937), Raymond (1937), Howell (1937), and others did additional work in the area after Keith's (1932) report. Schuchert (1937) reviewed the work in the area and presented a revised stratigraphic column (Table 1) that was accepted as standard for this part of Vermont.

Further paleontological studies by Howell (1939a) demonstrated an age older than Upper Cambrian for part of the Hungerford Formation; thus the Saxe Brook and Skeels Corners formations were proposed. Howell (1944) incorporated these new formations in the Cambrian Correlation Chart (Table 1).

In the following year, Cady (1945) extended his stratigraphy of west-central Vermont into this area. The standard stratigraphy that had been followed with modifications since Keith (1923) was at this time greatly revised. Cady realized that the rocks along the western front of the Green Mountains Province could be correlated with those in the Vermont Lowland, although his interpretation of the structural relations in the Milton area differ from those presented in this report. By continuous lateral

Hitchcock 1861	
Eolian limestone	Dev.
Talcose cong. Georgian slate Quartz rock Red Sandrock series	U. Sil.*
Hudson River group	L. Sil.#

Keith 1932	
Georgia slate Corliss cong.	L. Ord.
Williston ls. Highgate slate Mill River cong	U. Cam.
St. Albans slate	M. Cam.
Shelburne marble Milton dolomite Parker slate Mallett dolomite Winooski dolomite Monkton quartzite	L. Cam.

Howell 1944	
Gorge fm. Rockledge fm. Hungerford fm. Saxe Brook fm.	U. Cam.
Skeels Corners fm. Mill River fm. St. Albans fm. Rugg Brook fm.	M. Cam.
Parker fm. Mallett fm. Winooski fm. Monkton fm.	L. Cam.

Vermont Geological Survey 1961	
Cutting dolomite Shelburne marble	L. Ord.
Clarendon Springs dolomite Rockledge cong. Skeels Corner slate Danby dolomite	U. Cam.
Rugg Brook dolomite Winooski dolomite	M. Cam.
Parker slate Monkton quartzite Dunham dolomite Cheshire quartzite Underhill fm. Pinnacle fm.	L. Cam.

Keith 1923	
Georgia slate Swanton cong. Williston ls. Shelburne marble Highgate slate Milton dolomite	U. Cam.
Colchester fm. Mallett dolomite Winooski dolomite Monkton quartzite	L. Cam.

* present Silurian
\# present Ordovician

Schuchert 1937	
Grandge slate Corliss cong. Highgate slate Highgate limestone Highgate breccia	Ord.
Gorge limestone Georgia slate Rockledge breccia Hungerford slate Mill River breccia Milton dolomite	U. Cam.
St. Albans slate Rugg Brook cong.	M. Cam.
Parker slate Mallett dolomite Winooski dolomite Monkton quartzite	L. Cam.

Cady 1945	
Cutting dolomite Shelburne marble	L. Ord.
Clarendon Springs dol. Undifferentiated slates, limestone breccias, & dolomites, that interfinger above and below. Danby dolomite	U. Cam.
Winooski dolomite Monkton-Parker horizon Dunham dolomite Cheshire quartzite	L. Cam.

Table 1. Stratigraphic Development

tracing of the beds, Cady proved that the Monkton was not the oldest Cambrian formation in the area, as supposed by Keith and his followers. Cady's geologic maps and structure sections also show that the supposed fault at the base of the Monkton, which repeated the Winooski Dolomite, was not present and that two similar carbonate formations bound the Monkton Quartzite. Cady (1945, p. 532) retained the name Winooski for the dolomites above the Monkton and introduced Clark's (1934, 1936) name Dunham for those beds below the Monkton (1945, p. 529).

The unpublished work of the Harvard Summer School of 1942, under the direction of P. E. Raymond and M. P. Billings, in the Milton area, and the recent work of Shaw (1949, 1958) in the St. Albans area, will be discussed in detail in a later part of this report. Dennis' (1964) revisions in the Enosburg area will be discussed under the formations concerned.

As stated previously, one of the problems was to correlate Cady's stratigraphy in west-central Vermont with that in the Milton area and with Shaw's formations in the St. Albans area. The stratigraphic units in this area, as represented by Cady (1945), and in the recent State Geological Map (1961) are shown in Table 1.

Present classification

In the Milton area east of the Champlain thrust there is a general transition from a southern calcareous or dolomitic facies to a northern more argillaceous and sandy facies. For this reason, the present classification is presented in the form of two columnar sections (Fig. 2), one to show the stratigraphy in the southern part of the area near Burlington and the other to show stratigraphic units in the area around Georgia Center and northward. The Rockledge Formation is the highest stratigraphic unit observed in the northern column. Those formations shown in the section above the Rockledge (Fig. 2) are from Shaw (1949). Detailed descriptions of the formations follow.

CAMBRIAN (?)

Pre-Cheshire Formations

General statement: In southern Vermont Whittle (1894) used the term *Mendon* for the rocks below the Cheshire Quartzite but above what he called Archean. Keith (1932) subdivided the Mendon series into formations. Clark (1934) assigned names to the formations below his Gilman Quartzite of southern Quebec. Booth (1950) extended Clark's

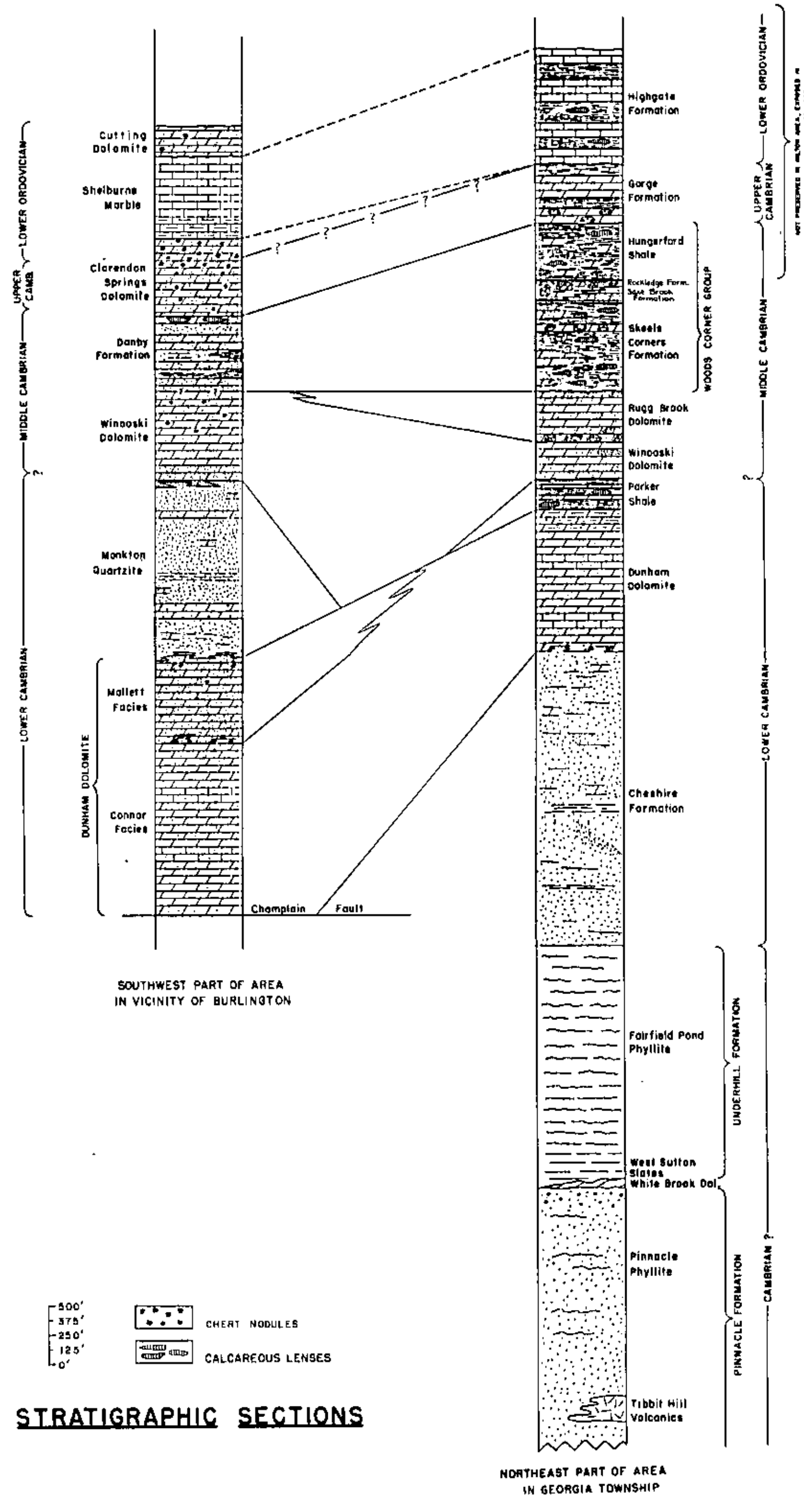

Figure 2. Columnar sections to show the stratigraphic relations of the rocks near Burlington in the south and near Georgia Center in the north. Pre-Cheshire thicknesses are conjectural.

nomenclature of these Pre-Gilman formations into northwestern Vermont. Dennis (1964) re-mapped and reclassified the formations concerned.

Pinnacle Formation

Name and distribution: The name Pinnacle Formation here includes Clark's Tibbit Hill Schist, Pinnacle Graywacke, and Call Mill Slate. This reclassification became necessary because the Tibbit Hill was found interbedded with typical Pinnacle Graywacke near East Fairfield (Dennis, 1964). The Call Mill Slate occurs very sporadically in Vermont, never in outcrops large or consistent enough to map, and is, therefore, also included in the Pinnacle Formation.

The rocks of the Pinnacle Formation were first described by Logan (1863, p. 246). Logan did not differentiate between the volcanics and the graywackes. He called the rocks below the White Brook (unnamed then) "chloritic, micaceous and epidotic rocks." He erroneously considered them to be at the core of a syncline.

The bottom of the Pinnacle as here defined is not exposed in the Milton area, but it unconformably overlies the Pre-Cambrian Mount Holly complex in the Middlebury quadrangle (lower part of Mendon Formation, Osberg, 1952; Pinnacle Formation, Cady, personal communication, 1958). The top of the Pinnacle is, by implication (Clark, 1936) defined by the overlying White Brook Dolomite or its equivalents, where present. Definition by lithology of the Pinnacle itself is not practicable, because of the very great facies variations within the formation. Where the White Brook is absent, the top of the Pinnacle is taken to be at the stratigraphically highest appearance of the coarse graywacke facies.

In Clark's usage the type locality of a formation is not necessarily its name locality. Thus, the type Pinnacle, as defined by Clark, is in "lot one, range one, Dunham (Quebec)." The name is taken from Pinnacle Mountain near Abercorn (Quebec). The type locality Pinnacle is a coarse graywacke; the Pinnacle capping Pinnacle Mountain is essentially phyllitic (V. Booth, personal communication to Cady, 1947). These two lithologies, coarse graywacke and quartz-chlorite-sericite phyllite, make up the bulk of the metasedimentary rocks of the Pinnacle Formation in Vermont.

Graywacke: The graywackes of the Pinnacle Formation were first defined and given stratigraphic status by Keith (1932, p. 394) who called them Nickwaket Graywacke. The term graywacke is a controversial one. The original definition of *Grauwacke*, the German term from which graywacke is derived, is: "Sandstone made up of fragmental granite debris" (Lasius, 1789, quoted in A.G.I. Glossary of Geology, 1957).

The representative graywacke is traditionally the graywacke of Tanne in the Harz mountains[1]. Similar rocks make up a high percentage of the rocks in eugeosynclinal belts. Most geologists would recognize a typical graywacke, but when it comes to defining it, opinons differ widely; all seem to agree now (1964) that rocks of the Tanne type must be comprised within the meaning of the term.

There are a number of good recent discussions of graywackes (e.g. Krynine, 1948; Helmbold, 1952 and 1958; Pettijohn 1954). The writers do not feel called upon to renew the discussion, but would merely refer to the above papers, and to the second edition of Pettijohn's text (1959). Pettijohn suggests that a true graywacke should have some of the diagnostic features of a turbidite (graded bedding, lack of bedding planes, lack of or poor sorting). The graywacke facies of the Pinnacle is indeed poorly sorted, sometimes has graded bedding, and comprises at least one exposure of slump breccia. But the beds of the graywacke facies are often quite thick (up to 10 feet at least) while in the case of "classical" graywackes each bed is considered to be the product of one turbidity current, never more than 2–3 feet thick. Yet, the graywacke facies of the Pinnacle is a polymineralic microbreccia, with usually too much groundmass to be called an arkose. On balance, the arenitic facies of the Pinnacle would be considered a graywacke in both Pettijohn's and Krynine's classifications.

H. C. Cooke (oral communication, 1953) followed the Pinnacle northeastward from Clark's type area and found that it grades into a white metaquartzite south of the St. Francis river.

In Vermont the arenitic facies of the Pinnacle predominates between the Canadian border and the Missisquoi valley. South of the Missisquoi, the proportion of phyllitic interbeds (Underhill facies) increases considerably. Locally, quartz pebble and polygenous boulder conglomerates appear. These are almost always near the top of the formation.

Petrography: The petrography of the graywacke and conglomerate facies of the Pinnacle is given in great detail by Booth (1950, p. 1142–1145).

Phyllite or Underhill facies: Phyllitic interbeds in the Pinnacle are common and their proportion within the formation increases considerably from north to south and from west to east. In the adjacent

[1] Often incorrectly rendered as "Tanner Graywacke"; "Tanne Graywacke" would be the correct stratigraphic name in English, for inflexions of proper names must not be carried from one language into another.

Mount Mansfield quadrangle Cady and Christman (personal communication, 1960) have found it convenient to group all phyllitic rocks in a separate formation, the Underhill Formation. The connected problem of stratigraphic nomenclature will be discussed with the Underhill Formation.

The chief minerals of the phyllites are quartz, sericite and chlorite, with accessory magnetite and albite. Small amounts of heavy minerals can be seen in many thin sections (zircon, rutile, apatite, tourmaline, sphene, epidote, as well as pyrite, muscovite, biotite and hornblende).

Quartz grains are often present as phenoclasts, well-rounded and about 0.5mm in diameter. Lithic fragments usually escape identification, owing to the rather uniformly fine grain of the phyllites, which would reduce such fragments to the size of their constituent minerals. Booth has found a number of fragments of igneous origin (Booth, 1950, p. 1142). Quartz veins, often parallel to the bedding or schistosity, are common, and may represent both exudation quartz and recrystallized chert.

It seems that, in Krynine's classification of sedimentary rocks, these phyllites would rank as fine-grained graywackes.

Tibbit Hill Volcanics: The lowest part of the Pinnacle Formation, as exposed in the Georgia Mountain anticline, largely consists of dark green metavolcanics. Originally Clark (1936) had mapped these volcanics as a separate formation, the Tibbit Hill Schists. The name is taken from Tibbit Hill, a little over a mile southwest of Brome Lake near Knowlton, Quebec. In the Sutton map area the outcrop of this formation is wide and unified, and appears to underlie the Pinnacle Graywacke at all known contacts. Hence Clark's classification of the Tibbit Hill as the oldest formation of the Oak Hill succession was perfectly justified. In the Enosburg area, however (Dennis, 1964), the volcanics appear to diminish in volume from north to south, and at the same time they acquire interbeds of graywacke and phyllite which can be shown not to be merely pinched anticlines: one band of pillow lava south of East Fairfield has pillows whose tops uniformly face east. This band is both overlain and underlain by graywacke. Hence graywacke and volcanics are interbedded, making it preferable to combine both in one formation. In the Lincoln Mountain and Middlebury quadrangles (Cady and others, 1962) Pinnacle Graywacke directly overlies Precambrian; so that either the lowest Pinnacle is a graywacke, or the volcanics, while possibly at the bottom of the formation, die out toward the south.

Outcrops of Tibbit Hill are very distinctive in the field. They are fairly massive, fine grained, usually dark green, sometimes vesicular and often characteristically pitted. The typical Tibbit Hill has no distinctive schistosity, but there are more schistose varieties which often resemble fine-grained graywacke or phyllite. These may be metamorphosed tuffs and/or water-deposited mafic volcanic detritus. In doubtful exposures the presence of epidote usually confirms basic igneous origin; that is, Tibbit Hill as against metasediment. Lenses of calcite and calcite-filled amygdules are quite sporadic.

The common minerals that make up these metavolcanics are albite, epidote and chlorite. Christman (1959) has confined the name Tibbit Hill to greenstones in which amphibole and/or feldspar can be recognized in the field. This was not the intent of Clark when he defined the Tibbit Hill; the abundance of amphibole appears to be a characteristic of metamorphic grade rather than of composition. The micropetrography of the Tibbit Hill has been so well described by Christman (1959) and also by Booth (1950), that it seems unnecessary to repeat these descriptions here.

Age: As stated above, the Pinnacle is known elsewhere to overlie the Precambrian Mount Holly complex. It has not yielded any fossils or radiometric ages. Since it is below the *Olenellus* bearing Cheshire Formation, its age may be late Precambrian or what has sometimes been named "Eocambrian": conformably below the oldest known fossil-bearing rocks. On the geologic map of Vermont such rocks are shown as Cambrian (?).

White Brook Dolomite[1]

General statement: The White Brook is an excellent marker horizon. At its type locality, the headwaters of White Brook south of Sutton, Quebec, (Clark, 1936) it is a dolomite of varying light coloration, usually whitish to pinkish or cream. The weathered surface is very conspicuous: a dull buff to brown, often on a low erosion-resistant ridge. The erosion resistance is largely due to a high quartz grain content, as well as quartz pods and quartz stringers criss-crossing the dolomite. Bedding has never been observed in Vermont, though Clark (1936) mentions outcrops showing sand grains concentrated along bedding planes. In some outcrops there is an abundance of irregular pods of whitish marble, possibly of secondary origin.

On a fresh surface this dolomite is white, but it weathers to dark red. Clastic fragments of subangular quartz and red jasper measure up to 5 mm, whereas flakes of muscovite and fragments of feldspar are smaller.

[1] Dennis (1964) maps the White Brook Dolomite as a member of the Underhill Formation.

An abundant non-magnetic, black, opaque mineral is probably ilmenite.

Insoluble residues make up approximately one-third of these dolomitic lenses.

Limestone lenses are also abundant. Five miles N.20°W. of Fairfax, on the crest of the ridge on the east side of Vermont Route 104, boulders of dolomite that weather dark red and orange, lie in a matrix of light-gray limestone. This conglomeratic lens is approximately 30 feet thick and can be traced about 0.75 mile.

Undoubted White Brook Dolomite has not been seen south of the Lamoille river, but Cady (manuscript map, 1960) has correlated it with the Forestdale Member of the Underhill Formation in the Middlebury area. The Forestdale Marble (Keith, 1932, p. 394) occupies the same stratigraphic position as the White Brook. On the explanation of the above-mentioned map Cady has also implicitly correlated the White Brook with the Battell Member of the Underhill, Osberg's (1952) Battell Member of the Monastery Formation. The Battell (Osberg, 1952, p. 44) is a black graphitic quartz-muscovite schist with lenses of dolomitic marble. It occupies a stratigraphic position above the Pinnacle Formation which may well be equivalent to that of the White Brook.

An extensive petrographic description of the White Brook Dolomite appears in Booth (1950, p. 1145–1147).

