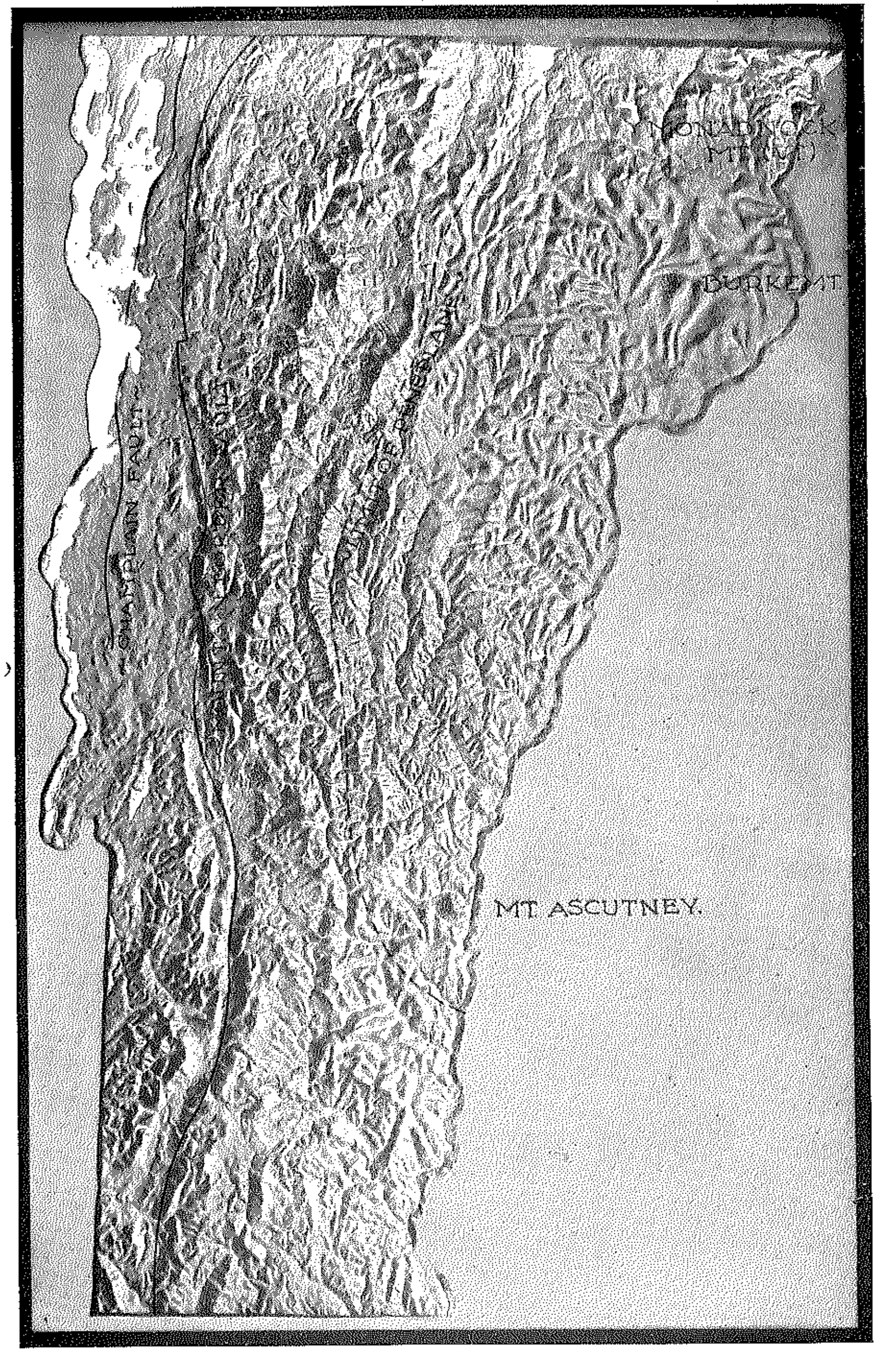

RELIEF MAP OF VERMONT

REPORT
OF THE
STATE GEOLOGIST
ON THE
GEOLOGY
OF
VERMONT

1937-1938

TWENTY-FIRST OF THIS SERIES

ELBRIDGE C. JACOBS
F. G. S. A.
State Geologist

STATE OF VERMONT

OFFICE OF STATE GEOLOGIST

BURLINGTON

To the Board of Conservation and Development,
Montpelier, Vermont.

Gentlemen: I herewith present my biennial Report, as State Geologist, for 1937-38.

The Report is late owing to the long time needed for its preparation.

In the Report I present an interesting article by my colleague, Professor Charles G. Doll, on the Geology of Clay Point, Colchester; a posthumous report by the late Professor Charles H. Richardson, and James E. Maynard of Syracuse University, on The Geology and Petrography of Vernon, Guilford, and Halifax; a short paper by Professor Benjamin F. Howell of Princeton University, entitled The Cambrian Rugg Brook Formation of Franklin County; and the results of my geological investigations in the Green Mountains of northern Vermont.

Besides the preparation of this bulletin, I have attended to the large correspondence connected with this office and have advised with various people on their geological problems.

Respectfully submitted,

ELBRIDGE C. JACOBS,
State Geologist.

Fleming Museum,
University of Vermont.

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The Geology of the Green Mountains of Northern Vermont

ELBRIDGE C. JACOBS
UNIVERSITY OF VERMONT

CONTENTS

Introduction

In his First One Hundred Years of American Geology[1] the late George P. Merrill wrote: "The year 1809 must ever be notable in the history of American geology, since it brought forth (William) Maclure's Observations on the Geology of the United States, with a colored geological map of the region east of the Mississippi. With the exception of Guettard's mineralogical map of Louisiana and Canada, published in 1752, it was the

[1] New Haven; Yale University Press (1924).

earliest attempt at a geological map of America, and has caused its author to become known as the father of American geology."

On the map "A continuous range of mountains was figured extending from northern Maine, along its western boundary, through eastern Vermont, western Massachusetts, across southeastern New York and New Jersey to Pennsylvania," etc. These mountains were made up, according to the early classification, of "Primative rocks," which included granite, gneiss, mica-slate (schist), clay-slate, "primative limestone," "primative trap" (basic igneous rocks), sienite (syenite), porphyry, serpentine, and others. Maclure included in his "Secondary rocks" the limestones and slates "skirting Lake Champlain about Ticonderoga and Crown Point."

The "continuous range of mountains" evidently included the Green Mountains and the Taconics.

The first agitation for a geological survey of Vermont was made as early as 1836 and the first state geologist, Professor Charles Baker Adams, was appointed in 1844. Since then eight state geologists and many other geologists, both within and without the State, have contributed to our knowledge of this commonwealth but, although Vermont is predominantly mountainous, geological investigations have been carried on very largely in the lowlands.

The reasons for this preference are not difficult to find. Geologizing in the Green Mountains is especially arduous and difficult. The mountains are in general heavily wooded; the rock masses much broken and difficult of access. The lower slopes are mantled with glacial accumulations and, in the field seasons, rank vegetation which too often hide important contacts. The mountains are made up of metamorphic rocks in which fossils, the guiding stars of the sedimentary geologist, are almost unknown; so that a stratigraphy of the rocks has perforce to be based on lithic similarity, or thin section study, and in most cases is impossible.

Furthermore, the subject of metamorphism was but little understood by the early geologists. The petrographic microscope and, with its aid, the study of thin rock sections did not come into use until about 1870. Without these aids the investigation of metamorphic rocks is futile. The chemical analyses of rocks is an important aid to the geologist but the earlier analyses were far from accurate and so not critical in their findings.

Small wonder, therefore, that wise geologists have kept to the lowlands with their fossiliferous strata, and let "fools rush in where angels fear to tread."

The first geologist to include a consideration of the Green Mountains in his investigations was President Edward Hitchcock of Amherst College. In 1857 President Hitchcock was invited to take charge of the geological work in Vermont. He associated with himself his two sons, Edward Hitchcock, Jr. and Charles H. Hitchcock (who was later Professor of Geology in Dartmouth College), and Albert D. Hagar. Hitchcock was one of the foremost geologists of his day and his Geology of Vermont, in two quarto volumes, which he published in 1861, was an outstanding work of its time and the most comprehensive ever attempted in this State.

Hitchcock's announced objects are: 1. To classify and map the solid rocks of the State. 2. To study the surface geology, including the glacial accumulations. 3. To collect, arrange, and name specimens of rock, minerals, and fossils from every part of the State, for the State Cabinet. 4. To obtain a full collection for the Cabinet of specimens valuable in an economical point of view, including many that are smoothed and polished (glacial specimens). 5. To identify the metamorphosed rocks of the State with those that have not been changed, etc.

Hitchcock notes that eminent geologists of his era were not agreed upon the character of the metamorphic rocks of Vermont and that "this has been a sort of battle ground for opposing theories." However, he is satisfied that a "mighty wave of metamorphic influence has swept over the State from north to south, increasing in intensity as it advanced." We shall have to take exception to the direction of the "metamorphic influence."