Underhill Formation

Name and Distribution: The rocks of the Underhill Formation are mainly greenish quartz-chlorite-sericite phyllites, lying stratigraphically between the Pinnacle and Cheshire formations, where present. Their type locality is the township of Underhill, in the Mount Mansfield quadrangle (W. M. Cady, oral communication, 1960). The present writers would place the rocks of the type locality within the Underhill facies of the Pinnacle Formation, for they are clearly stratigraphically equivalent to rocks of the Pinnacle Formation in the Milton area, being below an excellent marker horizon, the White Brook dolomite and slate. However, the Underhill facies of the Pinnacle and the phyllites of the Underhill Formation are practically indistinguishable in the field, and so, wherever the dividing White Brook dolomite and slate are absent, all Underhill type rocks must be mapped as one unit. In the western outcrop belt Underhill rocks are well defined between White Brook Dolomite or coarse Pinnacle Graywacke below and the Cheshire Formation above. Rocks within this clearly defined interval are recognized as a separate member within the Underhill Formation, the Fairfield Pond Phyllite.

Fairfield Pond Phyllite: The Fairfield Pond Phyllite includes the West Sutton Slate and the lower (phyllitic) part of the Gilman "Quartzite" of Clark (1936). In this report the name "Gilman" has been abandoned, because there has been some confusion as to its application.

As mentioned before, Clark distinguished between the *name locality* and the *type locality* of a unit. The name locality of his Gilman Quartzite, Gilman, Quebec, is actually underlain by green quartz chlorite sericite phyllite of Underhill type. The type locality for the Gilman, on the other hand, is the top of Oak hill, Quebec (Clark, 1936, p. 144), where the rock is an impure quartzite which correlates with the Cheshire Formation of this report. Since the quartzitic upper part of Clark's Gilman is readily distinguishable in the field from the underlying Fairfield Pond Phyllite, and has indeed been recognized separately by Keith (1923) as Cheshire Quartzite, this report distinguishes the upper quartzitic part of Clark's Gilman as the *Cheshire Formation* and lower phyllitic part of Clark's Gilman as the *Fairfield Pond Phyllite* of the Underhill Formation which also includes the West Sutton Slate.

Cady and others (1962), and J. B. Thompson, Jr., have followed Fairfield Pond and Underhill type rocks southward and have established their probable partial stratigraphic equivalence to Perry's (1928) Pinney Hollow Formation, to which they bear a great resemblance in the field. Cady has found that Keith's (1932) Moosalamoo Phyllite is equivalent to the Fairfield Pond Phyllite.

Booth (1950) was uncertain as to the application of Clark's names Gilman and West Sutton. Consequently, he continued mapping Clark's Gilman, both quartzite and phyllite, southward as such, but near Sheldon he swung its lower contact west, so that, toward the southern part of his map, in the Milton area, Booth's Gilman included little but the quartz-rich Gilman; in other words, the Cheshire. At the same time Booth inadvertently extended the application of Clark's West Sutton, including within it the phyllitic parts of the Gilman that he (Booth) excluded from his new interpretation of that name, as well as considerable amounts of Pinnacle graywacke and phyllite, including intervening White Brook Dolomite. These facts must be borne in mind when referring to Booth's description of the area.

In the Milton area, the Fairfield Pond is a monotonous quartz-chlorite-sericite-phyllite, often veined with quartz. This lithology is indistinguishable from the Underhill facies of the Pinnacle, except that the upper part of the Fairfield Pond is generally dark gray and fissile, while the lower part is greenish gray and somewhat less fissile.

West Sutton Slate: This member sporadically overlies the White Brook. The name and type locality are both in the vicinity of West Sutton, Quebec (Clark, 1936, p. 143). It is a well-cleaved slate, usually with a characteristic reddish tinge due to disseminated hematite. The member is continously mappable in Quebec, starting from some distance north of the border, but, with an average thickness of less than 100 feet, it cannot appear on a one-inch map (the White Brook, of course, should also be omitted from a one-inch map, but it has been included in part on Plate 1 with locally somewhat exaggerated thickness because of its importance as a marker horizon). In Vermont the West Sutton is rarely exposed, and probably mostly absent. It nowhere in Vermont appears to exceed the thickness noted by Clark in Quebec.

Booth's (1950) interpretation of the West Sutton, as noted before, is erroneous. The bulk of his "West Sutton" (including the true West Sutton) is really Fairfield Pond, the remainder Pinnacle or Cheshire.

Lower Cambrian

Cheshire Formation

General statement: As reported by Cady (1945), the Cheshire was first named by B. K. Emerson in 1892, on the unpublished Hawley sheet of the United States Geological Survey. The first published account of the Cheshire Quartzite is in Emerson (1917). The formation was named from Cheshire, Massachusetts, where it occurs as "a granular quartz rock of very massive habit, rather fine and even grain. . . . It is extensively used for making glass. In places it is very feldspathic. . . . The feldspar washed out of it forms small beds of very pure kaolin." (*ibid.*) This description of the Cheshire is also applicable to the formation in southern and central Vermont (Cady, 1945; Keith, 1923). In northwestern Vermont, however, there is a facies change to an impure quartzose subgraywacke, although more quartzitic portions occur in certain areas (notably on Oak Hill, Quebec).

Clark (1934, p. 9) assigned the name Gilman to the argillaceous quartzites in the Lower Cambrian series of southern Quebec and also included the Fairfield Pond Phyllite of this bulletin. He believed these units to be homotaxial in position with the clean white Cheshire quartzites of southern Vermont (Clark, 1936, p. 144). Jacobs (1939, p. 20) used the name Brigham Hill Graywacke for beds in the same stratigraphic position as the Gilman.

Booth (1950) followed Clark's nomenclature, since Clark's area adjoined his. Shaw (1954) also followed Clark. Booth (ibid., p. 1148) recognized four facies in his Gilman: "(1) a coarse to very coarse-grained sandstone or quartzite (mainly in the Milton quadrangle), (2) a fine-grained argillaceous siltstone, (3) a mottled argillaceous quartzite, and (4) a whitish relatively pure massive quartzite." M. J. Rickard (written communication, 1959), distinguishes (1) greenish-gray phyllitic schist (siltstone), (2) dark gray siltstone-fine quartzite schist, (3) white-fawn schistose quartzite (top).

In this bulletin the Cheshire Formation includes lithologies (3) and (4) of Booth, or lithology (3) of Rickard. The contact between the Fairfield Pond lithology and the Cheshire is gradational. The line was drawn above the frankly phyllitic dark gray to greenish phyllite, and below the rather characteristic mottled gray silty impure quartz schist of the Cheshire. Breaks that would be joints in the Cheshire are developed as "kink-bands" or "fold layers" in the more phyllitic Fairfield Pond. Osberg (manuscript map, 1959) has recognized Cheshire almost as far north as the St. Francis river. North of the St. Francis river H. C. Cooke and J. G. Dennis (manuscript map, 1953) mapped what is essentially Fairfield Pond lithology as Gilman.

Distribution: The abundant outcrops of Cheshire are located in a north-south belt near the eastern edge of the area. This belt extends approximately 14 miles south from the north boundary of the quadrangle. The widest continuous expanse of Cheshire, about 2.25 miles, is in the latitude of East Georgia.

A narrow strip of Cheshire extends through the south-central part of the quadrangle from a point 0.8 mile southeast of Cobble Hill. Isolated patches of the quartzite may be found in the vicinity of Arrowhead Mountain, Cobble Hill, and Pages Corners. No exposures are present on the west side of the area.

Description: The Cheshire is predominantly a massive gray argillaceous quartzite. The weathered surface is a very light gray but appears white from a distance. Green and purple hues can be distinguished on many of the freshly broken surfaces. Bedding is generally obscure.

In some of the more argillaceous outcrops a slaty cleavage is well developed. In the purer quartzites cleavage is absent, but a well-defined set of fractures has developed in response to the deformation in the area. A limonitic coating is common on the cleavage planes and also on the fractures. The best bedding is observed in the purer quartzites or in restricted areas where quartzites and argillaceous types alternate (Plate II, Fig. 3).

PLATE II

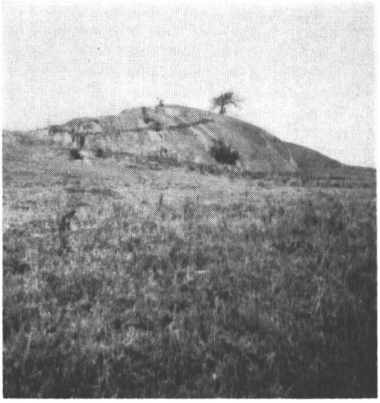

Figure 1. *Roche moutonnée* of Cheshire, 2 miles, N65°E of Georgia Station. View looking west.

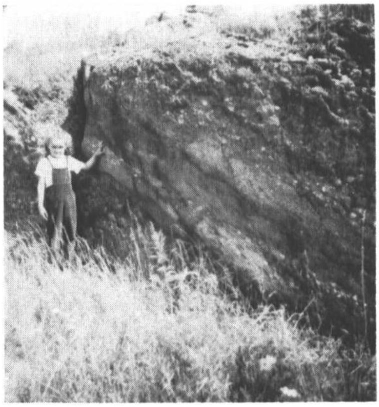

Figure 2. Alternating grits and conglomerates of Pinnacle. Beds just above the hand are a poorly cemented, friable, cross-bedded sandstone. East side of Vermont Route 104, approximately 5 miles north of Fairfax.

Figure 3. Vertical beds of Cheshire Quartzite on north bank of Lamoille River approximately 0.5 mile east of Georgia Station.

Figure 4. Quarry of Dunham Dolomite, 1.5 miles east of Sand Bar Bridge on U.S. Route 2. Note bedding as displayed by slight differences of weathering on the various colored rocks.

A conglomerate, in which white quartz pebbles 0.25 to 0.5 inch in diameter are set in a sandy matrix, lies near the base of the Cheshire.

These conglomeratic beds are best observed one mile east of Georgia Station along the road north of the Lamoille River.

A lens of black shale, approximately 30 feet thick, was observed in the lower part of the Cheshire 0.75 mile N.25°W. of Hardscrabble School. Smaller shale lenses are observed throughout the lower part of the formation.

In thin section the individual grains of the Cheshire average 0.1 to 1 mm. in diameter. They are sub-rounded and are chiefly quartz with minor amounts of feldspar, mica, and zircon. The cement is calcite, dolomite, or quartz. Ankerite can be identified in some of the interstices. The quartz grains in thin sections of the Cheshire Quartzite from the vicinity of Cushman Hill are much smaller; they average approximately 0.05 mm.

Thickness: Because these rocks are massive it is difficult to determine the structure except from the map-pattern shown by the formation as a whole. Undoubtedly there are numerous minor folds in the area which cannot be detected and which would greatly affect any determination of the thickness. Four miles northwest of Fairfax, the top and the bottom of the Cheshire can be located with the most certainty. Here the breadth of outcrop is approximately 1.4 miles. The few observed dips average 45° to the east. These figures indicate an approximate thickness of 5,200 feet. Two dips in this section show a westerly dip of the beds. A series of folds is undoubtedly present in the area and probably a figure half that presented, or 2,500 feet, would be more correct. Clark (1936, p. 146) arbitrarily sets 3,000 feet as the thickness for the Gilman in southern Quebec. Booth (1950, p. 1149) uses Clark's figure for the thickness of his Gilman in northwestern Vermont. The thin east limb of the Dead Creek syncline has probably been attenuated by deformation. Also, the Cheshire wedges out eastward.

Paleontology and age: Stone found large fragments of an olenellid type trilobite in the cliffs east of Colchester School No. 2 approximately 2.5 miles south of Colchester Pond. Clark (1936, p. 146) reports that a few poorly preserved fossils are found in the Gilman of southern Quebec. *Kutorgina* sp., of Lower Cambrian age, is one of these forms. Howell (Jacobs, 1939, p. 20) identified a single fossil from the west slopes of Bald Hill in Westford township as a hyolithid. In the St. Albans area Shaw (1949, p. 11) reports numerous trilobite fragments and a few specimens of *Salterella* sp.

Fossils are scarce and mostly poorly preserved, but the above finds establish the Cheshire as early Cambrian.

Dunham Formation

General statement: Keith (1923, 1932), Schuchert (1937), and others thought that the dolomites above and below the Monkton Quartzite were the same formation repeated by faulting. They adopted the name Winooski for these beds in accordance with the description by Hitchcock (1861, p. 329). Cady (1945, p. 528) demonstrated that these two bands of dolomite do not belong to the same formation. He retains the name Winooski for the dolomites above the Monkton and correlates the beds below with the Dunham Dolomite (Clark, 1934, p. 10) of southern Quebec.

The Dunham Dolomite is predominantly sandy near the top, where it grades into the Monkton. Cady (1945, p. 528) has amended the Mallett Formation of Keith (1923, p. 110) and used this term to denote an upper member of the Dunham Dolomite. Shaw (1949, p. 12) has noted a lateral thickening of the Mallett member northward in the St. Albans area. Near the Canadian border this arenaceous type represents the larger portion of the Dunham Formation. Shaw (1949, p. 12) has, therefore, designated the upper sandy portion as the Mallett facies and the lower carbonate rocks as the Connor facies of the Dunham Dolomite. The use of facies in this manner is in line with the definition of "sedimentary facies" by Moore (1949, p. 32).

Distribution: The prominent cliffs along the eastern shore of Lake Champlain in the Milton area are composed of Dunham Dolomite. This belt of Dunham extends north-south through the area and attains a maximum width of two miles in the vicinity of Malletts Bay.

In the center of the area a belt of Dunham extends south from the north boundary for approximately 14 miles. The maximum width of this belt, approximately 1.5 miles, is observed in the vicinity of Arrowhead Mountain. A narrow strip of Dunham, seldom exceeding 0.25 mile in width, forms the core of the Dead Creek syncline farther east. This Dunham in the central and eastern part of the area has been mapped as Rutland Dolomite by Keith (1923, p. 128), Jacobs (1939, p. 21), and others.

The Mallett facies of the Dunham is recognized only in the western part of the area.

(1) *Connor facies:* This facies is predominantly a dolomite showing wide variations in color. Near the base, gray is the predominant color; orange, red, brown, and purple are common higher in the formation. At the transition into the overlying Mallett facies gray arenaceous dolomites and occasional beds of gray limestone are as much as three

inches thick. Regardless of the color of the fresh surface, this dolomite weathers to a characteristic buff or brown. Beds of the Connor facies range from a fraction of an inch up to four feet in thickness.

Thin dark red-purple wavy partings occur throughout the Dunham but are concentrated in the highly colored portions of the dolomite. These partings are composed of clastic material dominantly of clay size. Clastic fragments in the bands show no marked degree of roundness, and the largest measure up to 0.05 mm. in diameter. The bands are most numerous in the western part of the area. They range in thickness from a fraction of a millimeter to 15 mm.

These bands represent an argillaceous sediment deposited on an irregularly rippled surface on the bottom of the Dunham seas. Shrock (1949, p. 110, Fig. 66–68) shows similar shale bands developed in massive sandstones.

This dolomite is known in the building trade as the Swanton or Wakefield mosaic or mottled marble. Many exposures show the mottled nature of the formation. Irregular shaped patches of orange, pink, purple, and red are mottled with shades of gray. The size of the spots in this variegated pattern varies from a fraction of an inch to several inches in a given exposure.

Because the variations in color are one of the most obvious features of the Connor facies, an attempt was made to discover what caused such a wide difference. Eleven samples were collected from a quarry along U. S. Route 2, 1.5 miles east of Sand Bar Bridge (Plate II, Fig. 4). The color of these samples was determined by comparison with the National Research Council Rock Color Chart (1948). The colors observed in this quarry are listed in Table 2.

A spectrographic analysis was made to determine the elements which might account for variations in color. The analysis was checked for the following elements:

Al	V	Ba	K	Fe	Mn	Li
Ti	B	Cd	Bi	Co	Zr	Sr
Na	As	Zn	Cu	Ni	Ag	
Pb	Sn	Mo	Cr	W	Sb	

Of these Fe, Ti, Al, Si and Na showed an increase as the color became darker (Fig. 3). By petrographic examination and the study of the insoluble residues an attempt was made to determine if the elements were present as mineral impurities or as replacement of the Mg of the dolomite. The insoluble residues of the dark-hued rocks of the Dunham

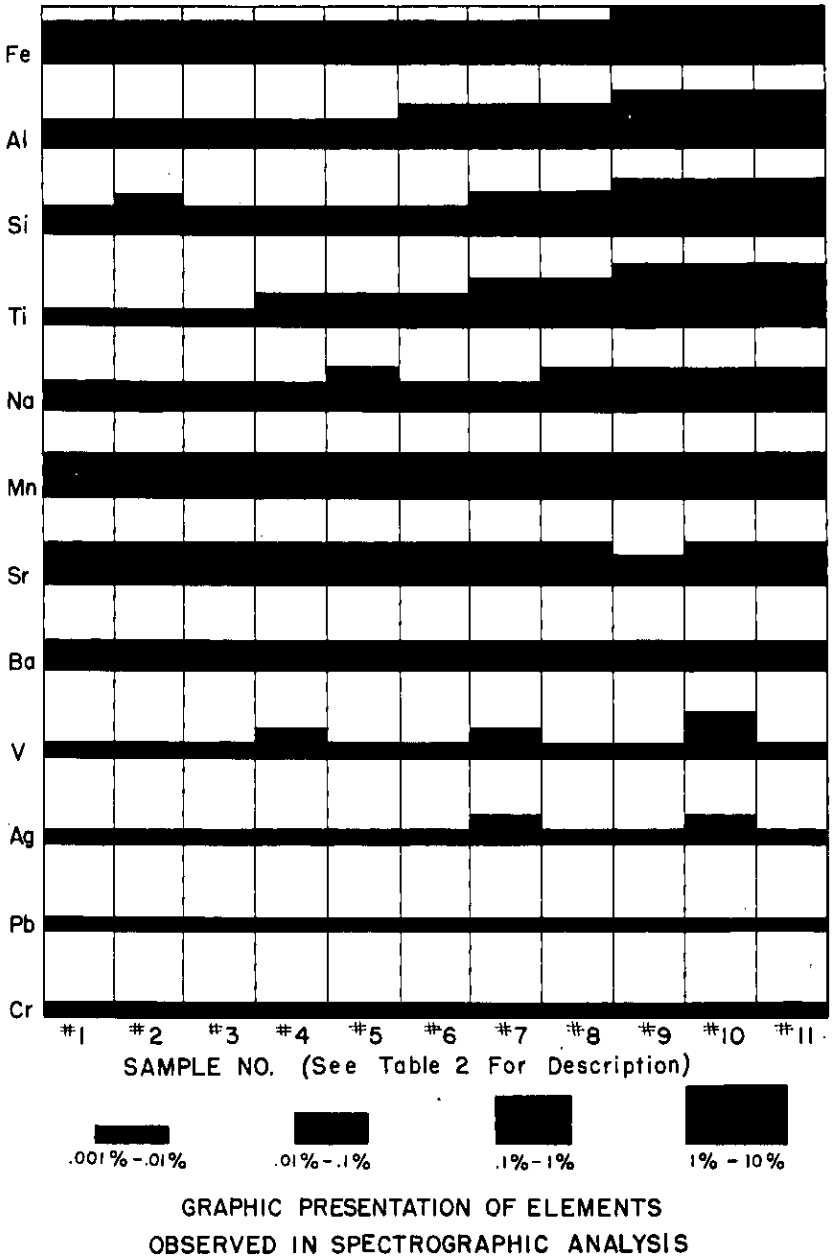

Figure 3. Graphic presentation of elements observed in spectrographic analysis.

TABLE 2

COLORS OBSERVED IN THE DUNHAM DOLOMITE AT QUARRY ALONG U. S. ROUTE 2, 1.5 MILES EAST OF SAND BAR BRIDGE

Sample No.	*Color*	* *Munsell Color Code*
1.	very light gray	N-8
2.	light gray	N-7
3.	light gray mottled with very light gray	N-7 mottled with N-8
4.	pinkish gray	5YR8/1
5.	grayish orange pink mottled with pinkish gray	10R8/4 mottled with 5YR8/1
6.	moderate orange pink mottled with grayish orange.	10R6/4 mottled with 10YR7/4
7.	pale red mottled with pale reddish brown	10R6/2 mottled with 10R5/4
8.	pale red purple mottled with light brownish gray	5RP6/2 mottled with 5YR6/1
9.	grayish red mottled with pinkish gray.	5R5/2 mottled with 5YR7/1
10.	grayish red mottled with white and yellowish gray	10R4/2 mottled with N-9 and 5Y8/1
11.	pale reddish brown	10R5/4

* from Rock Color Chart, National Research Council, 1948

were exceptionally high in clastic content. The lighter colored Dunham averaged about 3.5% insoluble residue, whereas the reddish-brown variety ran as high as 31%. Common clastics of the Dunham are quartz, feldspar, muscovite, and a black opaque mineral, probably ilmenite. Also some scattered grains of a highly pleochroic material, probably zircon and/or epidote. The residues of the reddish-brown Dunham contained so much reddish-orange clay that it was impossible to identify any fragments. The authors believe that the variations in color are related to the percentage of reddish-orange clay in the insoluble residues of these carbonate rocks. The progressively higher clay content produces darker tones and hues in these beds. The clay residues are too fine to make a definite statement as to the material responsible for the color. It is probably hematite or some other hydrous ferric iron.

Schuchert (1937, p. 1023) has suggested that "mottling of the marble

(Connor facies of the Dunham Dolomite) is due to the shallowness of the sea in which the beds were laid down." It is apparent from the present study that the darker tones and hues of the mottled dolomites could be the result of local concentrations of detrital material in small scalloped-out areas on the floor of a shallow limy sea. On the other hand, dark red and purple argillaceous bands, which resemble buried ripple marks, could result from continuous layers of detrital material on the sea floor. Finally, in the very dark beds of Dunham the detrital material is fairly evenly distributed.

Proof of the shallowness of the sea in which the Connor facies was collecting can be observed in the outcrops along the southwest slopes of Eagle Mountain. Here intraformational sharpstone layers (Shrock, 1948, p. 208) are present (Plate III). Fragments of a light-colored dolomite are included in a darker dolomite which contains more detritus. This fragmentation is caused by storm waves that disrupted the bottom. These storm waves could also account for the more widespread distribution of the detrital materials to make up the darker matrix.

The base of the Dunham Dolomite is gradational with the underlying Cheshire Formation. The contact, exposed at numerous places in the central and eastern part of the area, is a zone of dolomitic sandstone which attains a thickness of 30 feet in many places. Some exposures are deeply weathered to a dark red-brown earthy layer. This transitional zone has been mapped with the Dunham Dolomite.

(2) *Mallett facies:* The Connor dolomitic facies grades upward and interfingers laterally northward into the arenaceous Mallett facies of the Dunham. This gradation can best be observed in the vicinity of Fox Hill. The lower part of the Mallett is a light-gray arenaceous dolomite grading upward into a dolomitic sandstone. The bedding is more massive than in the underlying Connor facies. Sandstone beds increase in abundance northward. Shaw (1958, p. 527) reports a 15-foot bed of quartzite in the Mallett facies near the Canadian border.

The sand particles of the Mallett are well-rounded and frosted quartz grains as much as 2 mm. in diameter. Many of the grains have been cracked so that they look like miniature faceted ventifacts. In places the grains are so well cemented together that fracture has occurred through the grains.

Near the top of the Mallett the sand grains have been concentrated and form nodules one foot or more in diameter. These stand in relief on the weathered surface (Plate IV, Fig. 1).

A small erosional interval might well represent the Mallett-Parker

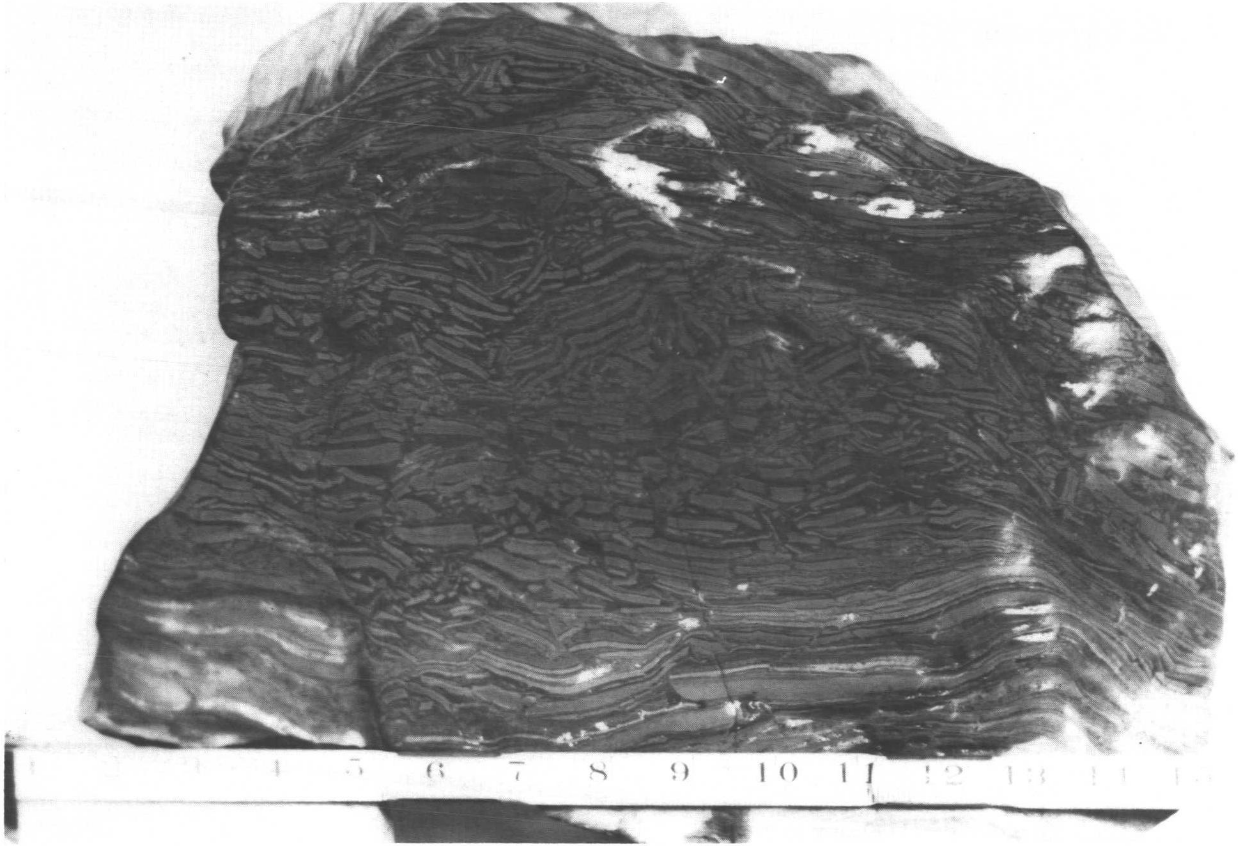

PLATE III

Intraformational sharpstone layers developed in the Connor facies of the Dunham Dolomite. Taken from large boulder on southwest slopes of Eagle Mountain.

contact in the northern part of the area. Schuchert (1937, p. 1025) and Shaw (1958, p. 530) report evidences of local unconformities in the St. Albans area.

Thickness: The Dunham Formation on the west side of the area is not entirely represented, inasmuch as the lower beds are cut off by the Champlain fault. However, a maximum of 2,100 feet is exposed. The upper 700 feet of this are assigned to the Mallett facies.

In the central part of the area the thickness reaches a maximum of 1,100 feet. To the east approximately 325 feet are exposed, but these exposures are in synclinal inliers, so that the true thickness here is not known.

Paleontology and age: Fossils are scarce in the Dunham Dolomite. The first author of this report has found only fragments of *Olenellus* sp. Schuchert (1937, p. 1023–1024) and Cady (1945, p. 530) list those found by Walcott and previous workers. This list which includes *Ptychoparella* sp., *Olenellus* sp., *Kutorgina* sp., *Nisusia* sp., *Hyolithes* sp., and *Salterella* sp., establishes a Lower Cambrian age for the Dunham Dolomite.

Monkton Formation

General Statement: In his original description of this formation at Monkton, Vermont, Keith (1923, p. 107) correlates it with the Cheshire quartzites of southern Vermont. Cady (1945, p. 531) shows that the Monkton lies at about the same horizon as the Parker shale and is thus stratigraphically higher than the Cheshire.

Distribution: On the west side of the area the Monkton extends approximately nine miles north from the south boundary of the quadrangle. The widest section of this belt is approximately one mile, with the best exposures on the south side of U. S. Route 2, 0.5 mile west of the intersection of U. S. Route 7 (locally known as Chimney Corners). The Monkton pinches out northward and eastward; consequently it does not appear in the northern or eastern parts of the area.

Description: On the northwest slopes of the 380 foot hill northeast of Malletts Bay a large quarry (Plate IV, Fig. 2) exposes approximately 175 feet of the lower part of the Monkton Formation. In this quarry red, pink, buff, brown, and white quartzites are interbedded with red and buff sandy dolomites similar in lithology to the underlying Mallett facies of the Dunham. Six feet of dolomite, resembling Dunham (Connor facies), lie about 40 feet above the lowest quartzites exposed in the quarry. The insoluble residues of this dolomite are similar to those of the darker-colored Dunham.

PLATE IV

Figure 1. Sand nodules in the Mallett facies of the Dunham Dolomite, 2 miles, N15°E, of Georgia Plains.

Figure 2. Quarry of Monkton Quartzite on the northwest slope of the 380 foot hill, northeast of Malletts Bay.

Figure 3. Typical Skeels Corners shale with alternating sandy limonitic layers, 0.3 mile west of West Georgia.

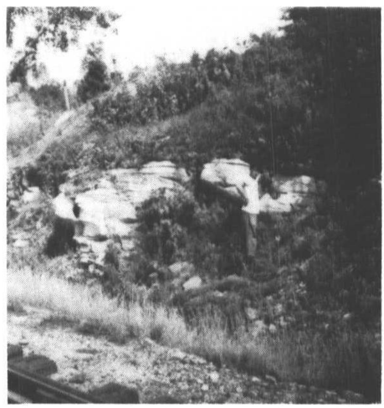

Figure 4. White limestone lens in the black shales of the Skeels Corners Formation in railroad cut west of Colchester Pond.

The lower part of the Monkton is predominantly a red or brown quartzite with beds up to three feet thick. In this part of the formation thin black and dark-purple siliceous partings that stand in relief on the weathered surface produce a washboard effect. Dolomitic cement is present in some layers of the quartzite so that the weathered rock becomes pitted and crumbles rather easily.

The upper portions of the Monkton are primarily buff to white quartzite. The upper beds are more massive than those exposed in the lower part of the formation. In the upper part these beds are separated by two or three inch layers of a yellowish-weathering gray arenaceous shale. The top of the Monkton is interbedded with the overlying Winooski dolomite. This gradation takes place in a few feet which is considerably less than the Monkton-Dunham transition. The top beds of the Monkton are a mud-cracked surface with peculiar markings that might be the trails of crawling organisms.

Cross-bedding, oscillatory and translatory ripple marks, swashmarks, and mud cracks are prevalent throughout the formation. These features are best observed in the quarries north of the water tower on the west side of U. S. Route 7, 0.5 mile north of the town of Winooski. Schuchert (1937, p. 1038) also observed numerous exposures with fossil rain drop impressions.

Thickness: North of Malletts Bay the breadth of outcrop of the Monkton is approximately one mile and the average dip of the beds is 17° east. Thus about 1,500 feet of Monkton are exposed here. The formation pinches out four miles to the north and five miles to the east. It is more extensive southward, but variable in thickness. It pinches out in the town of Pittsford, Vermont, some 50 miles to the south (Cady, 1945, p. 532).

Keith (1923, p. 108) reported 300 feet of Monkton at the northeast corner of Malletts Bay. Keith's diagram (Longwell, 1933, p. 53) showed the Monkton repeated by faulting in this locality. No overthrust faulting to repeat the beds could be determined. Thus, a greater thickness of Monkton would be required to justify the outcrop pattern of Keith's diagram.

Origin: Bain (1927, p. 224) has suggested that the Monkton was deposited in a rapidly filling estuary. If this were the case the Monkton would have a greater percentage of argillaceous material. It appears to the authors to be a delta deposit from an actively eroding land mass. The primary features mentioned above support this thesis. Also the variations in thickness and the outcrop pattern of the formation tend to favor it. The cross-bedding observed in the Milton area, along with the pinching out to the east, suggest a western source for the sediments. The area north of Burlington would thus be one of the main points of debouchure for this debris. At other places where the Monkton is locally thick, streams may have deposited greater loads of sediments. Longshore currents in the seaway moved from the north or northeast to spread the sediments southward from the areas of deposition.

Paleontology and age: Until recently, no established fauna was known from the Monkton. Kindle and Tasch (1948) have made extensive collections from the thin arenaceous shale beds between the white quartzites 0.75 mile west of the intersection of U. S. Route 2 and 7.

They identified the following forms:

Trilobita	
Olenellus thompsoni	(Hall)
O. vermontanus	(Hall)
O. hermani n. sp.	
O. spec. undet.	
Antagmus adamsi	(Billings)
A. typiculis	Resser
Bonnia swantonensis	Resser
Brachiopoda	
Kutorgina cingulata	(Billings)
Nisusia festinata	(Billings)
Paterina cf. *swantonensis*	Walcott
Acrotreta sp. undet.	
Gastropoda, etc.	
Helcionella sp. undet.	
Hyolithes sp. undet.	
Scolithus sp.	

These forms would place the Monkton in the Lower Cambrian at about the same horizon as the lower part of the Parker Shale, as recently confirmed by Shaw (1962).

Parker Formation

General statement: The name Parker Shale was adopted by Keith (1932, p. 371) for excellent exposures at Parker Cobble on the old Noah Parker farm 1.5 miles N.20°E. of Georgia Plains. This name is a revision of earlier nomenclature in which he used the term Colchester Formation (1923, p. 110). It is now known that the shales in the vicinity of Colchester are Upper Cambrian.

Distribution: On the west side of the area the Parker Shale extends south from the north boundary of the quadrangle to the north slopes of

Diamond Hill, a distance of approximately six miles. At no point does this belt exceed 0.5 mile in width. In the east the Parker Shale extends south approximately 1.5 miles from the north boundary of the quadrangle. Here the breadth of outcrop never exceeds 250 to 300 feet.

Description: The rocks in this formation are predominantly blue-black shale or slate. Fresh surfaces of the shale show many mica flakes. These mica flakes are less abundant in other shales or slates in the area. In places the shale is pure and exhibits a good fissile parting parallel to the bedding. Elsewhere it is arenaceous and at some places there are sandstone beds up to three inches thick. The Parker is a black argillaceous sandstone in the railroad cut 1.5 miles northwest of Oakland Station.

Dolomite lenses are common. A resistant bed of dolomite near the top of the formation is exposed on the west slopes of Bradley Hill. The top of the formation was eroded in a post-Parker emergence (Schuchert, 1937, p. 1026), so that this dolomite is lacking in most of the area. Shaw (1949, p. 28) demonstrated that a dolomite separates two distinct faunules in the Parker. Although he has not observed this dolomite bed south of the Fonda quarries in the St. Albans area, it might possibly be the same one as on Bradley Hill, although direct evidence for this is lacking.

Schuchert (1937, p. 1025) interprets the dolomite capping at Parker Cobble as a remnant of this dolomite bed. In this report, however, it is considered to be the overlying Rugg Brook Dolomite. The dolomite in the Parker Shale has about 38% insoluble residues whereas the dolomite capping Parker Cobble is practically pure carbonate, having only 2% residue. Well-rounded and frosted quartz grains, similar to the Mallett facies of the Dunham, are common in the dolomite of the Parker Formation.

Reef-like structures of limestone and dolomite (bioherms)[1] are associated with the Parker shales. The lenses of limestone and dolomite measure as much as 100 feet by 60 feet and form low mounds because they are more resistant to weathering than the surrounding shales.

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[1] The term bioherm has been used to refer to these mound-shaped lenses of limestone and dolomite by practically everyone who has worked in the stratigraphy of northwestern Vermont. Cummings (1932, p. 333) defines bioherms as "moundlike, lenslike or otherwise circumscribed structures of *strictly organic origin*, embedded in rocks of different lithology." The term was proposed earlier by Cummings and Shrock (1928, p. 599). As the *strictly organic origin* of these forms in northwestern Vermont has never been demonstrated the authors of this report suggest that the term bioherm be used with more discretion until definite proof of their organic origin is presented.

Thickness: In the Milton area the Parker attains its maximum thickness of 250 feet on the west slopes of Bradley Hill. At Parker Cobble the formation is about 200 feet thick. It pinches out on the north slopes of Diamond Hill about three miles south of the thick outcrops on Bradley Hill. The Parker thickens northward in the St. Albans area where Shaw (1949, p. 23) reports a maximum thickness of 1,000 feet in the vicinity of the Fonda quarries at Swanton.

In the vicinity of Oakland Station in the eastern part of the area the Parker has thinned to about 30 feet. It disappears southward in this eastern section about one mile south of Oakland.

Paleontology and age: Although the smallest in areal extent, the Parker Shale is one of the richest formations in the Milton area for fossils. Walcott described a Lower Cambrian fauna from this formation at Parker Cobble and used these shales for his type locality of the Lower Cambrian series in North America.

The fossils collected by the authors represent the lower faunule of the Parker; that is, below the dolomite horizon mentioned previously. The forms collected were:

Nisusia festinata	(Billings)
Austinvilla n. sp.	
Billingsaspis adamsii	(Billings)
Bonnia parvula	(Billings)
B. swantonensis	Resser
B. spec. undet.	
Kootenia marcoui	(Whitfield)
Olenellid Fragments	
Pagetides elegana	Rasetti

Alan Shaw (1958, p. 531) has found through a detailed study of the Parker fossils that Middle Cambrian forms are present near the top of this formation in the St. Albans area.

Middle Cambrian

Winooski Formation

General statement: Cady (1945, p. 532) uses this name for the dolomite beds above the Monkton and below the quartzitic beds that are typical of the overlying Danby Formation. This use is a revision of the term as used by earlier workers and now places the type locality at Winooski Falls in Winooski City in Colchester township.