President Hitchcock and his associates, between 1857 and 1861, traversed the State, from east to west, in thirteen different latitudes and published in his volumes some finely-colored sections, as well as a generalized section. As a result of his study of these sections Hitchcock concludes that the rocks of Vermont "have been thrown into a succession of folds while in a semi-plastic condition by a force from the direction of the Atlantic, and that their crests have been subsequently denuded."

He traces out two chief "anticlinals," the first in the eastern part of the State, extending through Guildford, Newfane, Windham, Sharon, Washington, Peacham, Danville, and Sheffield; the second, along the crest of the Green Mountains. Between these anticlinals synclines are found, "most of them remarkably sharp, bringing the strata into an almost perpendicular position." He further recognizes that the schists and gneisses are "not only crumpled together but pressed down by the lateral thrust of the mountains towards the west."

A good deal of Hitchcock's work is still valuable, particularly the locations of economic minerals, mineral springs, and the like. But the old explanations of glacial accumulations, and erosional features—explanations based upon the Mosaic deluge—have long since given way to the more rational theory of Agassiz, while old correlations of Vermont strata have, in light of paleontological discoveries and progress, been almost wholly revised.

In the matter of faults Hitchcock was all at sea. Professor Schuchert[1] tells us that "overthrusting was unknown in those

[1] Charles Schuchert: Cambrian and Ordovician of Northwestern Vermont; Bull. Geol. Soc. Amr., vol. 48 (July 1, 1937).

days" and "not till 1861 did anyone see a fault" (in Vermont, where it turned out to be a big overthrust beneath the "red sandrock" which is now called the Monkton quartzite). To be sure Hitchcock[1] shows a fault, in his generalized section, which is the Champlain thrust, but he explains it as an "inverted dip," that is a recumbent fold which would bring the older strata above the newer. In discussing his sections through St. Albans he remarks: "There may be faults. The great difficulty arising from this view is that one fault will not satisfy the opponent of this view. The theorist's desire for faults, in speculating upon these rocks, is no more readily satiated than the miser's desire for gold—the more he obtains the more he wants!"

Perhaps this gibe was inspired by the letter of Sir William Logan to M. Barrande, a letter which Hitchcock reproduces[2] and from which the following quotation is taken: "A series of such dislocations traverses eastern North America from Alabama to Canada"*** "The one in question comes upon the boundary of the Province (Quebec) not over a couple of miles from Lake Champlain. From this point it proceeds in a gently curving line to Quebec, keeping just north of the fortress; thence it coasts the north side of the Island of Orleans, leaving a narrow margin on the island of Hudson River or Utica formation. From near the east end of the island it keeps under the waters of the St. Lawrence to within eighty miles of the extremity of Gaspé." This is probably the first mention of the great overthrust which is now known to extend down through western Vermont to Cornwall, and probably farther.

In this frame of mind Hitchcock could not make much real progress in this region of many thrust faults. His own sections show many faults but he could not recognize them as such.

Hitchcock's terminology is today archaic. "Calciferous mica-schist," "talcose schist," "talcose conglomerate," "plumbagenous shale," "aeolian limestone" etc., without a glossary, can mean but little to the average reader.

In more recent years C. S. Whittle[3], Raphael Pumpelly[4], T. N. Dale[5], W. G. Foye[6], Arthur Keith[7], G. H. Hubbard[8], and others, have worked on the more southern parts of the Green Mountains but the northern portion has remained untouched.

During the past seven years, as opportunity has offered, the writer has been engaged in investigating the Green Mountains in the region lying between the Winooski and Lamoille rivers

[1] Geology of Vermont, vol. 1, p. 375 (1861).
[2] Geology of Vermont, vol. 1, p. 379.
[3] Algonkian Rocks in Vermont, Jour. Geology, vol. 2 (1894).
[4] Geology of the Green Mountains in Mass., U.S.G.S. Mono. 23 (1894).
[5] Structural Details of the Green Mountain Region, U.S.G.S. Bull. No. 195 (1902). The Cambrian Conglomerate of Ripton in Vermont, A.J.S. (4) 30 (1910).
[6] Report of Geological Work in the Rochester Quadrangle, 11th Rpt. Vt. State Geol. (1917-18).
[7] Stratigraphy and Structure of Northwestern Vermont, Journal of the Washington Acad. of Science, vol. 22, No. 13 (1932).
[8] Geology of South Central Vermont, 14th Rpt. Vt. State Geol. (1923-24).

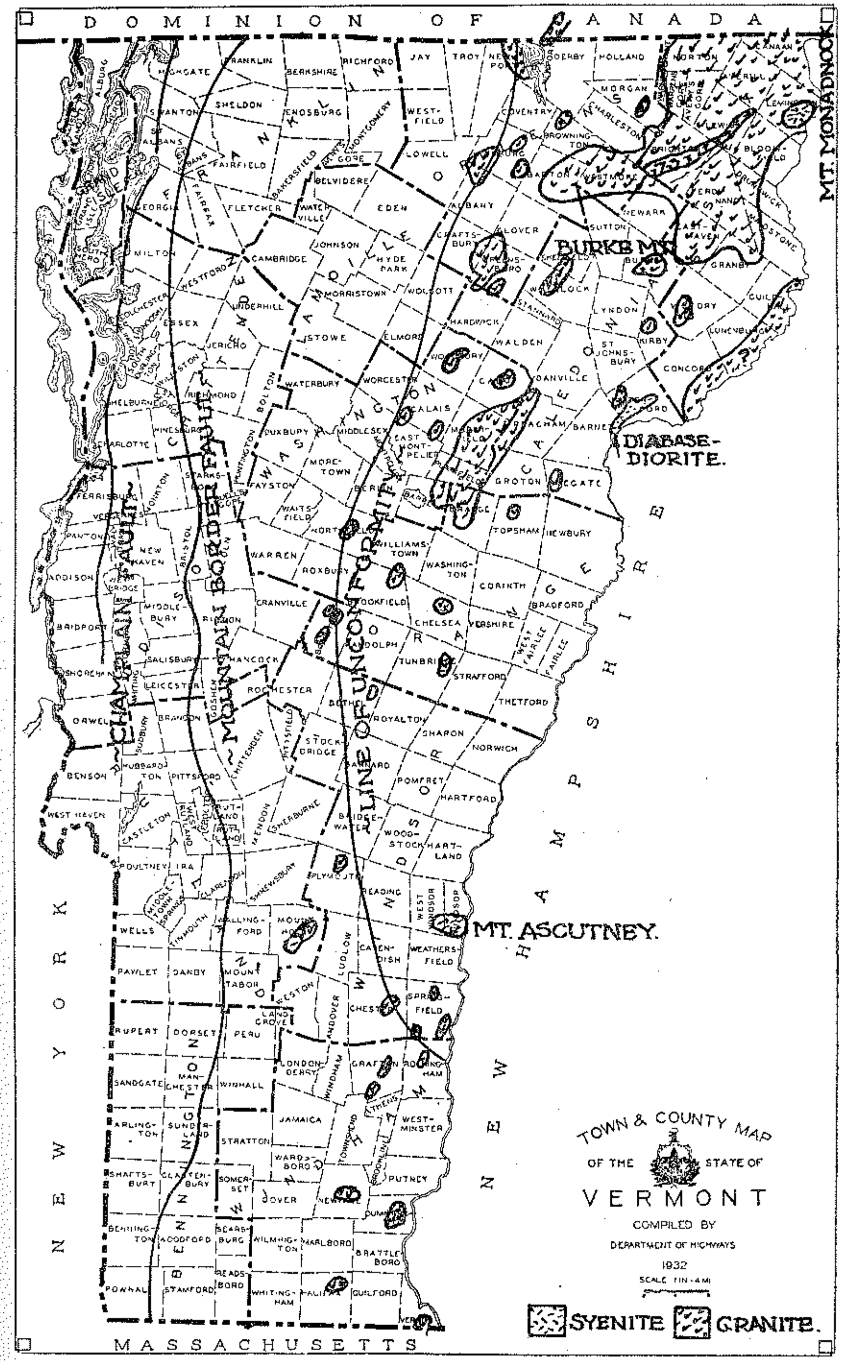

PLATE 1

as well as their approaches in the eastern part of the Milton quadrangle, studying the composition, structure, and metamorphism of the rocks, and endeavoring to establish formations and their ages. The work is not complete but it is thought best to record the results so far obtained, leaving further work for subsequent reports of the State Geologist.

In the Twentieth Report (1935-'36), under the caption, An Account of Vermont Geology, the writer tried to present in as simple way as possible the basic facts of geology, in order that the general reader might the better understand what followed. The reader of the present article is referred to this Report, to the reference books mentioned therein (p. 43), and to other works on geology, as a preliminary to studying this article.

The writer is deeply indebted to the United States Geological Survey for the examination of several rock sections; especially to his colleague, Professor Charles G. Doll, for much aid and criticism; to Miss Natalie E. Carleton, a former graduate student, for work on the sections; to Mr. Clarence G. Bailey, another former graduate student, who has made the drawings; to Mr. Wallace M. Cady, of Middlebury, who has traced out the boundaries in the Central sequence; and to others.