Distribution: The Winooski Dolomite forms a band 0.75 mile wide from the south border of the area to the vicinity of West Milton, some nine miles to the north. The breadth of outcrop broadens north of this point to the vicinity of Roods Pond. In this distance of three miles no shale or quartzite beds divide the great succession of Cambrian dolomites into readily mappable units. Here the boundaries of the formations are obscure because of the similarity of these dolomite beds. The great expanse of dolomite in the western part of Milton township led Keith (1923, p. 112) to designate these beds as one formation, "the Milton dolomite" or "the Milton terrane." Keith originally called all this dolomite Upper Cambrian but later (1932, p. 372) revised his stratigraphy and correlated it with the Lower Cambrian. He undoubtedly included Lower and Upper Cambrian dolomites in his term Milton and possibly Middle Cambrian beds as well.

The Winooski pinches out to the north. No outcrops are correlated with it on the east side of the area.

Description: The Winooski Dolomite lies directly above and at a few places appears to be gradational with the Monkton. In this zone of gradation the Winooski shows a trace of pink color. Higher in the formation and where the Monkton is not directly below it, a light-gray or buff color is predominant. Sand grains are not as abundant as in other dolomitic formations in the area. Insoluble residues average about 5% and are predominantly quartz. Vugs, common in the central part of the area, are lined with small terminated quartz crystals. At some localities, especially in the vicinity of Diamond Hill, doubly terminated crystals of quartz can be found in the cavities and can be picked out of the weathering products of this formation. Elsewhere the quartz has com-completely filled the vugs so that small nodules stand in relief on the weathered surface.

Many bedding planes are characterized by stylolites with which pyrite cubes and nodules are associated. These are best observed in the southern part of the area where the beds are 6 to 12 inches thick. To the north the bedding is more massive.

Thickness: In the vicinity of Roods Pond the Winooski attains a maximum thickness of 800 to 900 feet. It must be kept in mind that this is the area in which the upper limits of the formation are obscure. Thus, it is possible that parts of the overlying Rugg Brook may be included in this figure. The formation thins northward and pinches out in the vicinity of Miltonboro. South of West Milton approximately 350 feet of dolomite have been assigned to this formation.

Paleontology and age: No fossils were observed in the Winooski and none have been reported. It has been assigned to the Middle Cambrian because of the presence of Middle Cambrian fossils in the upper partof the underlying Parker Formation in the St. Albans area.

Rugg Brook Formation

General statement: Schuchert (1933, p. 366) originally used the term Rugg Brook for a dolomitic conglomerate that he believed to be directly beneath the Middle Cambrian shales in the St. Albans area. Howell (1939c, p. 97–101) has enlarged the original definition to include more than the conglomerate beds. In recent field work Shaw (1959, p. 534) follows Howell's terminology and includes up to 300 feet of dolomite in this formation. It is the uppermost member of Dennis' (1964) Bridgeman Hill Formation, and correlates with Clark's (1934) Scottsmore Quartzite.

Distribution: On the west side of the area the Rugg Brook forms a narrow band from the north boundary of the quadrangle for about eight miles south to the vicinity of the Lamoille River. The maximum width of this belt is 0.8 mile in the latitude of Bradley Hill, where gentle dips of the formation enlarge the breadth of outcrop.

The formation thins eastward and only appears as a narrow band about one mile south of the northern boundary of the quadrangle in the vicinity of Oakland. Farther south occasional outcrops are too thin and sporadic to be mapped at 1 inch = 1 mile.

Description: Howell's (1939c, p. 99) description of the formation as "a sandy, sometimes conglomeratic, salmon brown to buff brown weathering gray to buff colored dolomite" applies to most of the formation. Conglomerates are prominent locally but are by no means restricted to the base of the formation as suggested by Schuchert (1933, p. 366). The conglomerates are composed of poorly rounded boulders as much as two feet in diameter. These boulders are predominantly arenaceous dolomite very similar to the matrix. Dolomite and quartzite pebbles as well as angular pieces of jasper and quartz reach a maximum diameter of two inches. The most southerly exposure of the conglomeratic phase of the Rugg Brook is along the Lamoille River west of the new dam, 0.75 mile upstream from West Milton. Here the boulders are associated with concentrically layered masses suggestive of algae. In some places the boulders are completely surrounded by these layered structures.

Except for the conglomeratic beds, the formation is very similar to the underlying Winooski Dolomite. Rounded sand grains, which stand in relief on weathering, are more abundant and ubiquitous in the Rugg Brook. At two localities the Rugg Brook contains sufficient sand to call it a dolomitic sandstone. At one of these localities, 0.5 mile N.70°E. of Miltonboro, approximately 60 feet of deeply weathered, friable sandstone is exposed in the small hill encircled by the 300 foot contour line. At the other, 0.6 mile southwest of Oakland, a clean, white quartzite with many veins of secondary quartz is exposed.

Thickness: The Rugg Brook is rarely over 100 feet thick in the western part of the area. However, in the vicinity of Bradley Hill and Miltonboro approximately 450 feet have been assigned to this formation.

Near Oakland the Rugg Brook is less than fifty feet thick and pinches out rapidly to the south.

Paleontology and age: No fossils have been reported from the Rugg Brook. Because of the absence of fossils and the similarity to the underlying Winooski Dolomite, it is very difficult in much of the area to place the lower limits of this formation exactly. Dolomitic conglomerates, where observed, have been assigned to the Rugg Brook. The contact between the Winooski and the Rugg Brook from Miltonboro south to the Lamoille River has been drawn with uncertainty and is shown on the geologic map with question marks.

Woods Corners Group[1]

Shaw (1958, p. 536) proposed the name Woods Corners group to include the Mill River Conglomerate, Skeels Corners Formation, Rockledge Conglomerate, Saxe Brook Formation, and Hungerford shales of the St. Albans area. This is justified as all five of the formations show similar faunas and are believed to constitute an essentially continuous depositional sequence. As will be shown below, the writers believe that the Danby Formation grades laterally with formations of this group toward the north and east. Thus, the Danby Formation is considered in this report to belong to the Woods Corners group. The Woods Corners group correlates with Clark's (1939) and Dennis' (1964) Sweetsburg Formation to the north.

Danby Formation

General statement: Keith (1932, p. 396) identified two separate for-

[1] The Woods Corners Group as defined by Shaw contains fossils assigned to the *Cedaria* assemblage of Dresbachian age. Wilson (1943) and Shaw (1958) have concluded that the Cedaria zone may be correlative with the Middle Cambrian of Europe. Shaw (1958) uses these fossils as evidence of a Middle Cambrian age for the Woods Corners Group of Vermont. Cady (1960, Pl. 3) follows Shaw.

mations: the Danby Formation consisting of sandstone, quartzite, and dolomite, and the Wallingford Formation consisting predominantly of dolomites. Cady (1945, p. 535) has included both of these formations within the Danby and uses the term Wallingford as an upper dolomitic member. This upper member has not been identified in the Milton area.

Distribution: The Danby Formation is exposed in a belt 0.5 mile wide in the western part of the area extending from the southern boundary north about 12 miles where it is covered by a large Pleistocene delta of the Lamoille River. The present position of the Lamoille River is south of this sand plain. Nowhere north of these deltaic deposits do typical beds of Danby outcrop. It is also absent in the eastern part of the area.

Description: The Danby Formation is the most arenaceous dolomite in the Milton area. Beds of gray dolomitic sandstone, six to twelve inches thick, are separated by thicker beds of sandy dolomite. The characteristic alternation of sandstone and dolomite makes it possible to determine the attitude of the Danby Formation more readily than that of the massive dolomites above and below. On the western slope of the hill east of Munson Flat, two miles N.10°W. of Colchester, the sandstone predominates and is sufficiently indurated to be termed a quartzite. Here massive beds of white quartzite, six to eight feet thick, are separated by beds of brown-stained dolomitic sandstone.

There are also seams of shale in the Danby; the two most prominent are near the base of the formation. One exposure on the slopes behind the barn of the Elm Hill farm, 1.25 miles N.35°W. from Colchester, contains approximately 35 feet of black shale interbedded with sandy shales and dolomites. In the bed of Indian Brook, just west of U. S. Route 7, another exposure reveals an outcrop of black shale three to six inches thick. Keith (1932, p. 397) mentions seams and layers of greenish slate associated with the Danby beds in west-central Vermont.

Near the top of the Danby, three elongate mounds of limestone outcrop 0.8 mile N.45°W. of Colchester. These features are similar to limestone mounds (bioherms; footnote, page 39) in the Skeels Corner Formation. At this locality the rest of the Danby Formation is highly arenaceous and somewhat friable. Insoluble residues show that the Danby here is about 60% detrital material (Fig. 4). Most of the detritus consists of rounded and frosted grains of quartz averaging about 2 mm. in diameter.

The presence of these shale beds and limestone mounds associated with the Danby and the lack of typical Danby outcrops in the eastern part of the area and north of the sand plain west of Arrowhead Mountain has led the authors to believe that the Danby interfingers with and changes laterally into shale formations of the Woods Corners group.

Thickness: South of this area the Danby has been reported to be as much as 800 feet thick (Cady, 1945, p. 536). Nowhere in the Milton area does the Danby exceed 550 feet.

Paleontology and age: Other than possible worm borings in a dolomitic sandstone on the Collins farm, 1.4 miles N.30°W. of Colchester, no fossils were seen in the Danby Formation. Fucoidal markings and possible trails of organisms were all that a day-long search in the shale members on the Elm Hill farm revealed.

Thus no fossils have been found in the Milton area to date the Danby Formation. However, the interfingering of the Danby north and east with the lower formations of the Woods Corners group would indicate a Middle Cambrian age. Rodgers (1937, p. 1575) has suggested that the equivalents of the lower portions of the Danby at Whitehall, New York, are presumably Dresbachian.

Skeels Corners Formation

General statement: The extensive black slates and shales in this part of Vermont were originally assigned to the *Georgian* by Walcott (1891). These slates have also been included in the Hungerford Formation of Schuchert (1937) and the Georgia Formation of Keith (1923, 1932). They have thus been regarded as being from Lower Cambrian to Lower Ordovician in age. Howell (1939a) proposed the term Skeels Corners Formation to include a lower portion of these slates which contain the horn-shaped fossil, *Bovicornellum vermontense.* Shaw (1958, p. 539) has extended this original definition to include all the beds in the St. Albans area that lie between the Mill River and the Rockledge conglomerates.

Distribution: The Skeels Corners Formation occupies a belt 0.25 to 3 miles wide that extends north-south throughout the center of the Milton area.

Description: The typical exposures of this formation are black slates or shales with thin limonite-stained sandstones. These limonitic layers range from 1/16 to 1/2 inch thick. Where these layers are absent it is difficult, and in most cases impossible, to determine the attitude of the bedding. The greatest development of these limonitic bands is in the northern part of the area (Plate IV, Fig. 3). To the south a few of these bands still persist, but more commonly the bedding is shown by white-calcareous sandstone or thin layers of limestone.

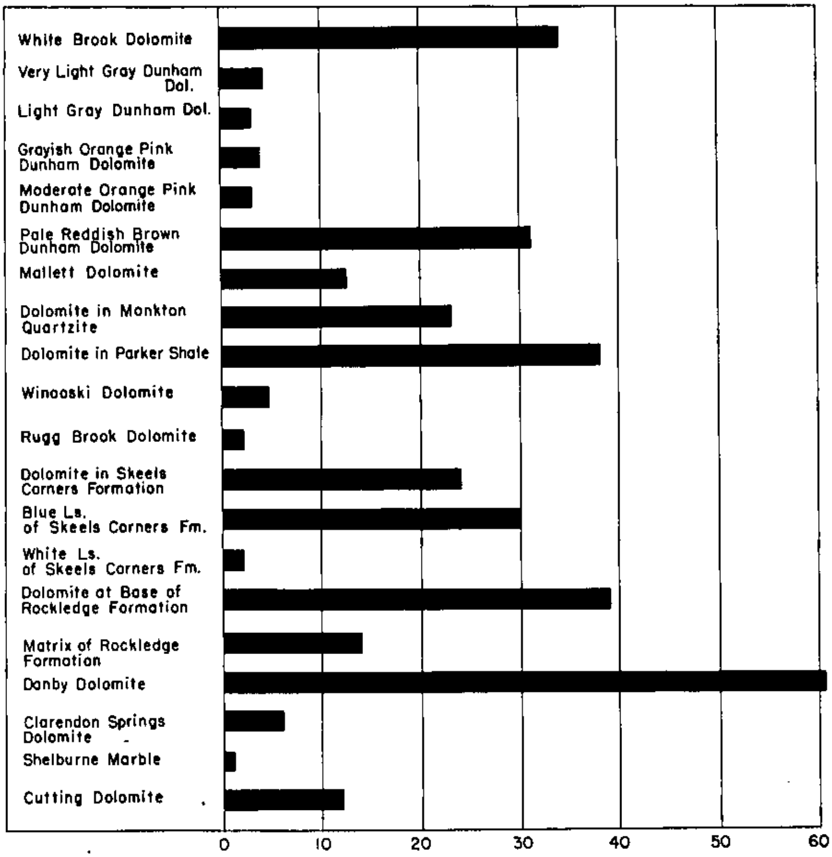
The Skeels Corners includes many lenses of arenaceous dolomite and dolomitic sandstones. In some places the sandstone is indurated enough to be termed a quartzite. The greatest development of these dolomitic and arenaceous beds is near the base of the formation. None were observed south of Côbble Hill.

Near the top of the formation, in the vicinity of Cobble Hill and farther south, the Skeels Corners contains two conspicuous beds of limestone conglomerates reaching a maximum thickness of 80 feet. The limestone boulders, the largest of which is approximately one foot in diameter, are much smaller than the fragments of the overlying Rockledge Formation. The matrix is more calcareous than that of the Rockledge and contains rounded sand grains which stand in relief on a weathered surface. The boulders have been stretched and distorted during the deformation, and cleavage cuts the boulders as well as the matrix of the conglomerate.

A conglomerate with fragments of dark, argillaceous dolomite embedded in a light-colored arenaceous dolomite was found in two places. The darker fragments are flat plates never exceeding two inches in length. They appear to be a sharpstone conglomerate as defined by Shrock (1948, p. 208).

Reef-like masses of dark-blue to black limestone (bioherms; footnote, page 39) form conspicuous mounds in the Skeels Corners Formation. The largest of these, exposed on the north side of the road two miles west of Georgia Center by Bench Mark 266, is approximately 500 feet long, 200 feet wide, and stands today as a mound some 30 feet above the surrounding shales. Some of these limestone masses have been broken and large blocks of the material are embedded in the surrounding shales. In the central and southern part of the area these limestone masses do not form low mounds but outcrop as lenses in the surrounding shales (Plate IV, Fig. 4). White and light-gray limestone is as common in the southern part of the area as the dark-blue variety is in the north. The conglomeratic limestone south of Cobble Hill undoubtedly could have been formed from the broken fragments of some of these more continuous calcareous lenses. The white limestone lenses are exceptionally pure with angular, freshly broken quartz grains as the chief residual constituent. The dark-blue limestone contains much clay and a carbonaceous scum is present in the residues (Fig. 4).

Thickness: Because of the incompetency of the shales this formation has been deformed to a greater degree than the other beds in the area,



PERCENTAGE OF INSOLUBLE RESIDUES OF CERTAIN ROCKS OF THE MILTON AREA, VERMONT

Figure 4. Graphic presentation of the percentages of insoluble residues of some rocks in the Milton area, Vermont.

rendering it almost impossible to determine the thickness of the formation. However, by plotting the attitudes available in the northern part of the area, the thickness of the Skeels Corners Formation can be estimated to be approximately 750 feet. It thins appreciably to the south where it changes to a more calcareous facies.

Paleontology and age: The black shales in the northern part of the area produced numerous fossils. Those collected have been given to Shaw and were used by him in the presentation of various papers on the fauna of northwestern Vermont. The forms collected in the Milton area include:

Bovicornellum vermontense	Howell
Armonia franklinensis	(Howell)
Catillicephala sp. undet.	
Bolaspidella macgerriglei	
Solenopleura vermontensis	Howell
Lingulella vermontensis	Howell
A new linguloid genus	
Oboloid brachiopods	
Hyolithes sp.	

Several of these forms have been identified in the St. Albans Shale by Howell (1937), and a Middle Cambrian age is suggested. The fossils listed above, together with others known from the same formation in the St. Albans area, indicate that the Skeels Corners is assignable to the *Cedaria* zone, which Wilson (1954) and Shaw (1958) assign to the Middle Cambrian.

Rockledge Formation

General statement: Schuchert (1937, p. 1049) introduced the name Rockledge limestone breccia for the Upper Cambrian rocks that have a lithology similar to the Mill River Conglomerate and Corliss Breccia of the St. Albans area. Shaw (1958, p. 542) recently suggested a "more noncommittal name," Rockledge Conglomerate. However, both these terms, limestone breccia and conglomerate, are too limited in their meaning. The Rockledge has various rock types within it, so that the authors of this paper have called it the Rockledge Formation.

Distribution: The Rockledge is a discontinuous formation overlying the Skeels Corners Formation. It occurs west of Georgia Center and at two localities southeast of Cobble Hill.

Description: The typical Rockledge is a coarse oligomictic breccia composed of light-gray limestone boulders in a matrix of arenaceous limestone, or, in some places, a sandy dolomite. The sand grains of the matrix stand in relief on weathering. The bedding of the formation is obscure. However, in many exposures an alignment of the sand grains in the matrix is helpful in determining the attitude of the beds. The percentage of insoluble residues is as high as 14%. Most of the residues are of clay size.

Limestone fragments in the Rockledge range from an inch to tens

PLATE V

Figure 1. Large limestone boulder in the Rockledge Formation west of Georgia Center.

Figure 2. Typical outcrop of conglomeratic Rockledge Formation west of Georgia Center.

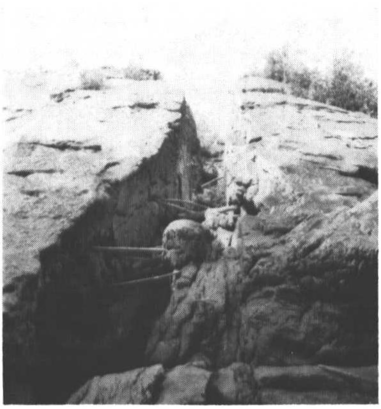


Figure 3. Large dike at Milton Power Plant. Located in a fracture zone and deeply weathered to form small chasm.

Figure 4. The hand is placed at the fault contact between Cheshire Quartzite and Dunham Dolomite along Hinesburg thrust. Because of the more resistant nature of the Cheshire it overhangs the dolomite. Located in woods above railway tracks 0.4 mile west of the north end of Colchester Pond.

of feet in length (Plate V, Fig. 1). These limestone fragments are similar in composition to the limestone mounds of the Skeels Corners Formation

PLATE VI

Figure 1. Cheshire-Skeels Corners fault contact along Hinesburg thrust. Hammer head is at fault contact. In field across road from former Milton School No. 3. One quarter mile south of BM 285. (Approx. 44° 35'N + 73°07'W)

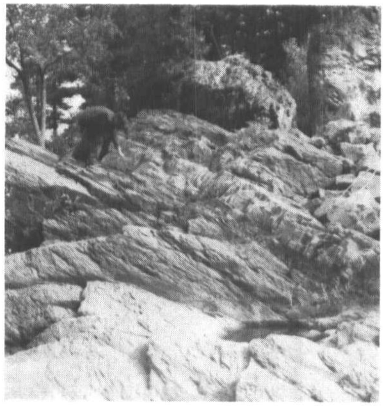


Figure 2. Hammer head at contact of the Skeels Corners Shale and rocks of the Arrowhead Mountain klippe. On south side of small island to rear of Milton power plant.