Geomorphology (Physiography)

As pointed out in the Twentieth Report, the geomorphology of the State falls naturally into five divisions: The Vermont Lowland, the Vermont Valley, the Taconics, the Green Mountains, and the Vermont Piedmont, which is a peneplain.

The Green Mountains

The Green Mountains, which are a part of the great Appalachian Chain, are the outstanding physiographic feature of Vermont and extend throughout the length of the State. Their southern extension, in Massachusetts, is called the Hoosac Mountains; while their northern continuation, in Canada, makes up the Notre Dame Mountains.

The Green Mountains, as outlined on the frontispiece, have the form of a distorted hourglass whose southern base extends from the Vermont Valley to the Connecticut River, a distance of some thirty-six or thirty-seven miles. The top of the hourglass lies along the Canadian border, in Franklin, Berkshire, Richford, Jay, and Troy, with a width of perhaps twenty miles. The constriction of the hourglass is north of Mt. Pico, in Chittenden and Pittsfield, where the width is about eight miles. North of this point the mountains spread out, fanlike, into three principal ranges. Of these the first, or Front Range (the most westerly) extends from Brandon into New Haven and Bristol townships. The second, or Main Range, extends the length of the State and contains the highest peaks. An offset of the mountain mass, northeast of Mt. Mansfield, is called the Sterling Range. The third range begins in Rochester and runs through Roxbury, Worcester, Eden, Lowell, and Newport to the border. In different parts of its course the third range is known as the Rochester Mountain, Braintree Mountain, and Worcester Range. There is also a fourth, poorly defined, range of low hills which extends from Randolph through East Roxbury, East Northfield, Berlin, Montpelier, Calais, West Woodbury, and dies out in Hardwick. One section of it is called the Northfield Mountains. This range does not properly belong to the Green Mountains.

The valley between the second range and the third range is very narrow in Rochester but widens northward to some six miles in Morristown and Johnson, beyond which it narrows to the border.

The highest peaks of the Green Mountains, from south to north, are: Glastonbury Mountain, 3,767 feet above sea level; Stratton Mountain, 3,869; Shrewsbury, 3,737 feet; Killington, 4,241; Pico, 3,967; Lincoln, 4,013; Ellen 4,135; Camels Hump, 4,083; Mansfield, 4,393; Belvidere, 3,360; and Jay, 3,861.

Drainage

The rivers which drain the Green Mountains belong to the Champlain-St. Lawrence, the Connecticut, and Hudson drainage basins.

To the Champlain-St. Lawrence belong the Missisquoi, Lamoille, and Winooski river systems, all of which are undoubtedly superposed streams. The Missisquoi rises in the mountains, in Lowell, Westfield, and Troy, flows into southern Quebec and then returns to the State in Jay and, flowing across the lowland, enters Missisquoi Bay, in which it has built a great delta. The Lamoille rises in Greensboro, Waldon, and Woodbury and, cutting through the mountain ranges, enters Lake Champlain south of the Sand Bar bridge. Its sediments were instrumental in forming the sand bar. The Winooski rises far east of the mountain mass, in Cabot, flows through its water gap in the mountains, and reaches the lake south of Colchester Point. It is some seventy miles long.

Farther south the New Haven and Middlebury rivers have cut gorges in the western front of the mountain mass and made their way across the lowland to the Otter Creek.

To the Hudson drainage belong the Batten Kill and the Walloomsac, which have their sources in the Green Mountain massif and in the Vermont Valley.

Belonging to the Connecticut drainage area are the Black River, rising in Plymouth; the Ottauquechee, having its head waters chiefly in Stockbridge; the Williams River, in Windsor County; Saxtons River, which rises in Grafton and flows southeasterly to its confluence with the Connecticut near Bellows Falls;

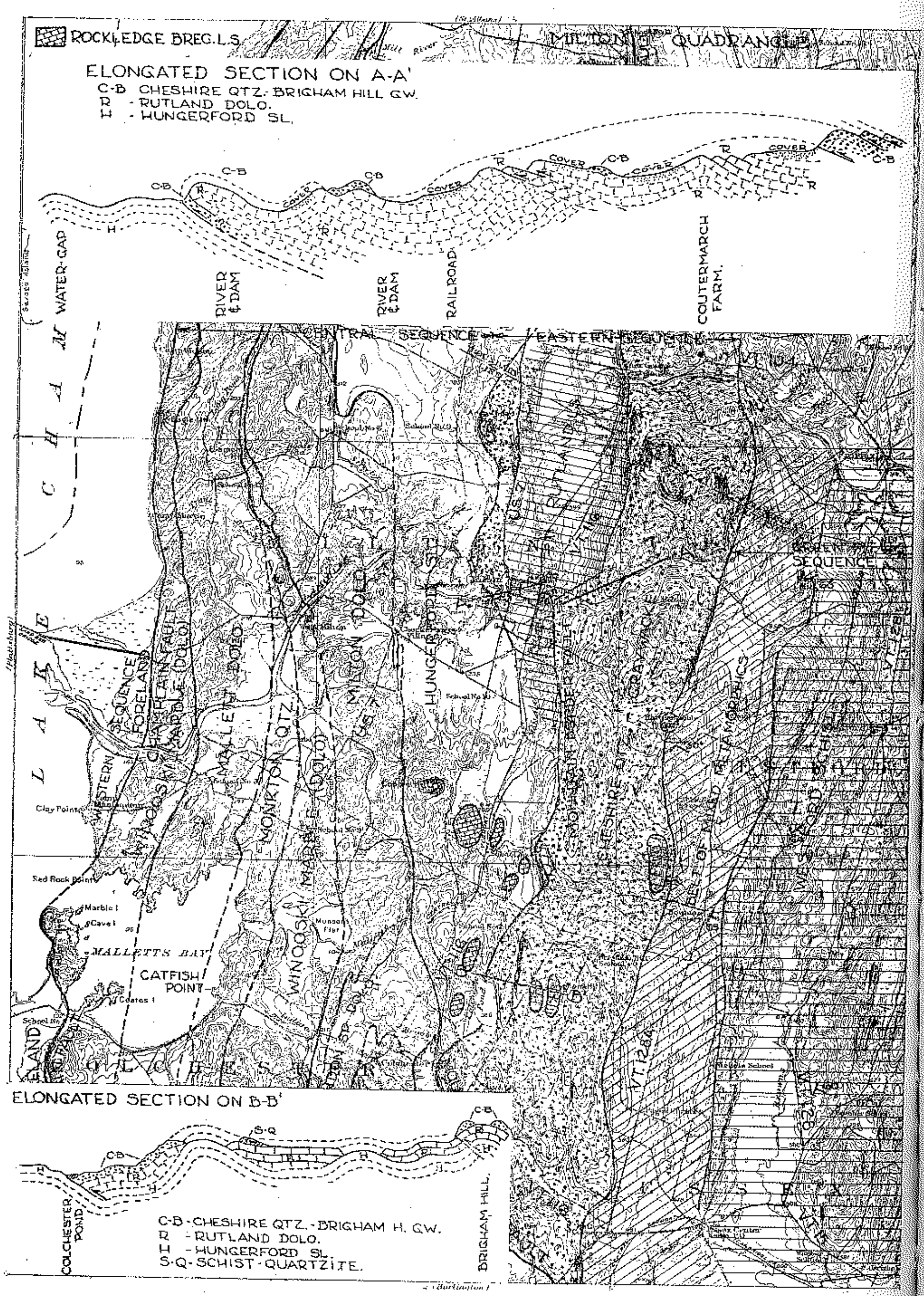

PLATE 2

the West River, whose upper branches are found far within the mountain mass in Londonderry, Peru, and Weston; and the Deerfield, which rises in Stratton, flows southward through the Green Mountains in Windham County and into Massachusetts, where it joins the Connecticut at Greenfield.

From his rather hurried examination of most of these rivers the writer believes that they are superposed streams which have been let down upon the mountain mass from a cover of sediments long since washed away.

Stratigraphy

In studying the geology of a mountainous region it is necessary to find a suitable point of attack, one where the edges of the mountain rocks are exposed and their attitude to the strata of the lowlands is revealed.

In the present investigation the Milton region (Plate 2) was chosen, since here, on the whole, the formations are most largely developed and the foot hills, or rather ridges, of the Green Mountains begin. Furthermore the rock structures around Milton village and in Brigham Hill are complex and, hitherto, have not been mapped.

This investigation therefore takes the form of a traverse from Arrowhead Mountain eastward across the Green Mountains to East Montpelier, a distance of some thirty miles. The traverse crosses eastern Milton (Plate 1), Westford, Cambridge, Underhill, Morristown, Stowe, Elmore, Worcester, Middlesex, Calais, and East Montpelier and is offset to include the chief structural features.

The Vermont Lowland

In 1923 Keith[1] found that the lowlands could be divided into several major tracts, or sequences, each separated from another by major thrust faults. He divided the Vermont lowland into a Western, a Central, and an Eastern sequence. Later[2] he added the Green Mountains sequence.