Figure 3. Arrowhead Mountain, a conspicuous topographic feature north of Milton village. Structurally this is part of a large klippe. The klippe is composed mainly of Cheshire Quartzite whereas the gentler slopes of the foreland are of shales of the Skeels Corners Formation. View looking northeast.

and are considered to be the result of a fragmentation of them (Plate V, Fig. 2). Shaw (1958, p. 546) discusses the origin of these breccias in detail.

The base of the formation is a thick sandy dolomite. As much as

30 feet are present west of Georgia Center. The insoluble residues of this dolomite run as high as 39%, and the mineral composition is similar to the Mallett facies of the Dunham Dolomite. Shaw (1958, p. 543) states that in the St. Albans area the Saxe Brook Dolomite is "the northern equivalent of Rockledge Conglomerate, but the separate formation names are retained because of the lithologic difference between the two units." In a diagram following his discussion of the Saxe Brook he shows the arenaceous dolomite thinning to the south and underlying the Rockledge. This, however, was in the vicinity of Hungerford Brook, some 12 miles north of the outcrops west of Georgia Center. It is quite possible that this sandy dolomite below the Rockledge might be correlated with the Saxe Brook Dolomite in the St. Albans area. However, the writers feel that for the present this sandy dolomite should be included as a basal member of the Rockledge throughout the Milton area and that the term Saxe Brook should not be introduced at this time.

Thickness: Nowhere in the Milton area is the top of the Rockledge definitely indentified, but the preserved part of the formation is approximately 150 feet thick. At least 30 feet of this would be represented by the arenaceous dolomite that locally underlies the breccia.

Paleontology and age: The authors recovered no fossils from this formation in the Milton area. Raymond (1937), Schuchert (1937), and others have identified Upper Cambrian forms from the boulders of limestone as well as from the matrix. Shaw (1958) in restudying these forms assigns a Middle Cambrian age.

An unconformity at the base of the Rockledge has been described by Shaw (1958, p. 544) and by Schuchert (1937, p. 1060). The authors did not identify this break but inferred from the studies of others that the underlying incompetent shales were crumpled at the time of deformation while the more competent Rockledge was not thus affected. A pseudo-unconformity could have been produced which resembled the hiatus described by Schuchert but this could not account for the break as described by Shaw. The break, however, would indicate only a small interval, as the fossils of the Rockledge and Skeels Corners formations are closely similar in age.

Upper Cambrian or Ordovician

Clarendon Springs Formation

General statement: Cady (1945, p. 536) extended this formation into the Milton area from the type locality 65 miles to the south.

Distribution: The Clarendon Springs Dolomite forms an inverted V-shaped belt extending in the central part of the area north from the south boundary of the quadrangle. The apex of the V-pattern is attenuated northward through the central part of the area for approximately six miles to the latitude of Arrowhead Mountain. The breadth of outcrop seldom exceeds one mile and in most places averages 0.5 mile.

Description: This formation is a light-gray, massive dolomite. Irregular bodies of white quartz and chert, measuring up to six inches in diameter, stand in relief on the weathered surface. Other masses of white quartz line cavities and veins. This quartz stands in relief on weathering and is particularly noticeable at the northern exposures N.40°W. of the village of Milton and in the region west of Malletts Creek two miles north of Colchester. Elsewhere in the area quartz and chert are present but not so concentrated.

Sand grains are present but not to the extent observed in the underlying Danby Formation. The insoluble residues show about 6% of detrital material. The residues also produced a number of chert balls averaging 5 mm. in diameter. These are similar to chert spherules described by Hills (1935) in the Cambro-Ordovician limestones and dolomites of Pennsylvania. Detrital fragments of magnetite are present in the residue. This mineral has not been found in the residues of previously discussed Cambrian beds.

Thickness: At least 500 feet of dolomite assigned to the Clarendon Springs Formation have been mapped in the Milton area. The scarcity of visible bedding planes makes it difficult to determine the attitude; the estimate of the thickness might be less if the structural relations could be worked out in more detail.

Paleontology and age: In the summer of 1932 Ulrich, Bridge, and Ruedemann discovered a fossil locality associated with cherts in a sandy dolomite 3.5 miles southwest of the village of Milton and 0.75 mile west of Cobble Hill. The fauna was never described in detail so that when Alan Shaw (1949) worked on the stratigraphic relations of the Gorge Formation in the St. Albans area he had these collections sent to Harvard from the United States National Museum and the Yale Peabody Museum. Preston E. Cloud and Franco Rasetti examined this collection of fossils and supplied Shaw with a list of the genera and species present (Shaw, 1949, p. 138–140). This list includes the following:

Trilobita	
Aposolenopleura cf. *A. dunbari*	Raymond
cf. *Calymenidius tuberculatus*	Rasetti
Hungaia magnifica	(Billings)
Kainella ? sp.	
* *Lecanopleura* ? sp.	
Levisella brevifrons	Rasetti
Levisella sp.	
* *Onchontus richardsoni*	(Walcott)
Onchontus sp.	
* *Platycolpus* (1 or 2 spp.)	
Pseudosaukia sesostris	(Billings
Pseudosaukia sp.	
* *Punctularia* ? sp.	
Richardsonella sp.	
Stigmametopus levisensis	Rasetti
Brachiopoda	
Finkelnburgia sp.	
Mesonomia sp.	
Palaeostrophia elax	(Clark)
Gastropoda	
Scaevogyra elevata	Whitfield

Those genera marked with an asterisk (*) are common to the Gorge Formation of the St. Albans area. "The association of *Platycolpus* and *Scaevogyra*, as is found in the Milton (= Clarendon Springs Dolomite), is regarded by the Cambrian Subcommittee (Howell and others, 1944) as characteristic of the lowest Trempealeauan rocks. It seems reasonable, therefore, that the Milton (= Clarendon Springs) Dolomite should be correlated with the lower dolomitic portions of the Gorge Formation." (Shaw, 1949, p. 140).

The authors of the present report discovered a locality 1.2 miles N.35°E. of Colchester. Here silicified fossils stand in relief on the weathered surface of the dolomite. Blocks of the rock were digested in acid but only a few specimens were obtained. It is hoped that further collections may be made at this locality so that a larger fauna will be available for study.

The few fossils collected are cephalopods and brachiopods. The cephalopods were examined by Rousseau H. Flower then of the New York State Museum and identified as *Ellesmeroceras* sp. of lowest

Ordovician age. The preservation of the few brachiopods recovered is so poor that identification is not possible.

This fossil locality lies in the upper half of the Clarendon Springs Dolomite. The exact stratigraphic position is difficult to determine as an overthrust of the Skeels Corners Formation covers the complete section. The trace of this fault lies about 500 feet to the east of the fossil locality. However, the upper portions of the Clarendon Springs Dolomite in the Milton area can be considered Lower Ordovician in age and thus the system boundary is located within the formation.

The position of Keith's "Milton Dolomite": This term was originally introduced by Keith (1923, p. 112) for the great succession of sandy dolomites exposed above the Mallett facies of the Dunham Dolomite three miles west of the village of Milton. He assigned these dolomites to the Upper Cambrian. The formation name included beds referred to in this paper as dolomites of the Parker, Winooski, Rugg Brook, Danby and Clarendon Springs formations. Keith also extended the name *Milton* north to the Canadian border so that it included the Gorge Formation of the St. Albans area. His *Milton* thus included all the formations overlying the Parker shales and beneath the Shelburne Marble. To the south in west-central Vermont, Keith (1932, p. 397) assigned the name Clarendon Springs Dolomite to beds of "fine grained dolomite of a light-gray or dove color" that lay below the Shelburne Marble.

Because of the discovery of Middle Cambrian fossils in black shales of the St. Albans area (St. Albans Shale, directly above Rugg Brook Dolomite) which Keith interpreted as overlying his *Milton*, he (Keith, 1932, p. 372) changed the age of the Milton to Lower Cambrian.

However, in the summer of 1932, as discussed on a previous page, Ulrich, Bridge, and Ruedemann discovered the silicified Upper Cambrian fossils associated with cherts in sandy dolomites 3.5 miles southwest of the village of Milton and 0.75 mile west of Cobble Hill. Schuchert (1933, p. 369) consequently regarded the *Milton* Dolomite as Upper Cambrian, the original age assigned by Keith. Schuchert (1937, p. 1046) again emphasized the position of the *Milton* by stating that, "all of these more northerly Lower Cambrian '*Miltons*' must be excluded, and the term restricted to the original meaning—namely, to the Upper Cambrian dolomites southwest of Milton, and to its equivalents." This, however, was not the original meaning, but it clarified the situation somewhat and the fossil locality of Ulrich and others was adopted as the type locality of the *Milton*.

On his map of west-central Vermont, Cady (1945) extended Keith's

Clarendon Springs Dolomite—which underlies the Shelburne Marble and which Keith (1932, p. 361) originally correlated with the *Milton* Dolomite—to this area but did not include the type locality of the *Milton* within it. Cady maps this locality as part of the Danby Formation, probably because of the lower Upper Cambrian (Dresbachian) age assigned to the *Milton* by Schuchert (1937, p. 1047).

The authors of the present report have mapped the *Milton* type locality within the Clarendon Springs Dolomite. This limitation can be justified in that the type *Milton* and at least the lower parts of the Clarendon Springs have been regarded as Trempealeauian in age, that they have a similar lithology, that both were assigned original positions below the Shelburne Marble, and that no structural evidence precludes this possibility. The term *Milton* should be dropped as a formation name because of the complexities and misunderstandings in its meaning; the rocks assigned to it should be included in the Clarendon Springs Dolomite.

Lower Ordovician

Shelburne Formation

General statement: Keith (1923, p. 117) assigned the name Shelburne to the white marbles that overlie his *Milton* Dolomite in the vicinity of Shelburne, Vermont, some 20 miles south of this area.

Distribution: The best exposures of the Shelburne Marble are within a mile of Colchester. Farther south the formation is almost entirely covered by sands of an old delta of the Winooski River. However, a few outcrops appear where post-glacial streams have cut through the sand cover.

Another exposure of rocks assigned to the Shelburne is found in an isolated patch 0.75 mile northwest of Cobble Hill. The lithology here differs from the main mass of Shelburne to the south, but it occupies the same stratigraphic position above the Clarendon Springs.

Description: In the southern part of the area the formation consists mainly of a light-gray marble with thin irregular lenses and veins of sandy dolomite. These, being more resistant than the marble, stand as small ridges on the weathered surface. This "chaining" or "curdling" effect is a characteristic feature of the Shelburne (Cady, 1945, p. 540). Beds as much as 20 feet thick occur in the marble. The insoluble residues show about 1% clastic material which is predominantly clay size. The minerals identified were quartz, biotite, muscovite, and magnetite.

On the north side of the large ravine 0.75 mile northwest of Cobble Hill, a black argillaceous limestone with white limestone bands a fraction of an inch thick lies above the Clarendon Springs Dolomite. These white limestone bands give a definite "pin stripe" effect to the beds. Within a mile to the north of this ravine the thickness of the limy beds has increased to two or three inches and the limestone beds are separated by beds of black calcareous shale one to two inches thick. These rocks are similar to the banded blue limestone of the Highgate Formation in the St. Albans area described by Shaw (1958, p. 550).

These beds northwest of Cobble Hill unquestionably lie stratigraphically above the Clarendon Springs. Thus they may be correlated with the Shelburne Marble to the south, because they have the same stratigraphic position. Because of similar lithology the authors have also correlated them with the Highgate Formation of the St. Albans area.

Thickness: The limits of the Shelburne Marble are not well known because of the glacial cover in the area. However, with the information available, the thickness may reach a maximum of 700 feet. In west-central Vermont, Bain (1931, p. 509, 523) lists a maximum thickness of 600 feet in the vicinity of Brandon. Cady (1945, p. 541) notes that the Shelburne thins and thickens along the strike. This might possibly be due in some places to erosion of the upper contact of the Shelburne Marble. A disconformity was found in the vicinity of Colchester and is described in the discussion of the Cutting Dolomite.

Paleontology and age: No fossils were found in the Shelburne Marble in the Milton area. In west-central Vermont fossils are scarce in this formation and give little evidence concerning the age. Cady (1945, p. 541) tentatively correlates the marble with Beekmantown B division. As noted above, the Shelburne can be correlated on lithology with the Highgate Formation of the St. Albans area, which Raymond (1937, p. 1134) identifies as Lower Ordovician rather than Upper Cambrian in age.

Cutting Formation

General statement: Cady (1945, p. 541) assigned this name to the beds above the Shelburne Marble and below the limestones and dolomites of the Bascom Formation in the eastern part of Shoreham township, eight miles northwest of Brandon, Vermont.

Distribution: The Cutting Dolomite represents the highest stratigraphic unit observed in the Milton area. It is located in a small V-shaped wedge along the south-central border of the area. Only two outcrops were located. These were in tributary streams of Indian Brook which have cut through the thick cover of sand in the region.

Description: The Cutting is a gray dolomite with an abundance of darker gray, well-rounded, frosted quartz grains. The basal three or four feet of the formation are exceptionally sandy and friable, held together by a dolomitic and calcareous cement. This formation lies with a distinct disconformity on the underlying Shelburne. This can be seen at Devil's Den on a tributary of Indian Brook 1.3 miles S.25°E. of Colchester. The stream has eroded a flume along joints of the Cutting Dolomite and the underlying Shelburne Marble. On the cliffs west of the flume the disconformity is well exposed. The Shelburne has been channelled to a depth of three feet, and the dolomitic sands of the Cutting have been deposited on this erosion surface.

Insoluble residues showed frosted and rounded sand grains up to 2 mm. in diameter. Magnetite is also present in the formation. The residue examined showed about 12% detrital material.

Thickness: Only about 40 feet of Cutting is exposed in this area but undoubtedly the entire formation and perhaps part of the overlying Bascom Formation *is* present beneath the sand plain. Cady (1945, p. 542) lists 530 feet for the thickness of the Cutting Dolomite.

Paleontology and age: No fossils were found by the authors but worm borings assigned to *Scolithus* have been noted to the south of the Milton area in the basal sands of the Cutting Dolomite (Cady, 1945, p. 541). Other fossils in west-central Vermont in the upper Cutting have led Cady (1945, p. 540) to correlate this formation with the Beekmantown C division.

Middle Ordovician

Excellent exposures of interbedded black shale and blue-black dense limestone that belong to the Middle Ordovician Trentonian form steep cliffs along the east shore of Lake Champlain. These beds underlie the Champlain fault and belong to the foreland or autochthon over which the previously described succession has been thrust.

The shales, being incompetent, show evidence of great deformation. Calcite and quartz have been deposited in the joints and bedding planes of this shale. North of Camp Rich the shales are overlain by a more competent blue-black limestone which is light-dove-gray on the weathered surface. These beds of limestone have withstood the deformation of the area much better than the shales.

These foreland rock units are shown on the enclosed geologic map as undifferentiated Trenton rocks. Hawley (1957) has published a description of these units and the reader is referred to that report for a detailed discussion.

General statement: The only igneous rocks in the area are mafic dikes, mainly lamprophyres. Kemp and Marsters (1893) have described many of the mafic dikes in the Lake Champlain area but have done little work with those inland from the lake shore. In the Milton area they described only those found at the northeast corner of Malletts Bay. Dikes in the Middle Ordovician shales along the lake are not discussed in the present report because our area is delimited on the west by the Champlain fault.

Distribution: Thirteen dikes seen by the authors in the Milton area are listed in Table 3. All are located south of the latitude of Milton village.

Description: The dikes range in width from a few inches to 15 feet. Only the dike 0.9 mile west of Bald Hill can be traced for any considerable distance. Here a stream channel follows the dike for about 250 feet.

The dikes show two main directions of strike, either they parallel the cleavage, which is a few degrees east or west of north, or they conform with a major jointing which is a few degrees north or south of west. All have very steep dips, in most cases vertical.

In practically all instances the dikes stand some four to six inches in relief on the weathered surfaces of the enclosing rocks. The dike 0.9 mile west of Bald Hill is responsible for a four foot waterfall in the small tributary stream. However, the large dike on the small island near the Milton power plant weathers to form a small chasm (Plate V, Fig. 3). The southern deeply weathered extension of the dike illustrated in Plate V is located in a fracture zone where the mafic material makes up approximately one-half of the total width. The northern end of the dike is located along a major joint plane and is composed entirely of the mafic material. Most of the dikes show a chilled border which weathers to a lighter color than the main body of the dike.

Petrography: Kemp and Marsters (1893) list four main types of mafic dikes in this region; diabase, camptonite, monchiquite, and fourchite. A complete study of these dikes in the Milton area was not made by the authors, but a petrographic examination showed that most of them are composed mainly of soda amphiboles, soda pyroxenes, and plagioclase. Thus they could be classed as diabase, camptonite, and augite-camptonite. Large phenocrysts of biotite, up to one-half inch in diameter, are conspicuous in the dike one mile south of Checkerberry Village. None of the feldspathic porphyries, common south of Burlington, was noted in the Milton area.

Similar lamprophyres have been described elsewhere in northern

TABLE 3
MAFIC DIKES OF THE MILTON AREA, VERMONT

Locality	*Width*	*Strike*	*Country rock*	*Remarks*
2 miles N.40°E. of Fort Ethan Allen	10″	N.70°E.	Fairfield Pond	
0.7 mile S.30°E. of Brigham Hill	12″	N.15°E.	Fairfield Pond	
0.9 mile east of Brigham Hill	18″	N.10°E.	Fairfield Pond	
0.5 mile S.40°W. of Bald Hill	6″	N.30°W.	Dunham	
0.9 mile west of Bald Hill	8′	N.10°W.	Cheshire	can be traced 250′ along stream channel; responsible for a four foot waterfall.
1 mile S.60°E. of Cobble Hill	2′	N.85°W.	Skeels Corners limestone cong.	
NE corner of Malletts Bay	3′	N-S	Monkton	orbicular masses resembling pillows; sill-like in places.
0.2 mile north of NE corner of Malletts Bay	15′	N.70°W.	Monkton	vertical exposure of about 25′; dike narrows to 3′ at top.
1 mile south of Checkerberry Village	4′	N.85°W.	Clarendon Springs	
On island at Milton power plant	15″	N.70°E.	Dunham	
(dikes arranged in order on traverse NW-SE along NE side of island)	4′	N.65°E.	Dunham	south end of dike located in fracture zone and deeply weathered (Plate V, Fig. 3).
	17″	N.65°E.	Dunham	
	4″	N.60°E.	Dunham	

Vermont: e.g. by Konig and Dennis (1964) in the Hardwick area, and by Woodland (1962) in the Burke area.

Age: These unmetamorphosed mafic dikes may be related to the White Mountain plutonic-volcanic series (Billings, 1956). Lead-alpha radiometric measurements of selected rocks of this series give a mean age of 186 ± 14 million years (Lyons and others, 1957). This would indicate a late Triassic age (Kulp, 1961).

Recently Woodland (1962) has made a detailed study of related lamprophyres in the Burke area. Woodland suggests that the lamprophyres may be more closely related to the Monteregian intrusives than to the White Mountain plutonic-volcanic series. The Monteregian rocks are considered to be Jurassic, possibly early Cretaceous (Larochelle, 1962, p. 40).