The Western sequence which, in this region, includes the lake shore, North and South Hero, Isle la Motte, and other, smaller, islands, is separated from the Central sequence by the Champlain thrust fault (the old Logan's line), while the Mountain Border thrust, with its outliers of Arrowhead Mountain and Milton lower gorge, is the dividing line between the Central and the Eastern sequences. Keith later changed the name of this to the Hinesburg thrust. In the Milton region the Mountain Border fault of Keith must, in the light of later discoveries, be extended to the west as indicated by the solid and dashed lines on Plate 2,

[1] Cambrian Succession of Northwestern Vermont; Arthur Keith, Am. Jour. Science, vol. 5 (Feb., 1923).

[2] Stratigraphy and Structure of Northwestern Vermont; Arthur Keith, Jour. Washington Acad. Sciences, vol. 22 (July 19, 1932).

since Arrowhead Mountain and its continuation southward are erosion remnants (*Klippes*) of the overthrusting Cheshire quartzite and Brigham Hill graywacke, from the east, which were once continuous across the Lamoille valley. Erosion has revealed the underlying, younger, Rutland dolomite, which thus constitutes a *Fenster*, or window.

The thrust line which separates the Eastern from the Green Mountains sequence is indefinite and has received no designation.

Of these sequences the Western, which extends from Canada along the lake shore to Orwell, is made up chiefly of limestones and shales, of Ordovician age. It was the least affected by the great thrusting movements; rather, it received the thrusting, and the rocks of the Central sequence, along the Champlain fault, are piled up on its eastern border. The Western sequence is called the Foreland (Plate 2).

The Central sequence is composed of dolomites and slates, of Lower Cambrian and Upper Cambrian ages, while the Eastern sequence contains dolomite, quartzite, and graywacke, of Lower Cambrian age.

The Green Mountains sequence is a complex of schists, gneisses, phyllites, quartzites, and some amphibolites.

In July, 1937, Schuchert[1] published the most detailed account of the geology of the Central sequence that has ever appeared. His map of the region studied, many illustrations and drawings, and the definite localities of the formations described (which too many writers fail to give) are of the greatest assistance to the geological student of this region. Since the journal in which this article appeared is not available to the general reader, it has been thought well to reproduce here portions of Schuchert's paper.

DISCUSSION

Comparing the generalized column of the old 1935-'36 Report of the State Geologist with Schuchert's table, one notes, in the Middle Cambrian division, various reassignments of the previously named formations and the introduction of several new ones.

HUNGERFORD SLATE

The Highgate formation, formerly regarded as Upper Cambrian, has been found by Schuchert to contain Lower Ordovician fauna and is restricted to the northeastern Highgate region; while the slate belt extending from Canada through central Highgate, Swanton, and western St. Albans and Georgia townships, and from one-eighth to seven-eighths of a mile wide, has been shown by him, on fossil evidence, to be Upper Cambrian.

[1] Cambrian and Ordovician of Northwestern Vermont; Charles Schuchert, Bull. Geol. Soc. America, vol. 48, No. 7 (July, 1937).

For this belt the name Hungerford slate has been chosen, from the type locality on Hungerford Brook, in southern Highgate.

Formations of the Central Sequence, Northwestern Vermont (Schuchert)

Taconian (including the Green Mts.) orogeny, late Ordovician time.
Long break.
Grandge slate, at least hundreds of feet thick.
Quebec orogeny. Best seen on Grandge farm.
Corliss breccia, 30 feet. Known only at type locality.

	Southwest of Milton	Georgia Township	Vicinity of Highgate
Lower Ordovician 1000 + feet	?	?	Corliss conglomerate, or Grandge slate. Highgate slate, 220 + feet Highgate limestone, 80 feet Highgate thrust breccia, 25 feet
Upper Cambrian at least 1000 feet		Georgia formation, at least 600 feet Rockledge breccia, 0–40 feet	Upper Gorge limestone, 145 feet Lower Gorge dolomite, 75 feet
	Hungerford slate, 600 + feet Milton dolomite 700 feet Break. Some of earliest	Erosional unconformity. Hungerford slate, 700 feet Mill River breccia, 20 feet Erosional unconformity Upper Cambrian absent	Break and thrust "Hungerford" slate, 200 feet "Milton" dolomite, 300 feet
	(Lower Cambrian)	(Middle Cambrian, St. Albans)	(Lower Cambrian. Parker)
Middle Cambrian 270 feet	Late Middle Cambrian. St. Albans slate, 60–270 feet Rugg Brook dolomite breccia, 0 to 20 feet Break. Most of Middle Cambrian unrepresented		
Lower Cambrian 415-1985 feet	Parker slate, 115–670 feet Short break, at least locally Mallett dolomite and quartzite, 100–630 feet Probable local breaks Winooski dolomite and marble, 200–385 feet Monkton quartzite, 0–300 + feet Thrust contact		

Ordovician basement, Western sequence (the Foreland), over which the above is thrust.

ROCKLEDGE BRECCIA

In the 1935-'36 Report, under the caption, Limestone Reefs and Bioherms[1], there were described "enormous marble-like

[1] Bioherm, from the Greek *Bios*, life + *herma*, a sunken reef.

oval or moundshaped growths, usually varying in longest diameter from fifteen feet to upward of 100 feet, and in thickness up to ten feet or more. They are often conspicuous white objects on the landscape. One on the Rockledge estate, some five miles north of St. Albans on the Highgate road, measures 170 x 110 x 8 feet; another mass, 90 x 50 feet, may be a part of it; four miles southwest of St. Albans there are four in close association, the smallest 15 x 10 feet and the largest 140 x 120 x 10 feet; nearby, one in the forest is 200 feet long and 80 feet wide; while one and one-half miles north of Highgate Center is the largest example, about 600 feet long" — "All are homogeneous masses of light-blue limestone that show no bedding. They appear to be algal growths in thin sheets and vertical columns" (Schuchert).

To this list Schuchert adds other localities: North of Skeels Corners, six and one-half miles from St. Albans, a bioherm 65 feet long, 35 feet wide, and 15 feet thick; four miles southwest of St. Albans, four bioherms in close association, the largest 140 x 120 x 10 feet; and others. These bioherms are among the most striking features of Vermont geology and are well worth a visit.

Closely associated with the bioherms are large exposures of limestone breccias[1], made up of "blue limestone of various sizes set in a limestone or dolomite paste which is replete with rounded grains of etched sand" (Schuchert).

The type locality is the Rockledge estate, where the breccia is to be seen surrounding the great bioherms. There are many other localities for the breccia, the most striking of which are on the Bliss farm, just north of Skeels Corners; the Pattee farm, one half-mile west of Georgia Center; at the Mayre Ledge, two miles south of St. Albans, west of the highway (Route U.S. 7); and, at a point a quarter of a mile southeast of this ledge. The above are Schuchert's or Keith's locations. Others, discovered by the writer, will be given in due course.

Fossils show the Rockledge breccia to be of Upper Cambrian age and so distinct from the Corliss conglomerate (Lower Ordovician) with which it was formerly included. Schuchert states that the Rockledge lies disconformably on the Hungerford formation and, with the Georgia slate, begins a new cycle of marine invasion.

Like the bioherms, these breccias are most striking and unusual. The localities given, and others, should be visited by those interested in the geology of this region.

GEORGIA SLATE

The Georgia slate, which occupies an area in the eastern part of Georgia township where it "forms a belt three miles wide,

[1] Breccias are irregular, unrounded fragments of rock, of varying size, set in a paste or cement of the same or other rock flour, or coarser material.

with a thickness rather over than under 2000 feet and crops out nearly continuously to a point beyond the Canadian border," was formerly classed as Lower Ordovician, though no fossils have been found in it. Schuchert states: "As the Georgia slate is intimately tied stratigraphically with the Rockledge breccia, now known to be of early Upper Cambrian time, there can be no doubt that these slates are also of this epoch."

WILLISTON LIMESTONE

The Williston limestone which Keith placed in the upper (Saratogan) part of the Upper Cambrian should, according to Schuchert, be classified as Beekmantown (Lower Ordovician) age.

THE GRANDGE SLATE

The remaining new comer in the geological column of the Central Sequence is the Grandge slate, whose type locality is on the Oliver Grandge farm, four and one-half miles north of Highgate Center. This is remarkable because it lies unconformably upon the eroded synclinal surface of the Lower Highgate, the upper Highgate members having been eroded away. The Grandge, like the Highgate, is found to be of Lower Ordovician age and, possibly with the Corliss conglomerate, marks a new cycle of deposition on the eroded Highgate. The evidence of uplift and erosion of the Highgate was formerly called by Schuchert the Vermont orogeny or the Vermont disturbance and it was placed at the close of the Upper Cambrian[1]. The orogeny is now found to have occurred in the Lower Ordovician. "Later, during the Taconic orogeney, both formations were folded together" (Schuchert).

The formations west of the Hungerford slate, Plate 2, have been kindly mapped for the writer by Mr. Wallace M. Cady, of Middlebury, a Columbia University graduate student who is at work on the geology of western Vermont. Mr. Cady finds[2] that the "Winooski" marble at Ethan Allen Park, Malletts Head and Eagle Mountain (and north along the lake shore) cannot be true Winooski, whose type locality is at Winooski Falls and whose continuation northward is shown on Plate 2, but that it is "one and the same in lithology and stratigraphic position as the Dunham dolomite"—of Clark[3], and is of Lower Cambrian age.

Thrusting

Northwestern Vermont is a region of extensive overthrusting to the northwest. The Champlain overthrust fault traverses the

[1] Textbook of Geology; Schuchert and Dunbar, John Wiley and Sons (1933).
[2] Written communication.
[3] Structure and Stratigraphy of Southern Quebec; T. H. Clark, Bull. Geol. Soc. of America, vol. 45 (Feb. 1934).

central part of Highgate and Swanton as a series of low escarpments rising above the Western sequence, upon which it is thrust, to varying heights. In St. Albans it lies less than a mile from St. Albans Bay, south of which it skirts the lake shore leaving only a narrow strand of the Western sequence.

The thrusting is differential in character bringing different members of the Central sequence up to the fault line. Thus, on F. W. Berry's farm, in western Georgia, the "Winooski" marble, of Lower Cambrian age, is found thrust onto Ordovician dove-colored limestone, which is probably Chazy, and this, in turn is thrust upon the Trenton shaly limestone, also of Ordovician age. About two miles farther south, along the shore, "Winooski" marble, forming here Eagle Mountain, is thrust upon the Trenton. Red Rock Point forms the northern entrance to Malletts Bay. A quarter of a mile east the "Winooski" marble forms cliffs which lie on Trenton shaly limestone while, just across the mouth of the bay, Malletts Head shows the same relationship.

But along the eastern shore of the bay, from Catfish Point northward, the Lower Cambrian Monkton quartzite presents a great escarpment to the west, with long gentle dip slopes to the east. Its base is concealed.

The last Report described in some detail the splendid overthrust at Lone Rock Point, which forms the northern end of Burlington Bay. Here "Winooski" marble is thrust onto Trenton shaly limestone while, a short distance to the north and east, Ethan Allen tower lies at the edge of this multiple escarpment.

The next headland, forming the entrance to Shelburne Bay, is Red Rocks Park, made up of a mass of Monkton quartzite rising about sixty feet above the lake. The base is not exposed but the underlying Trenton shaly limestone is seen across the Bay at Shelburne Point.

South of Shelburne Bay Pease Mountain and Mount Philo, in Charlotte; Shellhouse Mountain, in Ferrisburg; Buck Mountain, in Waltham; and Snake Mountain, in Weybridge and Addison, are all thrusts of Monkton quartzite lying on the Ordovician formations of the Western sequence, or Foreland.

Thrusting in the Central Sequence

Besides the Champlain fault thrusting there are various minor thrusts within the Central Sequence. Schuchert[1] describes the following:

North of Swanton Junction the Mallett dolomite is thrust onto the Parker slate.

East of Swanton, on the southeast slope of the Donaldson farm, the remains of the Hungerford thrust breccia, with a great bioherm about 105 feet long, Upper Cambrian in age, lies on the Parker slate of the Lower Cambrian.

[1] *Op. cit.*

North of St. Albans Bay the Lower Cambrian Winooski marble or dolomite lies by thrust on the Ordovician Highgate Springs series.

At Highgate Falls a striking thrust is to be seen in the north bank of the Missisquoi, dipping gently to the east. Here the Upper Gorge limestone or dolomite, of Upper Cambrian age, is seen thrust onto the Highgate slate, of Lower Ordovician age.

As will be shown the Rutland dolomite, of Lower Cambrian age, rests by thrust, in the lower gorge at Milton, on the Hungerford slate, of Upper Cambrian age.

On Cobble Hill, in southern Milton township, a dolomite, which Keith has thought to belong to the Eastern sequence, lies thrust onto Hungerford slate. It will be shown that this dolomite is probably Lower Gorge, of Upper Cambrian age, or possibly Milton dolomite, of the Upper Cambrian.

Thrusting in the Eastern Sequence

In several localities the rocks of the Eastern sequence, along the Mountain Border thrust, make salients into the Central sequence. In St. Albans, Aldis Hill, a *Klippe* made up of Lower Cambrian Cheshire quartzite overlain, the writer finds, by Brigham Hill graywacke, rests by thrust upon the Upper Cambrian Hungerford slate. Arrowhead Mountain, composed of Brigham Hill graywacke overlying Cheshire quartzite, is another *Klippe* resting on the Hungerford. Farther south, Cobble Hill is largely made up of Hungerford slate with a small *Klippe* of either Milton dolomite or Lower Gorge dolomite (probably the latter) both Upper Cambrian in age, resting upon it. East of Cobble Hill, and south of the Rutland dolomite area, the Cheshire quartzite-Brigham Hill graywacke ridge rests by thrust on the Hungerford slate.

In Williston township there is another salient. Here the quartzite and most of the graywacke are cut out and the Green Mountains sequence lies by thrust upon the sedimentaries of the Lowland. Differential thrusting has caused a tear fault about two miles long, discovered by Clarence G. Bailey, in 1936. It begins about three-quarters of a mile west of Williston village and strikes S. 80° E. South of this tear the mountain metamorphics have been shoved westward to rest by thrust upon the Williston limestone (which Keith classifies as Upper Cambrian but Schuchert, on the basis of fossil evidence, places in the Lower Ordovician) and the Hungerford slate of Brownell Mountain. Some six miles farther south, in the village of Mechanicsville and about a mile east of the Hinesburg road, Bailey discovered, in 1936, a large overthrust of Brigham Hill graywacke lying on the "Williston limestone." He named it the Mechanicsville thrust.

Formations in the Milton Quadrangle

Schuchert's mapping[1] extends from the international boundary to the latitude of Georgia Plains (Plate 2). As already stated Cady has mapped the formations of the Central sequence. The mapping of the Eastern and Green Mountain sequences is the writer's.

HUNGERFORD SLATE

In Milton township the eastern boundary of the Hungerford slate runs along the western base of Arrowhead Mountain and southward across the lower gorge of the Lamoille, where the river has cut a small water gap in it, at elevation 160 feet above sea level. Farther south the western boundary is found about a quarter of a mile west of Cobble Hill where it rests upon the Milton dolomite. To the south the contact is concealed. East of Cobble Hill the Hungerford extends across the valley to the Mountain Border fault, where the Brigham Hill graywacke rests upon it by thrust. The slate runs along this fault across the axis of Colchester Pond and south to the border of the quadrangle. The Hungerford forms a narrow ridge east of the Champlain Valley fair grounds (Vermont Route 15), crosses the Williston Road in South Burlington (U. S. Route 2), makes up most of Brownell Mountain, in South Burlington and St. George, and extends into Monkton. At various places the Hungerford bedding planes dip about five degrees easterly; the cleavage, 45 degrees easterly, indicating upright folds.

Schuchert describes the Hungerford as "blue-black to gray, well-banded slates, with here and there local lentils of yellowish or reddish-weathering, sandy dolomites, varying in thickness from one to ten feet."

COBBLE HILL

During the time when Champlain was a much larger and higher glacial lake several of the hills and low mountains in the Vermont lowland appeared as islands into which the beating waves cut benches. On Cobble Hill such a bench, or terrace, is strikingly apparent, nearly surrounding the hill, just above the 500-foot contour line. A similar terrace, strewn with graywacke shingle, is seen two miles directly east, along the Cheshire-graywacke ridge.

Cobble Hill is an erosion remnant of a once larger eminence. It is made up predominatingly of Hungerford slate, capped on the east side by a dolomite which lies thrust upon it.

The slate dips at a low angle easterly, with higher angled, easterly-dipping, cleavage, indicating an anticline overturned to the northwest. The capping is a medium-to-dark-gray, silicious

[1] *Op. cit.*

dolomite, weathering yellow, and containing numerous angular inclusions of black dolomite. It contains no chert. The rock is very similar to Schuchert's Lower Gorge dolomite at Highgate Falls. Neither the Lower Gorge nor the Cobble Hill dolomite has yielded any fossils. Professor Schuchert[1] thinks that the Cobble Hill dolomite may be either Lower Gorge, or Milton which also, in places, contains similar black dolomitic inclusions.

ROCKLEDGE BRECCIA

Southeast of Cobble Hill (which were better called Cobble Mountain) there is a knoll, sloping to the south, which is made up of Rockledge breccia. Thinly-bedded, light-blue limestone lentils, the largest 36 by 17 inches, are seen set in a paste of limestone with rounded quartz grains. Many of these lentils are oriented, south 50° west, while others lie in various directions. In the upper part of the knoll the lentils are veined with calcite and the limestone paste shows flow structure. There are no large bioherms. The underlying Hungerford slate shows bedding dipping 10° easterly, while the cleavage dips 25° easterly. The slate here evidently represents the side of a fold, whether a syncline or an anticline could not be determined.