STRUCTURAL RELATIONSHIPS

General Statement

Structural features in the Milton area follow the north-south trend noted by Cady (1945, p. 562) in west-central Vermont. Two major thrusts dominate the structure, the Champlain thrust on the west and the Hinesburg thrust on the east; several minor thrusts are also present. Two major synclines, one anticline and countless smaller folds are present. Three klippen are erosional outliers of the eastern thrust sheet. These features are shown diagrammatically in Figure 5.

Thrust Faults

Champlain Thrust

This thrust extends throughout the area roughly paralleling the east shore of Lake Champlain. The fault plane lies at the base of the steep cliffs of Dunham Dolomite that border the eastern shores of the lake. Thrusting along this fault has placed Lower Cambrian dolomites over the Middle Ordovician shales and limestones. The stratigraphic throw is approximately 9000 feet.

At no place in the Milton area was the fault visible, but at numerous localities the trace of the fault could be delimited within about five feet. At Lone Rock Point in the Burlington quadrangle, one mile south of the Milton area, the slickensided surface of this fault is visible (Schuchert, 1937, Plate 3). Here the average dip of the fault plane is 17°E. (Longwell, 1933, p. 70). However, the first author of the present report made a north-south traverse along the western slopes of Lone Rock Point and recorded only 12°E. for the maximum dip of the fault surface. The average was approximately 10°E. If one assumes a constant dip for the fault plane, the minimum net slip may be calculated to be approximately six to ten miles. However, if the angle of the fault plane increases with depth the net slip would be less. Cady (1945, p. 568) shows a displacement of approximately 20 miles for the Champlain thrust in the latitude of Milton.

The thrust undoubtedly developed as a strip fault, as the overlying Dunham Dolomite shows little deformation. The dip of the Dunham

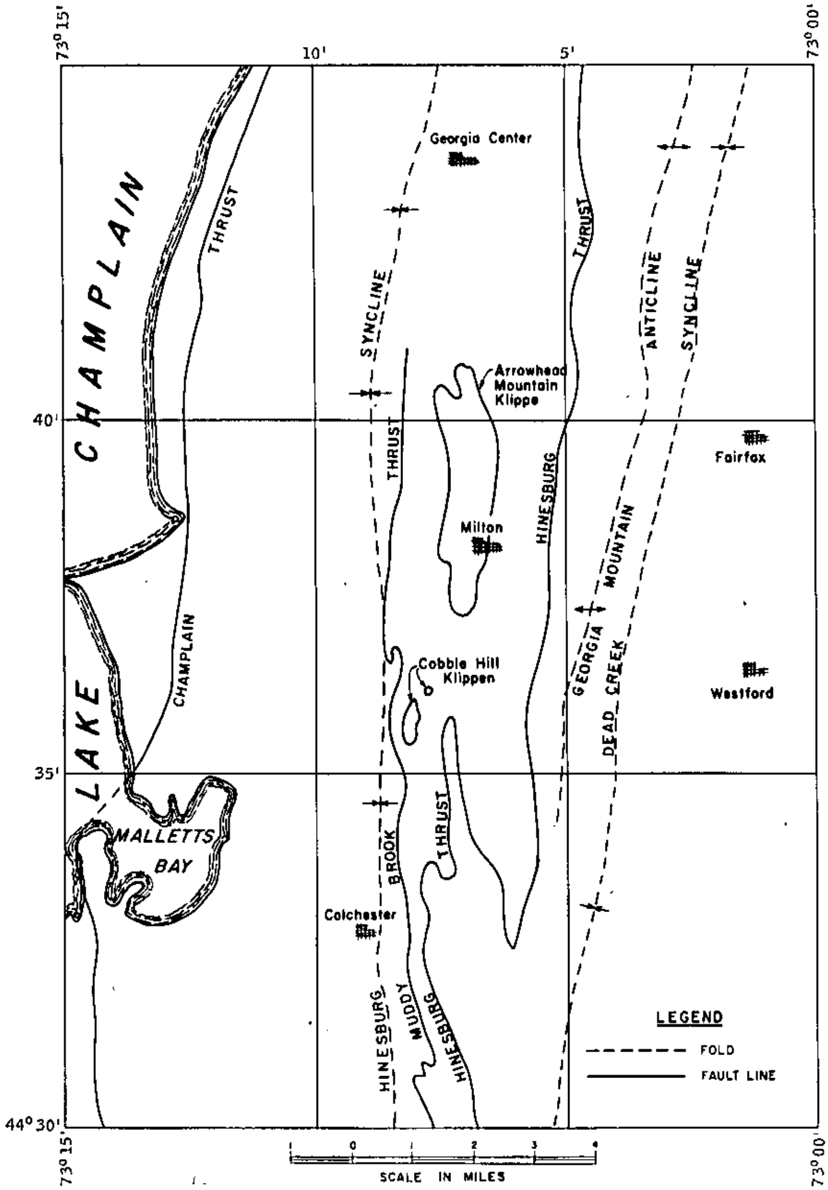


Figure 5. Major structural features of the Milton area, Vermont.

beds closely parallels the dip of the fault plane. Small east-plunging anticlines, the axes of which strike perpendicular to the line of the Champlain fault, have been developed in the competent Dunham Dolomite.

Hinesburg Thrust

Along the escarpment west of Wagner Hill and Georgia Mountain, the quartzites and graywackes of the Cheshire Formation overlie the Dunham Dolomite. This may be due to overturning of the beds along the east limb of the Hinesburg synclinorium in one of its minor folds, or to thrusting. Thrusting is normally only postulated when there is good field evidence for it. Such evidence is here restricted to a few localities. Away from these localities, thrusting may well pass into an unbroken overturned sequence, but for simplicity's sake the contact concerned is drawn through as a thrust on the map and structure sections accompanying this report. This is the Hinesburg thrust.

The first mention of the Hinesburg thrust is by Keith (1932, p. 364), in the vicinity of Hinesburg, Vermont. On his Fig. 1, Keith continued this same thrust into the St. Albans quadrangle. Cady (1945) first mapped the Hinesburg thrust in detail. He also recognized a thrust north of the Winooski River, but believed that this was Clark's (1934) Oak Hill thrust (Cady, 1945, p. 566 and Pl. 10). Since then Cady (oral communication, 1960) has mapped the critical area in detail, and is satisfied that the Hinesburg thrust is the same as that which runs along the base of the Fairfield Hill escarpment farther north.

A thrust contact along the strike of the Hinesburg thrust was mapped by Booth (1950). In the St. Albans area it was recognized by Shaw (1958) after Booth. In all these areas an alignment of klippen in the foreland is a good indication of thrusting along the Fairfield Hill escarpment to the east. In the Milton area, cross-cutting relationships around Colchester Pond are satisfactory direct evidence of thrusting along the (topographically) lower contact of the Cheshire. Remnants of Dunham Dolomite below the thrusted Cheshire in the Colchester Pond area, as well as in the Bridgeman Hill (St. Albans area to north) and Arrowhead klippen suggest that the thrust represents the drawn-out forelimb of an overturned fold.

Booth (1950) was not certain about the correlation of this thrust with the Hinesburg thrust and he used local names for thrusts inferred to exist north of the Winooski river. Booth's Brigham Hill thrust shown on his geologic map can be traced north of Essex Junction until it crosses Indian Brook at the latitude of Colchester. The present survey specifically checked its postulated continuation northeast of that point, but could find no evidence for it. Rather, it here seemed to merge into the Dunham-Cheshire contact, and to continue from there into the St. Albans quadrangle. Most of what Booth (1950) and Shaw (1958) called Fairfield Pond thrust is, therefore, the northward continuation of the Hinesburg thrust, with its location revised in several places. To the north, in southern Quebec, Rickard (written communication, 1960) has found evidence of thrusting along the same contact. Moreover, Rickard suggests that this thrust passes upward in the stratigraphic succession toward the north, and most likely becomes Clark's (1934) Oak Hill thrust near Dunham, Quebec.

From the vicinity of Brigham Hill northwestward to Mallets Creek and then southward to the southern boundary of the quadrangle, the Cheshire quartzites are in contact with and overlie the Skeels Corners Formation. The thrust plane cuts high in the Cheshire Formation, because a small area of typical Dunham Dolomite lies conformably on Cheshire just east of the Colchester railway siding. The transitional "punky" zone, characteristic of the Dunham-Cheshire contact in the eastern part of the area can also be observed at this point.

Blocks of Dunham Dolomite, varying in size up to 0.7 mile long and 0.2 mile wide underlie the Cheshire in many places. These blocks may have been dragged along the Hinesburg thrust surface by the resistant quartzites. The rocks in these blocks are highly fractured and lack the good bedding which is characteristic of the Dunham of the eastern limb of the Hinesburg synclinorium. The photograph in Plate V, Fig. 4, shows a well exposed contact between the Cheshire Quartzite and an underlying block of Dunham Dolomite 0.4 mile west of the north end of Colchester Pond. At this locality the fault surface is horizontal. Because of the resistant nature of the Cheshire, it overhangs the underlying dolomite.

Shales and limestone conglomerates of the Skeels Corners and the Rockledge formations of Upper Cambrian age lie beneath the fault. The fault plane, with the Cheshire Quartzite in contact with a limestone conglomerate of the Skeels Corners Formation, can be observed for a considerable distance on the Desranleau farm, 3.5 miles south of Milton and 0.5 mile south of BM 285 along the Central Vermont railway. The fault surface south of the farm, 0.1 mile east of the railroad underpass, strikes N.10°E. and dips 44°W. (Plate VI, Fig. 1).

Brigham Hill is capped by Cheshire Quartzite of this thrust sheet. This quartzite overlies Dunham Dolomite of the eastern limb of the large synclinorium of the area. The fault contact may be observed near the summit of the hill. The fault surface strikes N.10°W. and dips 30°W.

The rocks west of the Hinesburg thrust were folded prior to the thrusting because small synclinal remnants of a limestone breccia of the Rockledge Formation are found between the faults and the outlying klippen. These were synclines before the thrusting, and have been truncated by the thrust; otherwise they would have been stripped off by the thrusting. The east-west expanse of Dunham Dolomite in the reentrant of the thrust sheet just west of Bowman Corners would also have been stripped off had not the south plunge of the Georgia Mountain anticlinorium been developed before the thrusting.

Deformation following faulting is suggested by the changes of elevation along the line of the fault and also by the variation in dip of the fault plane at previously described localities where it can be observed.

Muddy Brook Thrust

The Muddy Brook thrust extends about nine miles north from the southern boundary of the area where it is lost in the great expanse of black shales of the Skeels Corners Formation in the vicinity of Arrowhead Mountain. The Skeels Corners on the east side of the fault are thrust westward over the Upper Cambrian and Lower Ordovician limestones on the east limb of the Hinesburg synclinorium.

Two exposures offer definite evidence for the fault in the Milton area. One is on the 400-foot hill, one mile east of Fort Ethan Allen. Here the Upper Cambrian Skeels Corners Formation rests on the Shelburne Marble of Ordovician age. A horizontal fault contact can be seen on the north side of the hill near an abandoned log cabin. Exposures 1.5 miles south of Checkerberry Village also demonstrate this fault. Rocks assigned to the Shelburne Formation lie in a small syncline; vertical beds belonging to the Skeels Corners Formation rest on these Ordovician rocks on the east limb of this fold. The Clarendon Springs Dolomite is missing. The fault contact can be located within about ten feet. It would be impossible to bring up the formations from the west limb of the synclinorium in this space. In all other places than these two exposures the Skeels Corners Formation in the Muddy Brook thrust sheet overlies and is in contact with the cherty dolomites of the Cambro-Ordovician Clarendon Springs Dolomite.

The Muddy Brook thrust probably developed in the incompetent shales as the Hinesburg thrust sheet overrode the area. The net-slip and the stratigraphic displacement along the Muddy Brook fault increase to the south because the westward extension of the Hinesburg fault is greater in that region. In the southern part of the Milton area the stratigraphic throw is approximately 1,000 feet.

The type locality of the Muddy Brook is west of Williston, approximately five miles south of the Milton area, where Upper Cambrian shales and conglomerates overlie Beekmantown rocks on the east limb of the Hinesburg synclinorium (Cady, 1945, p. 574). Cady believed that northward from the type locality the Muddy Brook fault passed beneath the Hinesburg sheet. However, in correspondence with Cady (May, 1950) the Muddy Brook fault is so shown because of the lack of outcrops in the drift covered area between Williston and the south boundary of the Milton quadrangle. The similar relationships of the fault in the Milton area with those in west-central Vermont has led the authors to correlate these two faults.

Minor Thrusts

Many small thrusts appear in the shales but are too small to show on the scale of the geologic map.

These small thrusts show displacements of a fraction of an inch to a few feet and thus further complicate an accurate measurement of the thickness of the shale formations in the stratigraphic column. All the minor thrusts dip east, and strike slightly east of north.

The best exposure of these minor faults is observed on the hill 1.75 miles east of West Georgia. Here slickensides, mineralization, drag folds, and other phenomena are associated with the faults.

Minor thrusts are also well developed in the Cheshire argillaceous quartzites of the Georgia Mountain anticline in the eastern part of the area. At numerous localities the thin quartzite beds appear broken and thrust. This is especially true on the west limb of the fold.

Klippen

Three klippen, or tectonic outliers, lie west of the Hinesburg thrust. The two small southern klippen are in the vicinity of Cobble Hill and the large northern klippe, of which Arrowhead Mountain is a part (Plate V, Fig. 3), is a conspicuous topographic feature north of Milton.

Cobble Hill Klippen

The name Cobble Hill klippen is here proposed for the two small klippen in the southern part of Milton township. The smaller one caps the eastern slopes of Cobble Hill and has been reported by a number of previous workers. The fault plane of this small klippe dips steeply east some 200 feet east of the crest of the hill. The klippe, composed of Dunham Dolomite, overlies the Skeels Corners Formation. The Dunham Dolomite strikes N.20°E. and dips 40° east.

A much larger klippe lies on the southern flanks of Cobble Hill. No report of this has been found in the literature. Approximately 2,000 feet long, it attains a maximum width of 1,000 feet. It is composed of Dunham Dolomite with a central core of Cheshire Quartzite. On the east side of this klippe the Cheshire is in normal stratigraphic succession beneath the Dunham. This contact strikes N.10°W. and dips 60° east. The western contact of the two formations was not observed. Thus the true mutual relationships of the beds cannot be determined from the field evidence.

In the discussion of the Hinesburg thrust the authors have shown that folding preceded faulting and that the fault cut stratigraphically high in the Cheshire Formation. Since the Cobble Hill klippen are regarded as tectonic outliers of the Hinesburg thrust, the east and west contacts could be normal and this klippe might be part of an overturned fold.

Arrowhead Mountain Klippe

Arrowhead Mountain is a conspicuous topographic feature north of the village of Milton. It forms the north end of a large klippe extending three miles south to the vicinity of the Milton power plant. The name Arrowhead Mountain klippe is proposed here for this structural outlier of the Hinesburg thrust.

The klippe is composed mainly of massive Cheshire Quartzite that shows little bedding. On U. S. Route 7, just north of the village of Milton, in a road cut along the west side of Arrowhead Lake (the lake back of Milton dam), a slightly dolomitic portion of the Cheshire dips gently west. The same attitude is seen in the cliffs southwest of the summit of Arrowhead Mountain. The front, or the west side of the klippe, rests on black shales of the Skeels Corners Formation whereas on the east the klippe rests on overturned east-dipping or vertical beds of Dunham Dolomite. The shales to the west of the klippe dip gently east near the fault plane but farther west are overturned toward the west.

On the north and south the Cheshire of the klippe overlies a sheet or several small slices of Dunham Dolomite. The Cheshire appears in fault contact with the Dunham. It is logical to assume that a bifurcation of the fault allowed the Cheshire to override the Dunham Dolomite. On the southwest slopes of Arrowhead Mountain a large block of Dunham is exposed along the fault plane. This is evidently a block dragged along by the Cheshire during faulting.

The Dunham Dolomite resting on the shales of the Skeels Corners Formation is best exposed at the north and south ends of the klippe. At the Milton power plant, near the southern end of the klippe, a post-glacial gorge has excellent exposures of this Dunham Dolomite and also of its contact with the underlying shales. This is the best exposure of the fault contact in the Arrowhead Mountain klippe. At this locality the Dunham Dolomite and shales of the Skeels Corners Formation exhibit clear evidence of faulting. One of the most striking proofs is the manner in which the two formations have been wedged together. On the south side of the small island behind the power plant the fault contact is clearly observed (Plate VI, Fig. 2). It strikes N.15°W. and dips 26° east.

On this small island the first ten feet above this fault contact contains numerous lenses of shale and dolomite wedged into the face of the klippe. A 28-inch brecciated zone (at left center, Plate VI, Fig. 2) can be seen above a 30-inch quartzite lens.

On the south banks of the river, just behind the power plant, an almost complete section can be seen from the fault to the main mass of Dunham. In descending order from the main Dunham the following wedges can be observed:

6 feet of shale which thins to the north,
7 feet of Dunham dolomite, which pinches out to the north,
3 feet of shale,
3 feet of calcareous quartzite,
4.5 feet of shale,
5 feet of a brecciated layer (thins to the north and can be correlated with the brecciated layer mentioned above on the small island),
9 inches of quartzite,
Main mass of Skeels Corners shales.

These figures represent a maximum thickness of the units above the fault but they differ greatly along the strike; in some places they pinch out entirely.

Booth (1950, p. 1162) shows the fault at Arrowhead Mountain to be continuous north and south in the black shales of the Skeels Corners Formation. He states that "until the apparently unbroken stratigraphic succession from Arrowhead Mountain to the escarpment and beyond is disproved, it is the writer's opinion that the Milton-Arrowhead rocks do not form a klippe, despite the analogy of the distribution pattern of all other isolated hills in the Champlain Lowland north of the Winooski."

The Dunham dolomite on the Star farm, 0.5 mile north of Milton on the west side of the East Georgia road, is vertical with tops to the west, very steep west dips, or east dips with beds overturned. The Cheshire just north of Milton village along U. S. Route 7 shows gentle west dips. The attitudes described would place the Cheshire quartzites on top of Dunham beds, which is not a normal stratigraphic succession.

North of Arrowhead Mountain boulders of Dunham Dolomite are seen in the basal shales of the Skeels Corners Formation. These boulders are apparently not wedged into the shales as seen in the face of the fault described at the Milton power plant. They are interpreted by the authors as evidence of post-Dunham erosion.

The field evidence stated above has led the authors of the present report to accept Arrowhead Mountain as a fault outlier of the Hinesburg thrust. This is not unreasonable considering the nature of the movement along the Hinesburg fault south of Cobble Hill and the subsequent folding of the thrust sheets. The relationships as mapped make it entirely possible that the klippen of Cheshire and Dunham rocks slid from the rising anticlinorium, particularly the Georgia Mountain anticline. Harrison and Falcon (1936) and Jones (1961) have described the mechanics of this type of tectonic movement.

Thrust faults of previous workers

The Rosenberg thrust sheet as described by Clark (1934, p. 8) has been assumed to be one of several thrust slices east of Lake Champlain in northwestern Vermont and southern Quebec (Fig. 2). In Quebec this sheet is bounded on the west by the Rosenberg thrust; in northwestern Vermont, it is delimited by the Champlain thrust, a southern extension of the Rosenberg fault. The eastern boundary of the Rosenberg slice in southern Quebec is the Oak Hill fault. This fault has been shown in the Milton area by Cady (1945, p. 563) and others. Keith (1923, p. 99) describes another fault, the Mountain Border fault, as an eastern limit of the calcareous and argillaceous Central sequence in northwestern Vermont. This fault also has been described by many later workers as the eastern limits of the rocks of the Rosenberg or Central sequence of northwestern Vermont. The existence of the Oak Hill thrust cannot be demonstrated in the Milton area. The Mountain Border fault lies in the approximate position of the Hinesburg Fault of this report.