Just north of the knoll is a smaller knoll also made up of the Rockledge—limestone lentils set in the usual paste of limestone, with sandy layers. But on the west side of the knoll one finds elongated lentils, generally oriented north and south (Fig. 1). The sizes of these lentils range from two by four inches to sixteen by six inches, while the long irregular stringer shown at the base of the photograph is 44 by five inches. But the noteworthy feature of this mass is the paste of slate in which the lentils are embedded and which rises around them like black ruching around a woman's neck. Outcrops of the underlying Hungerford are seen north of this knoll, with bedding planes dipping fifteen degrees easterly.

This is the only locality reported where the Hungerford lentils are surrounded by a slaty paste, instead of by limestone paste.

The Rockledge breccia once extended across the valley to the east for, east of the railroad, it forms a ridge over which Vt. Route No. 116 passes, presenting a steep escarpment to the west. This ridge is somewhat less than a mile in length and some three-eighths of a mile wide, beyond which it plunges down into the valley to the east. The formation rests disconformably on the Hungerford slate. East of Route 116, on the land of George Desrauleau, the Rockledge forms several low, north-to-south-running escarpments facing the west. The usual white and blue lentils of limestone are again set in a sandy limestone paste which shows flow structure. On the east margin of the ridge the Hungerford slate appears, forms the valley floor, and rises to the

[1] Written communication.

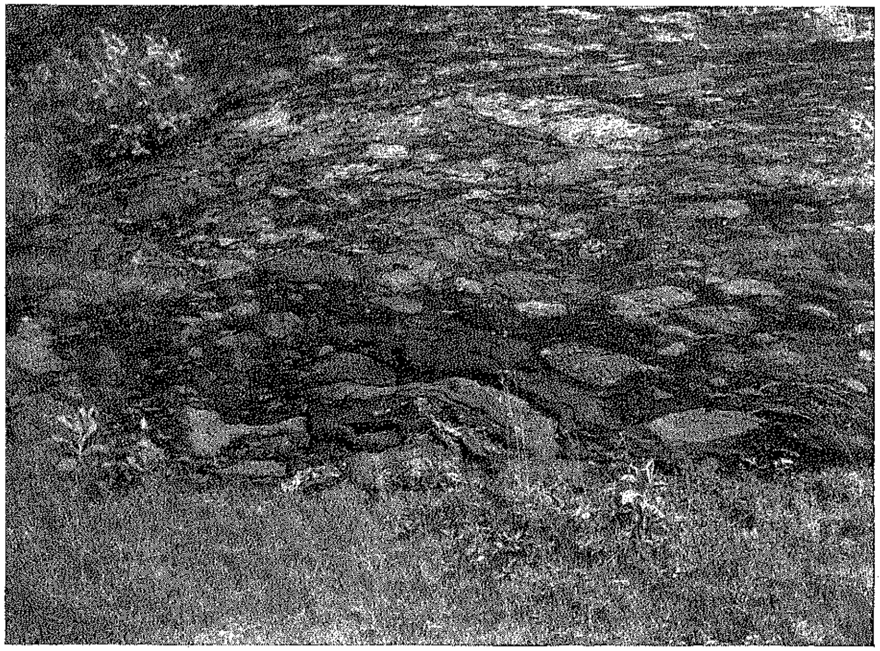

FIG. 1. ROCKLEDGE BRECCIA, SOUTHEAST OF COBBLE HILL

next eastward road. Its contact with the graywacke along the Mountain Border fault is concealed.

The Rockledge breccia further appears on the east side of the ridge south of School No. 3 and, northeast of this, along Malletts Creek. Two outcrops of the breccia are also to be seen on the east side of the ridge west of Colchester Pond.

In southern Williston, at the base of Brownell Mountain, the Rockledge is seen by the dam on Sucker Brook (Burlington quadrangle).

ORIGIN OF THE ROCKLEDGE

Professor Schuchert has traced the Rockledge breccia, interruptedly, "from a point south of the Missisquoi River to a point two miles south of Georgia Plains, a distance of 13 miles."

He believes that the bioherms, lentils, and paste are of biogenic (algal) origin and that the lentils were derived from the bioherms by the waves of the Lower Cambrian sea beating upon them, breaking them up and comminuting some of the limestone to limy sediments in which the fragments foundered. The rounded sand grains in the paste appear to him to be of sand dune origin.

The knoll described, southeast of Cobble Hill, is especially interesting because, while the fragments on top foundered in a limy paste, those below found a resting place in the black muds of the sea floor.

The Eastern Sequence

The members of the Eastern sequence which appear in the Milton quadrangle are the Cheshire quartzite, the Brigham Hill graywacke, and the Rutland dolomite.

THE CHESHIRE QUARTZITE

The Cheshire quartzite, with two interruptions, runs along the Mountain Border fault the entire length of the State. Southward, it extends into Massachusetts to its type locality, the town of Cheshire. The first interruption extends from a point one and one-half miles east northeast of Fort Ethan Allen, southward for about fifteen miles. In this stretch the mountain gneisses and, interruptedly, the Brigham Hill graywacke, are in contact with the sedimentaries of the lowland. The second interruption, according to Keith, extends from the vicinity of Rutland northwards for about twelve miles.

The Cheshire makes up Hog Back Mountain, in Monkton and Bristol, and is also well exposed at the gorge of the Middlebury River, in East Middlebury. It underlies the Lake Dunmore region and rises in Mt. Moosalamoo. Farther south, east of Rutland and along the Vermont Valley, the Green Mountain front is made up of the quartzite, which also occupies a wide area some distance east of Williamstown, Massachusetts. Keith gives its maximum thickness, in Wallingford, as about 800 feet.

The Cheshire quartzite is in general, a fine-grained rock, white to light-gray and dark-gray in most localities, but in places it resembles maple sugar.

In the southern part of the State it is composed of clear white, interlocking quartz grains and smaller amounts of turbid orthoclase, plagioclase, microcline, and perthite, all showing intense strain shadows. The average grain size is 0.32 x 0.27 mm. and the ratio of quartz to feldspar is about 2 to 1. Minor constituents, present in very small amount, are rutile, zircon, shreds of sericite, ilmenite altering to leucoxene, and limonite. The Cheshire is the metamorphic equivalent of rather pure sandstones.

In the Mountain Border zone of the Milton quadrangle the quartzite is of finer grain (average, 0.16 x 0.11 mm.) and is very rusty in appearance, from the greater content of sulphides.

Fossils found in the Lake Dunmore region, fix the age as Lower Cambrian.

In northern Vermont, besides making up, with the Brigham Hill graywacke, the Mountain Border ridge (Plate 2), the

Cheshire occurs in St. Albans Hill, Aldis Hill, and has been followed to the Missisquoi River (St. Albans quadrangle).

An erosion remnant of the Cheshire found resting by thrust upon the Rockledge breccia, south of Mayre Ledge (west of the highway and two and one-half miles south the St. Albans), and another, resting upon the Milton dolomite, west of Cobble Hill, suggest that the Cheshire once extended considerably farther to the west.

The further occurrence of the Cheshire in the Milton quadrangle will be considered presently.

THE BRIGHAM HILL GRAYWACKE

This, second, member of the Eastern sequence was named by the writer, in 1934[1], for its occurrence on Brigham Hill, which forms the highest point on the Mountain Border ridge. The graywacke is a very fine-grained, dark-gray to yellowish-hued rock (in some occurrences almost black), weathering reddish in places and showing fine filaments of graphite along the bedding planes. In some occurrences it is thinly bedded; in others the beds are six to eight inches thick. Where it occurs in open folds the beds are massive; where thrusting has occurred, they are sheared and crumpled. The rock is of striking appearance and forms an excellent horizon marker.

Thin sections show a cataclastic rock made up of angular to subangular fragments of quartz, orthoclase, plagioclase (albite), microcline, and perthite, set in a paste of argillaceous material in which delicate shreds of sericite have been developed. In some of the sections the sericite is well developed, oriented, and forms a mesh around the sial[2] grains, which average 0.15 x 0.11 mm. in diameter. Delicate filaments of graphite cross some of the sections. Fine grains of magnetite, a few larger grains of tourmaline, some small zircons, and patches of limonite form the accessory minerals. A single fossil, found on the western slope of Bald Hill by Miss Natalie Carleton, a graduate student at the University of Vermont, was examined by Professor B. F. Howell, of Princeton University, and determined by him to be an *Hyolithid*, of Lower Cambrian age. The graywacke is intimately associated with the (Lower Cambrian) Cheshire quartzite and normally lies above it, although in places the two rocks are infolded.

In 1934 the writer was privileged to spend a day with Professor T. H. Clark, of McGill University, and his students on his annual excursion in southern Quebec and saw there Clark's Gilman quartzite in which specimens of the brachiopod, *Kutorgina*, of Lower Cambrian age, occur. The appearance of the

[1] The Green Mountains of Northern Vermont; E. C. Jacobs, Proceedings, Geol. Soc. of America, 1934, p. 85.

[2] Sial is a mnemonic made up of Si (Silicon) and Al (Aluminum), two characteristic elements of quartz and the feldspars, for which they are abbreviations.

rock and thin sections show that the "quartzite" is identical with the writer's graywacke. Professor Clark said that the Gilman occupies a belt five to ten miles wide and, areally, covers 50 to 75 square miles. It is folded and Clark estimates its thickness at from 2000 to 4000 feet. The strike is about North 20° East (magnetic) and the dip about 75° easterly.