The Oak Hill fault was once considered necessary because the easternmost black shales of the Rosenberg slice or Central sequence had been incorrectly attributed to the Ordovician. These now have been definitely established as Upper Cambrian, and, to the north of the Milton area, as Middle Cambrian. Parker shales of Lower Cambrian age and Rugg Brook Dolomite of the Middle Cambrian also have been identified on the eastern limb of the synclinorium in the vicinity of Oakland. Thus the beds can be shown to be in normal succession; no thrust relationships are required to explain the succession of the Lower Cambrian dolomites and quartzites.

Thus, the Rosenberg slice and the Central sequence as defined and delimited by previous workers do not exist in the Milton area. Formations are in normal stratigraphic relations from the Champlain fault in the west to the Hinesburg thrust in the east.

Normal Faults

The two normal faults observed in the area are on the north banks of the Lamoille River in the vicinity of the Milton power plant. The scale of the geologic map is too small to show the details of these faults. They both strike N.20°E. with the downthrown block on the east side of nearly vertical fault planes. Drag folds and local deformation as a result of the faulting can be observed in both instances.

Folds

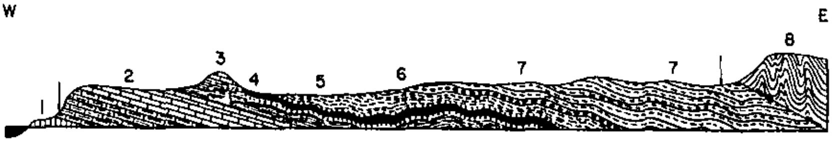
Hinesburg Synclinorium

A major synclinal axis that extends north-south through the central part of the area is a northern extension of Cady's (1945, p. 562) Hinesburg synclinorium. Except for a small break in the Milton area, this feature continues north as the St. Albans synclinorium (Cady, 1960).

The western boundary of this synclinorium is delimited by the Champlain thrust. On the east the Muddy Brook and Hinesburg thrusts cover the fold.

The Cutting Dolomite, exposed near the south boundary of the quadrangle, is the highest stratigraphic unit in the center of the Hinesburg synclinorium. An inconspicuous axis culmination in the drift-covered area south of West Georgia separates the north and south sections of the fold. In the north the Rockledge Formation is the highest stratigraphic unit exposed in the fold. This has been termed the Milton High by Shaw (1958, p. 533).

This northern section is discussed in the classic works of Walcott and others, and is labeled by Schuchert (1937, p. 1024) the "celebrated



THE CELEBRATED GEORGIA SECTION

1. Western Sequence
2-7. Central Sequence
8. Eastern Sequence
After Schuchert, 1937

2. Winooski-Mallett dolomite
3. Parker slate with dolomite capping
4. Basal Hungerford slate
5. Main mass of Hungerford slate
6. Rockledge breccia
7. Georgia formation of Keith

Figure 6. The "celebrated Georgia section" (after Schuchert, 1937)

Georgia section." In his paper Schuchert presents a structure section from Lake Champlain through Georgia township eastward to the rocks of Keith's Eastern sequence. This is reproduced with modifications in Figure 6. One can note in this section a general east dip for all the formations of the so-called Central sequence. Schuchert lists these formations as: (figures below refer to those listed in Figure 6).

2. Winooski-Mallett dolomite. This is presented in the present report as the Dunham Dolomite with a lower calcareous facies (Connor) and an upper arenaceous facies (Mallett).
3. Parker Slate with dolomite capping. The dolomite capping at Parker Cobble is presented in the present report as part of the Rugg Brook Formation of Middle Cambrian age. In Schuchert's diagram the dolomite cap with its gentle east dip would necessitate a long interval of erosion or the cap with its east dip should be exposed in the valley to the east.
4. Basal Hungerford Slate.
5. Hungerford Slate. These Hungerford slates are assigned in the present report to the Skeels Corners Formation. The basal zones of the Skeels Corners do not show the extreme crumpling of these incompetent shales (Plate IV, Fig. 3) and it is in these lower beds that the majority of the well preserved fossils have been found that indicate a Middle Cambrian age for the formation. The Hungerford Slate at the type locality in the St. Albans area overlies the Rockledge Formation.
6. Rockledge breccia at the base of the Georgia Formation.
7. Georgia Formation. Schuchert shows the Rockledge as a continuous

layer with gentle east dips to conform with the underlying beds of his structure section. These in turn are overlain by east dipping shales of the Georgia Formation.

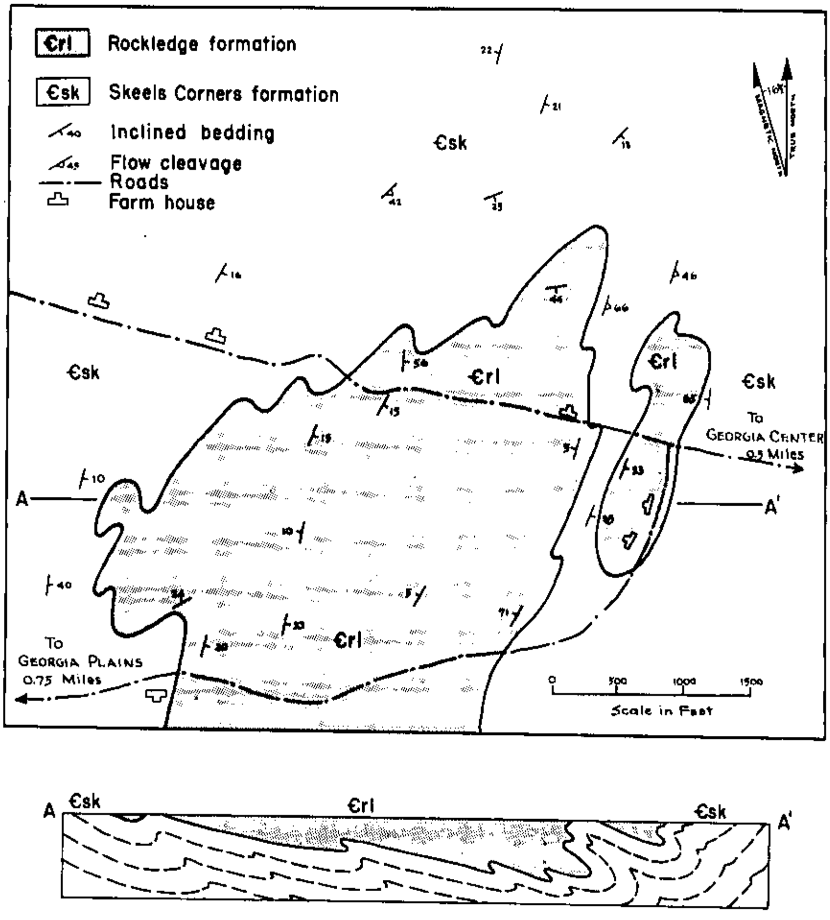
It was part of this "celebrated Georgia section" that members of the Harvard Summer School plane-tabled at a scale of 400 feet to the inch. The Hungerford-Rockledge and Rockledge-Georgia contacts were emphasized in this mapping program. With permission of M. P. Billings and P. E. Raymond, who supervised the work, a geologic map constructed from the plane table sheet is presented in Figure 7.

The Rockledge Formation lies in a syncline. A diagrammatic section at the bottom of Figure 7 shows this synclinal relationship.

On the west limb of the syncline the shales of the Skeels Corners Formation dip gently east beneath it. Steep west dips and bedding overturned to the west are characteristic of the east limb. These relations can be noted throughout Georgia township in the Milton area, and in the St. Albans area mapped by Shaw (1958).

A strong cleavage has developed in the shales on the east limb of the Hinesburg synclinorium and has obscured the bedding in many places. Secondary mineralization has developed at many places along the cleavage planes and this sometimes looks like the calcitic and limonitic layers that are characteristic of the bedding in the shales of the Skeels Corners Formation. Unless the formation is studied in detail, these vein fillings can be easily mistaken for the bedding. This and other complications undoubtedly led to the misinterpretation of the structure by early workers.

The east limb of this fold may be extended into the Oakland area and the cliffs east of Georgia Center. Steep west-dipping and vertical beds of sandy dolomite and micaceous shale are present in the Oakland area. These have been correlated with the Rugg Brook Dolomite and Parker Shale of the west limb of the synclinorium. To the east of these are beds of Dunham in the same structural relations. The Rugg Brook and the Parker are exceptionally thin on the east limb of the fold. These beds disappear along the strike about a mile south of the Oakland region, so that beds of Dunham Dolomite and shales of the Skeels Corners Formation are in an unconformable relation throughout the rest of the eastern part of the area. To the north of Arrowhead Mountain, boulders of Dunham Dolomite are found in the basal Skeels Corners Formation. Thus, there is no evidence to indicate that the Dunham Dolomite of the Eastern sequence of Keith and Schuchert is in a fault relationship as



Structure section along A-A′

Figure 7. Geologic map of part of the plane table area mapped by the Harvard Summer School field camp in Georgia township west of Georgia Center.

shown in Schuchert's diagram of the "celebrated Georgia section." This section can be best interpreted as an overturned east limb of the Hinesburg synclinorium, which locally has the Rockledge Formation at its core.

In the early 1920's this synclinal structure was suggested by Gordon (1923, p. 211) but no diagrams are included in his report to support the text. He states, "taking into account the low easterly dips of the members of the Red Sandrock series (= Dunham) at their western margin and the suggestion of their possible extension in that attitude eastward beneath the surface, the westerly dips of the rocks just described (west dip of Dunham Dolomite on road east of Georgia Center) might seem to show that the beds in question form a broad, shallow syncline over most of Georgia township west of the C. V. R. R. track. It is possible that they do and that the higher dips at the east represent a pushing up of the eastern limb, with crushing in some places." Gordon's idea was apparently not taken into account by succeeding workers, although suggested some 40 years ago. This interpretation is essentially the same as that shown on structure section A-A′ of this report.

Dead Creek Syncline

This structure is outlined by an alignment of outliers of Dunham Dolomite in the eastern part of the Quadrangle. Booth (1950) had interpreted the relationships as a thrust fault, part of his Brigham Hill thrust. He considered that the lithology east of the Dunham was not Gilman (Cheshire). The present survey has shown that there is indeed a thin outcrop band of Cheshire east of the Dunham concerned. It is admittedly somewhat less quartzitic than that immediately west of the Dunham, but it is decidedly Cheshire lithology, not Fairfield Pond. Both the change in lithology and the thinning in that direction are compatible with the wedging out eastward of Cheshire lithology. Also, east limbs of synclines would tend to be tectonically thinned in this area, since they are facing west: this places east limbs of synclines in the position of the attenuated forelimb.

Georgia Mountain Anticline

A major anticline extends north-south through the eastern part of the area. The southern portion of this fold is covered by the Fairfield Pond Phyllite of the Underhill Formation in the Hinesburg thrust sheet.

Booth (1950, p. 1159) had named this fold the Brigham Hill anticlinorium. Since its axial trace lies 1.25 miles east of Brigham Hill and since the name has been used previously in reference to an overthrust, the authors of the present report feel that the name is not appropriate. The axial trace also passes through Georgia Mountain, and the authors propose the name Georgia Mountain anticline for the major anticlinal structure in the eastern part of the Milton area.

The fold has a general southerly plunge from the latitude of Bowman Corners northward. South of this point, the plunge is to the north. The

Pinnacle Formation with its Tibbit Hill Volcanics is exposed in the core of the Georgia Mountain anticline in the northern part of the area. South of the Lamoille River the Cheshire Quartzite is found at the core, and remains at the core for approximately six miles. In the vicinity of Bald Hill isolated synclinal patches of Dunham Dolomite are preserved. Farther south, near Bowman Corners, the Cheshire plunges under an east-west outcrop band of Dunham which here represents the crest of the fold. Within the next mile the plunge changes to the north, so that Cheshire Quartzite is in the core of the anticlinorium where this structure meets the Hinesburg thrust.

Minor folds and drag folds

Minor folds are well developed in the great succession of Upper Cambrian shales. They are less common in the more massive limestones, dolomites, and quartzites. However, on the overturned west limb and along the crest of the Georgia Mountain anticline minor folds are common in the more argillaceous parts of the Cheshire Formation.

The plunge of most minor folds is subparallel to that of the major folds, and they are helpful in determining the tops and bottoms of the shale beds in areas of intense deformation.

The minor folds in the shales are as small as a fraction of an inch in cross-section, whereas in the argillaceous quartzites and dolomites they are six to twelve inches across.

Cleavage[1]

Flow cleavage (Leith) is well developed in the argillaceous rocks of the Milton area. It is so intense on the overturned east limb of the Hinesburg synclinorium that bedding has been destroyed in some places. Were it not for the thin limonitic and calcitic bands of the Skeels Corners Formation, its bedding would be entirely masked by the cleavage. In some places secondary calcite or quartz has been deposited along cleavage planes. These are very similar to the thin calcareous bands that represent bedding in the Skeels Corners, so that in many cases it is difficult to determine the true bedding. Flow cleavage is parallel to the axial planes of folds and generally dips east (see Plate 1).

Fracture cleavage (Leith) was observed at numerous exposures in the Cheshire Formation on the overturned west limb of the Georgia Mountain anticline. In exposures of alternating quartzitic and argil-

[1] A more detailed account of cleavage in northwestern Vermont is given by Dennis (1964).

laceous rocks, the relationships of the fracture and flow cleavage can be observed.

Joints

No attempt was made to measure all joints in the area or to prepare a joint-pattern diagram. The few that were recorded indicate a strong set of transverse vertical joints that strike approximately east-west. Many of these joints have been filled by some of the mafic dikes described earlier in this report.

BIBLIOGRAPHY

AMBROSE, J. W., 1942, Preliminary map, Mansonville, Quebec: Canada Dept. of Mines and Resources, Geological Survey Paper 42–1.

BAIN, G. W., 1927, Geologic History of the Green Mountain Front: Vermont State Geol., 15th Report, 1925–26, pp. 222–241.

BILLINGS, M. P., 1945, Mechanics of igneous intrusion in New Hampshire: Amer. Jour. Sci., vol. 243-A, Daly vol., pp. 41-68.

——1956, The geology of New Hampshire, Part II bedrock geology: New Hampshire State Planning and Development Commission, 203 p.

BOOTH, V. H., 1938, Oak Hill series in Vermont (abstract): Geol. Soc. Amer. Bull., vol. 49, p. 1869.

—— 1950, Stratigraphy and structure of the Oak Hill succession in Vermont: Geol. Soc. Amer. Bull., vol. 61, pp. 1131–1168.

CADY, W. M., 1945, Stratigraphy and structure of west-central Vermont: Geol. Soc. Amer. Bull., vol. 56, pp. 515–558.

—— 1960, Stratigraphy and geotectonic relationships in northern Vermont and southern Quebec: Geol. Soc. Amer. Bull., vol. 71, pp. 531–576.

CADY, W. M. and others, 1962, Bedrock geology of the Lincoln Mountain quadrangle, Vermont: U. S. Geol. Surv., Geol. Quad. Map GQ–164, scale 1:62,500.

CHAPMAN, D. H., 1937, Late-glacial and post-glacial history of the Champlain Valley: Amer. Jour. Sci., 5th ser., vol. 34, pp. 90–124.

CHRISTMAN, R. A., 1959, Bedrock geology of the Mt. Mansfield quadrangle, Vermont: Vermont Geol. Surv. Bull. 12, 75 p.

CLARK, T. H., 1934, Structure and stratigraphy of southern Quebec: Geol. Soc. Amer. Bull., vol. 45, pp. 1–20.

—— 1936, A Lower Cambrian series from southern Quebec: Royal Canad. Inst., Tr., vol. 21, pt. 1, pp. 135–151.

CUMMINGS, E. R., 1932, Reefs or bioherms?: Geol. Soc. Amer. Bull., vol. 43, pp. 331–352.

CUMMINGS, E. R. and SHROCK, R. R., 1928, Niagaran coral reefs of Indiana and adjacent states and their stratigraphic relations: Geol. Soc. Amer. Bull., vol. 39, pp. 579–620.

DENNIS, J. G., 1964, Geology of the Enosburg Falls and adjacent areas, Vermont: Vermont Geol. Surv. Bull. 23, 56 p.

DOLL, C. G., 1939, The geology of Clay Point, Colchester, Vermont: Vermont State Geol., 21st Report, 1927–28, pp. 74–85.

EMERSON, B. K., 1917, Geology of Massachusetts and Rhode Island: U. S. Geol. Survey Bull. 597, 289 p.

FAIRCHILD, H. L., 1916, Post-glacial marine waters in Vermont: Vermont State Geol., 10th Report, 1915–16, pp. 1–41.

FORTIER, Y. O., 1945, Preliminary map, Orford, Eastern Townships, Quebec: Canada Dept. of Mines and Resources, Geological Survey Paper 45–8.

FOYLES, E. J., 1928, Rock correlation studies in west-central Vermont: Vermont State Geol., 16th Report, 1927–28, pp. 281–289.

GORDON, C. E., 1923, Studies in the geology of western Vermont: Vermont State Geol., 13th Report, 1921–22, pp. 143–285.

HAGER, A. D., 1862, Report on the economic geology and scenery of Vermont: Claremont Mfg. Co., Claremont, New Hampshire, 252 pp.

HARRISON, J. V. and FALCON, N. L., 1936, Gravity collapse structures and mountain ranges as exemplified in S. W. Iran: Quart. Journ. Geol. Soc. London, v. 92, pp. 91–102.

HAWLEY, DAVID, 1957, Ordovician shales and submarine slide breccias of northern Champlain Valley in Vermont: Geol. Soc. Amer. Bull., vol. 68, pp. 55–94.

HELMBOLD, R., 1952, Beitrag zur Petrographie der Tanner Grauwacken: Heidelberger Beitr. Miner. Petrog. v. 3, p. 253–288. Translation, 1958, GSA Bull., v. 69, p. 301–314.

HILLS, J. M., 1935, The insoluble residues of the Cambro-Ordovician limestones of the Lehigh Valley, Pennsylvania: Journ. Sed. Petro., vol. 5, no. 3, pp. 123–132.

HITCHCOCK, EDWARD and others, 1861, Report on the geology of Vermont: Claremont Mfg. Co., Claremont, New Hampshire, vol. 1, pp. 1-558, vol. 2, pp. 559-988.

HOWELL, B. F., 1926, Cambrian *Paradoxides* beds in northwestern Vermont (abstract): Geol. Soc. Amer. Bull., Vol. 37, p. 242.

—— 1929, Cambrian *Paradoxides* beds in northwestern Vermont: Vermont State Geol., 16th Report, 1927–28, pp. 249–273.

—— 1934a, Contact of the Cambrian Winooski and Mallett formations of northwestern Vermont (abstract): Geol. Soc. Amer., Proc., 1933, p. 333.

—— 1934b, Base of the Upper Cambrian in northwestern Vermont (abstract): Geol. Soc. Amer., Proc., 1933, pp. 336–337.