The Brigham Hill graywacke seems to be coextensive and intimately associated with the Cheshire quartzite, extending probably throughout the State and into Quebec where it has its greatest development.

In his work on the Rutland Quadrangle, Professor F. J. Foyles[1], of Rochester University, has found the graywacke, at elevation 1190 feet, on Blue Ridge Mountain and along the western slopes of East and Bald mountains, as well as on the northeast slope of Blueberry Hill, in Pittsford.

On Monkton Ridge the graywacke is found infolded with the Cheshire. In the gorge of the Middlebury River, at East Middlebury, the same relationship is seen between the two formations, while graywacke outcrops have been found by the writer along the road west of Fern Lake, and on the northwest slope of Mount Pleasant, in Leicester.

Along the Mountain Border thrust, from Monkton to Essex Junction, where the Cheshire is cut out, the graywacke occurs in isolated patches.

Beginning with the most westerly Mountain Border escarpment, half a mile east of the Drury brick yard, on Vermont Route 15 and, farther north, associated with the Cheshire quartzite, the graywacke forms the Mountain Border ridge (Plate 2), which extends across the Milton quadrangle, and it is also seen in large development on the east bank of the Missisquoi River, at the East Highgate bridge, resting by thrust upon the Hungerford slate. It crops out again north of Sheldon Junction, on the Missisquoi, and north of Bridgeman Hill, in Franklin township.

North of the international boundary, as already noted, Clark has found it in great extent and thickness in his Oak Hill slice, in southern Quebec.

North of St. Albans, and about half a mile west of the Mountain Border fault, the graywacke, lying above the Cheshire quartzite, forms the upper part of Aldis Hill which is a thrust outlier, or *Klippe*, resting on the Hungerford slate.

The further occurrence of the graywacke in the Milton quadrangle will follow.

THE RUTLAND DOLOMITE

This formation, named by Keith in 1923[2], is described by him as lying along the eastern margin of the Champlain Valley,

[1] Personal communication.

[2] *Op. cit.*

practically coextensive with the underlying Cheshire quartzite and with the same interruptions along the mountain front. "It is well developed in the valley around Rutland and receives its name from that place." Fossils found in numerous localities prove its Lower Cambrian age. Keith estimates the thickness of the Rutland at about 1000 feet.

The dolomite is a fine-to-medium-grained rock of which there are two principal phases: one, light-to dove-color; the other, dark steel-blue. Besides these, in lesser abundance, there is a variegated phase of pinkish and greenish hues, weathering yellow. The Rutland is a striking-looking rock which is easily recognized.

Thin sections show the dolomite to be a fine-grained, highly crystalline rock. The light variety is very pure, with only small amounts of pyrite and iron oxides as accessories. The dark phase contains more sulphide and its oxidation products which give the rock its darker color. Small sial grains occur here and there in the slides. The variegated phase has, in addition, small round-to-oval areas containing exceedingly fine flakes of a green mineral, too small to identify. It may possibly be serpentine.

The writer has studied this dolomite in Williamstown, Mass., and north along the mountain front into Milton. No fossils have been found but the presence of all the typical phases of the rock and its close lithic similarity to the known Rutland show that it occurs in the Milton region.

As shown on Plate 2, the Rutland dolomite occurs west of the Cheshire-graywacke ridge and at least as far north as the Lamoille River. In the road quarry, two miles north of Milton village, along route, U.S. 7, both the light and dark phases are seen under the graywacke ridge. The dolomite is also exposed on Brigham Hill, Bald Hill, Hardscrabble Hill, and east of School No. 3. Furthermore it forms high cliffs in the lower gorge of the Lamoille, west of Milton village, and small thrusts on the ridge between the railroad and route, Vt. 116, as will be shown.

Special Features in the Milton Region

The Eastern sequence of the Milton region is an area of much complexity, owing to the extensive thrusting and erosion which have taken place.

The Cheshire quartzite and Brigham Hill graywacke make up the ridge running along the eastern border of Milton township and extending both to the north and to the south. Georgia Mountain is formed of the graywacke and, with the underlying Cheshire, is thrust onto the Rutland dolomite along the Mountain Border (or Hinesburg) fault.

Farther south, on the road from Milton village to Westford (north of Milton Pond), the folded Cheshire forms the escarpment of the fault. A few rods to the east the graywacke is seen lying on the Cheshire in eroded folds which are, apparently,

synclines overturned to the west. The graywacke extends eastward to about the boundary shown on Plate 2. Just east of Milton Pond the ridge is formed from eroded, overturned synclinal folds of the graywacke. Since the formation is folded its thickness cannot be determined but it is probably several hundred feet, possibly over a thousand.

ARROWHEAD MOUNTAIN

Arrowhead Mountain rises to 947 feet and, like Cobble Hill, shows a marine bench at the 500-foot contour. Most of the eminence is made up of Brigham Hill graywacke which rests by thrust upon the Hungerford slate, but the base is not exposed. The mountain and its continuation to the south are *Klippes*, or fault outliers, which erosion has detatched from the great ridge to the east, revealing the underlying, younger, Rutland dolomite as a *Fenster*, or "window." Cheshire quartzite probably lies between the graywacke and the Hungerford but this could not be determined.

SECTION ON A A′, PLATE 2

West of the Mountain Border fault, for about a thousand feet, the rocks are concealed. Beyond this cover, on the Coutermarch farm, the Rutland dolomite crops out in small escarpments, which show all three phases of the formation. West of these exposures the rocks are again covered. Thin seams of talcose material are found cutting the dolomite here. Furthermore, in excavating on the Pinegrove farm, in Milton village, some years ago, a vein of foliated talc was found in the dolomite. The talc deposits of the State occur in the mountain schists and gneisses, hence we have evidence that these "crystallines" lie at no great depth below the dolomite.[1]

On the ridge between route, Vermont 116, and the railroad there is a series of four thrust escarpments. The most easterly is a small remnant of Cheshire and graywacke; the other three are made up of Rutland dolomite. All the escarpments face the west. Fields extend from the last escarpment to the Lamoille River.

In Milton village the graywacke is exposed in the upper gorge of the river, under the bridge and below the recently constructed dam, and on both banks of the river, downstream, for about a quarter of a mile, when it disappears beneath the cover.

Somewhat farther west the Lamoille has eroded its lower gorge through a great thrust block of the Rutland dolomite, over a hundred feet thick and, discovering the underlying Hungerford slate, has cut a small water gap through a low ridge of this formation.

[1] In this connection, a small vein of chalcocite and associated basic copper carbonates was recently found cutting the Mallett dolomite on the Parrot farm, north of Malletts Bay.

Just east of the lower gorge power-house the Hungerford, forming the thrust plate, is seen in sharp contact with five feet of Cheshire quartzite, upon which rest six feet of the graywacke and, on this, 100 feet of Rutland dolomite, the dark phase below; the light on top. The dip of the thrust plate is 20° easterly.

Evidently the Cheshire-graywacke formations once extended across the whole section but, with the exception of the two remnants shown, have been eroded away. It is difficult to account for the presence of the Cheshire and graywacke lying between the Rutland and the Hungerford. Possibly the continuation of a tight fold was removed by the thrusting.

In the Hungerford water gap ridge the bedding dips 22° easterly; the slaty cleavage, 55° easterly, indicating an upright fold. It is thought that the westward thrusting of the Eastern sequence (Lower Cambrian) members was responsible for the folding in the underlying Hungerford (Upper Cambrian) slate.

In the continuation of the dolomite ridge, west of route, Vt. 116, south of Milton village, the Rutland dolomite is found in open synclinal folds, with the lighter phase on top; the darker, below. The bedding dips 4° easterly; the cleavage, 40° easterly. The western border of the ridge forms a steep escarpment. The Brigham Hill graywacke lies on the eastern border in thrust relation to the dolomite. The graywacke here makes a salient to the west, perhaps along a tear fault (Plate 2).

We have evidence, therefore, that folding in all three members of the Eastern sequence accompanied the thrusting of these formations to the west.

THE BRIGHAM HILL SECTION

PLATE 2, SECTION B B′

Brigham Hill (1,032 feet) forms the highest point on the Cheshire-graywacke ridge, south of Georgia Mountain. The Brigham Hill graywacke was named for its occurrence here. On the west the ridge descends in a series of three escarpments to Colchester Pond near which it lies by thrust on the Hungerford slate.

On the hill the graywacke forms a somewhat overturned, broken anticline, revealing the underlying Rutland dolomite as a *Fenster*, along the crest of the hill. The east limb of the graywacke dips 40° easterly; the west limb, 50° westerly.

The east limb is well exposed and shows well-jointed beds, four to eight inches thick, with branching inclusions, six inches or more in length and half an inch wide, which suggest fossil anelid trails or possibly algae.