—— 1937, Cambrian *Contropleura vermontensis* fauna of northwestern Vermont: Geol. Soc. Amer. Bull., vol. 48, pp. 1147–1210.

—— 1939a, New Upper Cambrian formations in northwestern Vermont (abstract): Geol. Soc. Amer. Bull., vol. 50, pt. 2, p. 1964.

—— 1939b, Revised Upper Cambrian succession of northwestern Vermont (abstract): Geol. Soc. Amer. Bull., vol. 50, pt. 2, p. 1964.

—— 1939c, The Cambrian Rugg Brook formation of Franklin County, Vermont: Vermont State Geol., 21st Report, 1937–38, pp. 97–101.

—— and others, 1944, Correlation of the Cambrian formations of North America: Geol. Soc. Amer. Bull., vol. 55, pp. 993–1003.

HURLEY, P. M., FAIRBAIRN, H. W., and PINSON, W. H., 1958, Intrusive and metamorphic rock ages in Maine and surrounding areas (abstr.): Geol. Soc. America Bull., v. 69, p. 1591.

JACOBS, E. C., 1935, Green Mountains of northern Vermont (abstract): Geol. Soc. Amer., Proc., 1934, p. 85.

—— 1937, An account of Vermont geology: Vermont State Geol., 20th Report, 1935–36, pp. 25–144.

—— 1939, The geology of the Green Mountains of northern Vermont: Vermont State Geol., 21st Report, 1937–38, pp. 1–74.

JONES, R. W., 1961, Structural evolution of part of southeastern Arizona. (abstract): AAPG Bull., v. 45, p. 413.

KEITH, ARTHUR, 1923, Cambrian succession of northwestern Vermont: Amer. Jour. Sci., 5th series, vol. 5, no. 26, pp. 97–139.

—— 1932, Stratigraphy and structure of northwestern Vermont: Wash. Acad. Sci., Jour., vol. 22, no. 13, pp. 357–379; no. 14, pp. 393–406.

KEMP, J. F. and MARSTERS, V. F., 1893, The trap dikes of the Lake Champlain region: USGS Bull., no. 107, 62 pp.

KINDLE, C. H. and TASCH, PAUL, 1948, Lower Cambrian fauna of the Monkton formation of Vermont: Canadian Field Naturalist, vol. 62, no. 5, pp. 133–139.

KONIG, R. H. and DENNIS, J. G., 1964, The geology of the Hardwick area, Vermont: Vermont Geol. Survey Bull. 24, 57 p.

KRYNINE, P. D., 1948, The megascopic study and field classification of sedimentary rocks: Jour. Geol., v. 56, pp. 130–165.

KULP, J. L., 1960, The Geological Time Scale: Report of the XXI International Geological Congress, pt. 3, p. 18.

—— 1961, Geologic time scale: Science, vol. 133, No. 3459, pp. 1105–1114.

LAROCHELLE, A., 1962, Palaeomagnetism of the Monteregian Hills, southeastern Quebec: Geol. Survey Canada, Bull. 79, 43 p.

LOGAN, W. E., 1863, Geology of Canada: Dawson Bros., Montreal, 983 p.

LONGWELL, C. R. and others, 1933, XVI International Geological Congress, Guidebook I, eastern New York and western New England: Supt. of Documents, Washington, D. C., 118 p.

LYONS, J. B., JAFFE, H. W., GOTTFRIED, DAVID, and WARING, C. L., 1957, Lead-alpha ages of some New Hampshire granites: Am. Jour. Sci., v. 255, pp. 527–546.

MCGERRIGLE, H. W., 1931, Three geological series in northwestern Vermont: Vermont State Geol., 17th Report, 1929–30, pp. 179–191.

MOORE, R. C., 1949, Meaning of facies: Geol. Soc. Amer., Mem. no. 39, pp. 1–34.

OSBERG, P. H., 1952, The Green Mountain anticlinorium in the vicinity of Rochester and East Middlebury, Vermont: Vermont Geol. Survey Bull., No. 5, 127 p.

PERKINS, G. H., 1908, Preliminary report on the geology of Chittenden County: Vermont State Geol., 6th Report, 1907–08, pp. 221–265.

—— 1912, A general account of the geology of the Green Mountain region: Vermont State Geol., 8th Report, 1911–12, pp. 17–100.

—— 1916, Geology of western Vermont: Vermont State Geol., 10th Report, 1915–16, pp. 200–232.

PERRY, E. L., 1928, The geology of Bridgewater and Plymouth townships, Vermont: Vermont, Report of the State Geologist for 1927–1928, pp. 1–64.

PETTIJOHN, F. J., 1954, Classification of sandstones, Jour. Geol., v. 62, pp. 360-365.

——1957, Sedimentary Rocks: Harper and Bros., New York, 718 p.

RAYMOND, P. E., 1924, New Upper Cambrian and Lower Ordovician trilobites from Vermont: Boston Soc. Nat. History, Proc., vol. 37, no. 4, pp. 389–466.

—— 1925, New Upper Cambrian and Lower Ordovician trilobites from Vermont: Vermont State Geol., 14th Report, 1923–24, pp. 137–203.

—— 1937, Upper Cambrian and Lower Ordovician trilobita and ostracoda of northwestern Vermont: Geol. Soc. Amer. Bull., vol. 48, pp. 1079–1146.

RODGERS, JOHN, 1937, Stratigraphy and structure in the upper Champlain Valley: Geol. Soc. Amer. Bull., vol. 48, pp. 1573–1588.

SCHUCHERT, CHARLES, 1933, Cambrian and Ordovician stratigraphy of northwestern Vermont: Amer. Journ. Sci., 5th series, vol. 25, no. 149, pp. 353–381.

—— 1937, Cambrian and Ordovician of northwestern Vermont: Geol. Soc. Amer. Bull., vol. 48, pp. 1001–1078.

SHAW, ALAN, 1949, Stratigraphy and structure of the St. Albans area, Vermont: Ph.D. thesis, Harvard University, 178 pp.

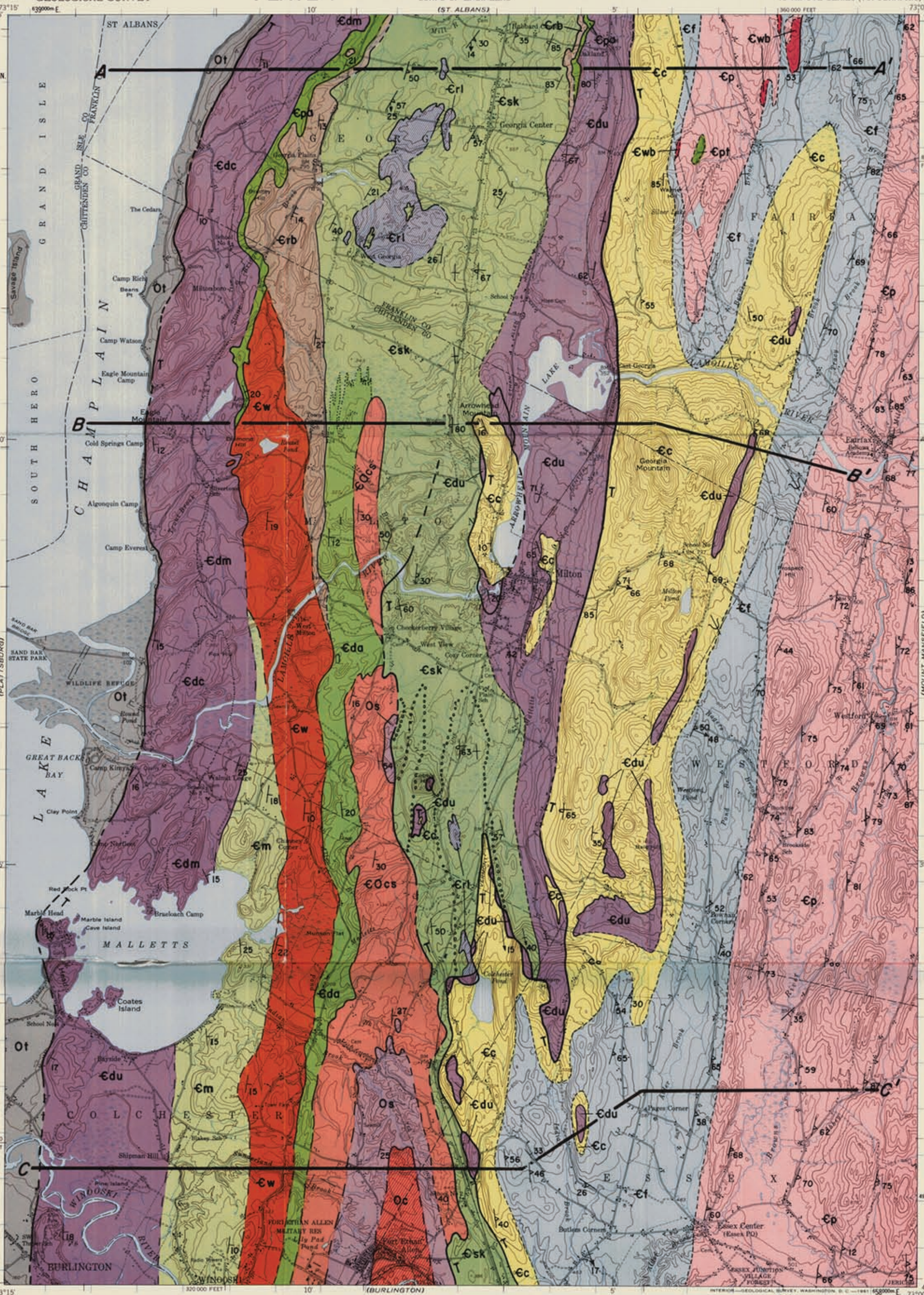
—— 1951, The paleontology of northwestern Vermont, I. New late Cambrian trilobites: Jour. of Paleo., vol. 25, pp. 97–114.
—— 1954, Lower and lower Middle Cambrian faunal succession in northwestern Vermont: Geol. Soc. Amer. Bull., v. 65, pp. 1033–1046.
—— 1958, Stratigraphy and structure of the St. Albans area, northwestern Vermont: Geol. Soc. Amer. Bull., v. 69, pp. 519–567.
—— 1962, Paleontology of northwestern Vermont IX. Fauna of the Monkton Quartzite: Jour. Paleo; v. 36, pp. 322-345.
Shrock, R. R., 1948, Sequence in layered rocks: McGraw-Hill, New York, 507 pp.
Ulrich, E. O., 1934, Do late Silurian or early Devonian deposits lie on early Ozarkian near Milton, Vermont? (abstract): Geol. Soc. Amer., Proc., 1933, p. 115.
Vermont Geol. Surv., 1961, Centennial Geologic Map of Vermont: Compiled and edited by Charles G. Doll and others: scale 1:250,000.
Walcott, C. D., 1886, Second contribution to the studies on the Cambrian fauna of North America: USGS, Bull., no. 30, 369 pp.
—— 1886, The stratigraphical succession of the Cambrian faunas in North America: Nature, vol. 38, no. 988, Oct. 4, p. 551.
—— 1891, Correlation papers, Cambrian: U.S. Geol. Surv., Bull. 81, 447 pp.
Whittle, C. L., 1894, The occurrence of Algonkian rocks in Vermont and the evidence for their subdivision: Jour. Geol., vol. 2, pp. 396–429.
Wilson, J. L., 1954, Late Cambrian and Early Ordovician trilobites from the Marathon Uplift, Texas: Jour. Paleontology, vol. 28, pp. 249–285.
Woodland, B. G., 1962, Lamprophyric dikes of the Burke area, Vermont: Am. Mineralogist, v. 47, pp. 1094–1110.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE 1

UNITED STATES
DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

MILTON QUADRANGLE
VERMONT
15 MINUTE SERIES (TOPOGRAPHIC)



LEGEND

MIDDLE ORDOVICIAN

Ot — SHALE & LS. OF TRENTON AGE BELOW CHAMPLAIN FAULT

Black shale and blue-black dense limestone

LOWER ORDOVICIAN

Oc — CUTTING FORMATION

Gray dolomite with abundance of grey, translucent, well-rounded, frosted quartz grains.

Os — SHELBURNE FORMATION

Light grey marble (?) with thin irregular lenses and veins of sandy dolomite.

UPPER CAMBRIAN

€Ocs — CLARENDON SPRINGS FORMATION

Light grey massive dolomite with irregularly shaped masses of white quartz and chert.

WOODS CORNER GROUP

€rl — ROCKLEDGE FORMATION

Coarse oligomictic breccia; light grey limestone boulders in a matrix of arenaceous limestone or sandy dolomite.

€sk — SKEELS CORNERS FORMATION
•••• LIMESTONE CONG.

Black slates or fissile shales with thin limonite-stained sandstones; lenses of dolomitic sandstone; dark-blue to black mound like masses of limestone.

€da — DANBY FORMATION

Alternating layers of thin gray dolomitic sandstone with thicker beds of sandy dolomite.

MIDDLE CAMBRIAN

€rb — RUGG BROOK FORMATION

Sandy, sometimes conglomeratic, salmon brown to buff weathering gray dolomite.

€w — WINOOSKI FORMATION

Light grey to buff dolomite; vugs lined with quartz crystals; stylolites common.

LOWER CAMBRIAN

€pa — PARKER FORMATION

Blue-black fissile shale or slate, mica flakes common on fresh surface; resistant dolomite lenses near top.

€m — MONKTON FORMATION

Red, pink, buff, brown and white quartzites interbedded with red and buff sandy dolomites; crossbedding, ripple marks and mud cracks common.

€du DUNHAM FORMATION

€dm — MALLETT FACIES

Arenaceous varicolored dolomite with well-rounded and frosted sand grains.

€dc — CONNOR FACIES

Dolomite showing wide variation in color; dark red-purple wavy bands of argillaceous material in relief on weathered surface.

€c — CHESHIRE FORMATION

Massive gray argillaceous quartzite; conglomerate zone near base.

UNDERHILL FORMATION

€f — FAIRFIELD POND PHYLLITE

Quartz-chlorite-sericite phyllite veined with quartz.

€wb — WHITE BROOK FORMATION

Whitish to pinkish dolomite, weathers dull buff to brown; quartz stringers common.

PINNACLE FORMATION

€pt — TIBBIT HILL VOLCANICS

Dark green metavolcanics; fine grained, massive, sometimes vesicular.

€p — PHYLLITE FACIES

Coarse graywacke and quartz-chlorite-sericite phyllite.

SYMBOLS

CONTACTS

ACCURATE

APPROXIMATE

INDEFINITE AND FACIES CHANGE

FAULTS

ACCURATE

APPROXIMATE

INCLINED BEDDING

OVERTURNED BEDDING

VERTICAL BEDDING

FLOW CLEAVAGE

FLOW CLEAVAGE SHOWING PLUNGE OF TRACE OF BEDDING

DRAG FOLD
(AXIAL PLANE DIP-45°, AXIS PLUNGES 10°)

TRENDS OF GLACIAL STRIATION

SPACED CLEAVAGE (VERTICAL)

Mapped by the Army Map Service
Published for civil use by the Geological Survey

Control by USGS, USC&GS, and USCE

Topography from aerial photographs by multiplex methods
Aerial photographs taken 1947. Field check 1948

Polyconic projection. 1927 North American datum
10,000-foot grid based on Vermont coordinate system

No distinction is made between dwellings, barns, commercial and industrial buildings

Unchecked elevations are shown in brown

Locations of all boundaries are approximate

1000-meter Universal Transverse Mercator grid ticks zone 18, shown in blue

APPROXIMATE MEAN DECLINATION, 1948

SCALE 1:62500

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

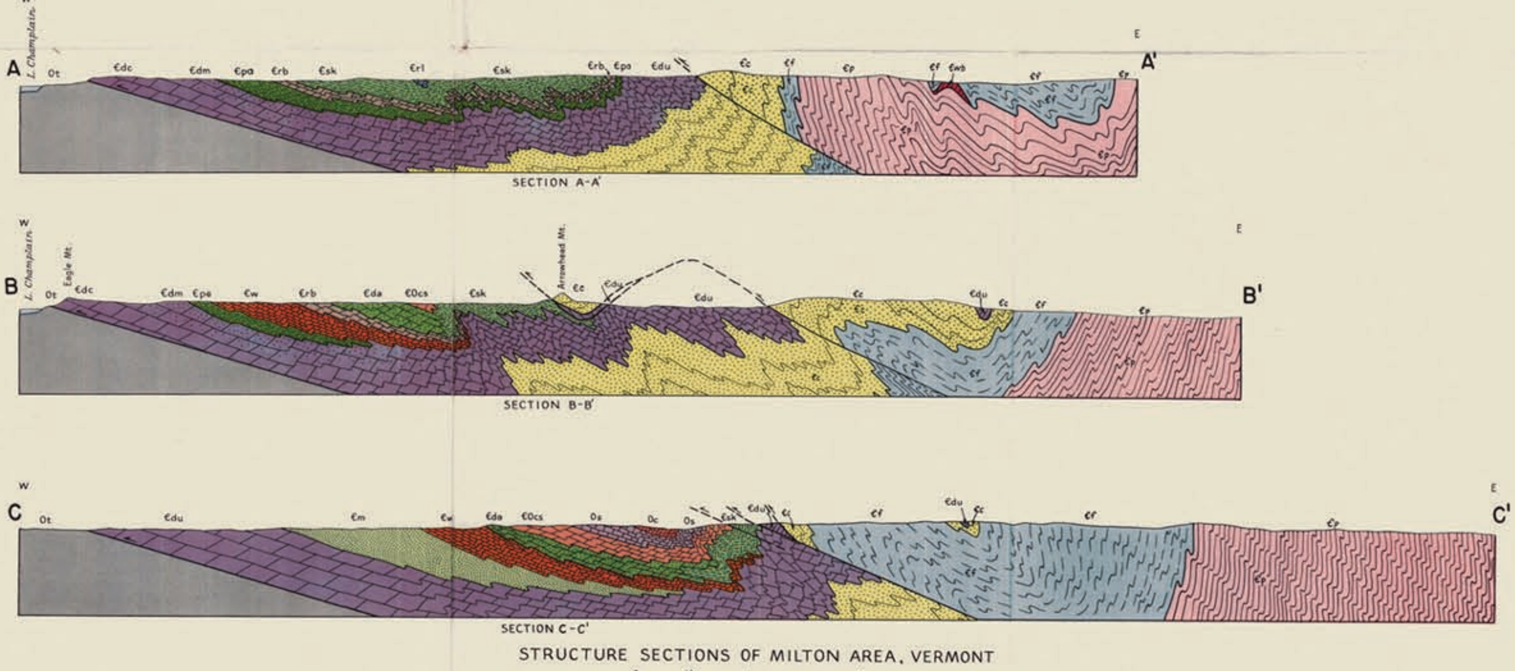
QUADRANGLE LOCATION

ROAD CLASSIFICATION
Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
U.S. Route — State Route

This area is also covered by 1:24 000 scale maps of Essex Center, Milton, Georgia Plains, and Fort Ethan Allen 7.5 minute quadrangles

MILTON, VT.
N4430—W7300/15
1948

Geology by S. W. Stone and J. G. Dennis



STRUCTURE SECTIONS OF MILTON AREA, VERMONT

Horizontal and Vertical Scale in Miles

VERMONT GEOLOGICAL SURVEY
Charles G. Doll, State Geologist
(Bulletin No. 26)