Somewhat farther down the slope the graywacke is found underlain by the Cheshire quartzite and both are thrust onto the Rutland dolomite, which is folded 14° easterly, 30° westerly, with cleavage 75° westerly. The fold is broken and shows the underlying Hungerford slate. Farther west there is a capping (marked S–Q) of green schist, and a quartzite which is not the Cheshire. The thin sections show, for the schist, a fine-grained quartz-sericite rock with accessory minerals of zircon, a few hornblende grains, a small amount of ilmenite and much resulting leucoxene, and iron oxides; for the quartzite, large, irregular grains of quartz, with strain shadows, surrounded by sericite flakes and filaments, and accessory constituents of hornblende, zircons, possibly bleached biotite, pyrite much altered to iron oxides, and ilmenite altered to leucoxene. These rocks clearly belong to the Green Mountains sequence and show its former extension to the west. Finally the graywacke which, with the associated Cheshire, was once continuous across the section, forms the great triple escarpment, over 400 feet high, and a lesser excarpment of 70 feet. The graywacke descends to the axis of Colchester Pond, where it is found resting by thrust on the Hungerford slate.

The dolomite and slate in this section were identified by lithic similarity to the corresponding rocks of known occurrence. It is recognized that they occur at widely differing elevations (for the slate, 180 feet, a.t., at the power-house contact and about 800 feet for the highest exposure on Brigham Hill; for the dolomite, 180 feet at the power-house contact and about 1,000 feet for the highest exposure on the hill), but the graywacke, about whose identity in the whole area there is no doubt, varies in elevation from 180 feet at the power-house to 1,032 feet on the top of Brigham Hill, so that it is probable that the slate and dolomite which occur in the section are correctly identified. The writer believes that the intense thrusting in the great ridge has folded and thrust upward the members into the positions that they now occupy.

The Rutland is exposed on Bald Hill, to the northeast and, further, near School No. 3, so that it is probable that it underlies the whole ridge. The occurrence of the Cheshire, graywacke, and Rutland on Hardscrabble Hill will be discussed later.

The Green Mountains Sequence

It has been seen that the Western and Central sequences are made up of sedimentary rocks while the Eastern sequence is composed of two sedimentary members, the Rutland dolomite and the Brigham Hill graywacke, and one metamorphic member, the Cheshire quartzite. The Green Mountains sequence contains nothing but metamorphic rocks. It is necessary at this point to consider metamorphism.

Metamorphism

The subject of metamorphism is a formidable one and would require for its adequate presentation much more space than there is room for here. The subject is well discussed, in an elementary manner in Pirsson and Knopf's Rocks and Rock Minerals[1] and more fully in Harker's Metamorphism[2].

Briefly stated, metamorphism is a natural process by which sedimentary, igneous, or even other metamorphic rocks are changed in their structure, texture, and mineral composition, either wholly or partially, into new rocks with strikingly different appearances and properties. Thus, dull limestone is changed into sparkling, crystalline marble; soft, weak shales are altered to harder, lustrous slates with their induced slaty cleavage; sand stones, in which the grains are plainly visible, become glassy quartzites which present smooth surfaces; impure sandstones, shales, and conglomerates of the sedimentary rocks are represented by schists and gneisses, with their easy splitting or foliations, and scaly surfaces, etc. For igneous rocks, "coarse-grained feldspathic types, such as granite, etc., are metamorphosed to gneiss; fine-grained feldspathic types, such as felsite, tuffs, etc., become slate and schists; ferro-magnesian rocks, such as dolerites, are represented by hornblende schists, amphibolite, talc, serpentine etc." (Knopf).

The agencies responsible for these changes are, briefly, pressure such as comes from mountain folding or thrusting; heat (better, change of temperature), which comes from within the earth, increasing with depth, or from the presence of highly heated magmatic bodies intruded into the earth's crust; and chemical substances, already in the rocks, which are rendered active by the other two agencies. These chemical substances are water, in the form of moisture or vapor, which all rocks contain in varying amounts; water solutions of various substances, and gases, such as chlorine, fluorine, boric acid, and others, which are given off by molten magmas. These substances and the hydroxyl, (OH), supplied by the moisture, are essential to the formation of such minerals as muscovite, biotite, beryl, tourmaline, etc., and therefore the presence of such minerals in the rocks argues the presence of igneous bodies, although the bodies may lie at considerable distances away.

The principal metamorphic rocks are gneiss, schist, phyllite, slate, amphibolite, quartzite and marble. These were described in the last Report of the State Geologist, to which reference is made.

The chief minerals found in metamorphic rocks are: quartz, the feldspars, muscovite, sericite, biotite, chlorite (which is a family of minerals, including penninite, perchlorite, diabantite,

[1] John Wiley & Sons, New York City.
[2] E. P. Dutton & Company, New York City.

etc.), garnet (also a family which includes the red almandite, the lighter grossularite and the green uvarovite), epidote, zoisite, clinozoisite, titanite, apatite, actinolite, zircon, rutile, graphite, tourmaline, beryl, magnetite, ilmenite (and its decomposition leucoxene), hematite, limonite, pyrite, pyrrhotite, staurolite, vesuvianite, sillimanite, and others.

When present in characterizing amounts in the rocks, some of these mineral names (hyphenated) are used as modifiers; thus, chlorite-schist, quartz-sericite-schist, quartz-sericite-gneiss, etc.

Minerals and rocks are stable under definite conditions of temperature and pressure. If these conditions, especially the temperature, are changed the minerals will change to fit the new environment.

Harker distinguishes, with increasing temperature (increasing depth of burial or increasing proximity to igneous magma), the following metamorphic zones, each named for its critical mineral: Chlorite zone, Biotite zone, Garnet zone, Staurolite zone, Cyanite zone, Sillimanite zone. "A zone of higher metamorphism normally underlies one of lower grade, but this relative position may possibly become inverted by subsequent disturbance"—by thrusting for example.

Instead of these six zones, based on the presence of typical minerals in the rocks, Grubenmann recognized three zones of metamorphism, based upon depth within the earth's crust. These are the Epi, or upper zone, which is the belt of weathering and extends to the water table; the Meso, or middle zone, or zone of cementation, where unconsolidated sediments become cemented together; and the Cata, or lower zone, where the most stable minerals are found and the action is chiefly chemical. In the Epizone the temperature is moderate, the pressure low, the stress strong; in the Mesozone the temperature and pressure are higher and the stress very strong; in the Catazone the temperature and pressure are very high but the stress is weaker.

The Epizone is characterized by the minerals chlorite, albite, epidote, sericite, dolomite; the Mesozone by staurolite, garnets, hornblende, actinolite, diopside, biotite, anorthite; the Catazone by the presence of sillimanite.

It is thus seen that metamorphism is not a static but a progressive process in which the minerals found depend upon their environmental conditions, of pressure and temperature. Mrs. Knopf[1] notes that: "metamorphism follows a definite and orderly progress by which rocks of given constitution, under given conditions of temperature and pressure, assume characteristic and recognizable forms. For example, under conditions of increasing temperature and pressure an argillite alters to a slate. A slate in turn is generally conceived of as passing into a fine-

[1] Eleanora B. Knopf: Retrogressive Metamorphism and Phyllonization, Am. Jour. Sci., 5th ser., No. 121 (Jan., 1931).

grained but perceptibly crystalline phyllite, this in turn becoming more and more coarsely crystalline until, under conditions of moderately high temperature and pressure, in the Epizone of Grubenmann, it becomes either a chlorite-muscovite schist or a chlorite-albite schist according to its original composition. Under higher pressure and temperature conditions, in the Meso- or Catazone of Grubenmann, it would become a garnetiferous muscovite-biotite schist or cordierite-silliman gneiss. Such is the normal course of progressive metamorphism."

On the other hand, under opposite physical conditions, schists are known in the Morristown-Stowe and in the Worcester valleys, as well as in many other mountainous regions, in which well-formed garnets are seen, in thin sections, surrounded and penetrated by chlorite, into which the garnets are changing. Some of the garnets are almost entirely replaced by the chlorite. This is retrogressive metamorphism. The garnet of the higher (garnet) zone has, to a large extent, been altered to the chlorite of the lower (chlorite) zone. Such retrogressive minerals are called diapthorites, from the Greek word, *diaptheiro*, meaning to destroy.

Other minerals, biotite, staurolite, cyanite, etc., show diapthoritic alterations but, with the exception of biotite, were not found in this investigation.

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The Green Mountains sequence extends eastward from the Mountain Border (or Hinesburg) fault to the Vermont Piedmont. The traverse made is not an unbroken line but, in order to include the principal mountain features, crosses Westford (Plate 1), Cambridge, Underhill, Morristown, Stowe, Elmore, Worcester, Middlesex, Calais, and East Montpelier, with extensions to the north and south.

The rocks of the sequence, in descending order of abundance, are gneisses, schists, quartzites, phyllites, graywackes, and amphibolites, with both acid and basic intrusives. These rocks are such a jumble, varying so in their appearance and attitude, that only in a few cases can they be brought into formations.

Where the Cheshire quartzite, Brigham Hill graywacke, and Rutland dolomite, of the Eastern sequence, are absent the Green Mountains sequence lies by thrust on the formations of the Central sequence, but the contacts are concealed. Where the Eastern sequence, or any of its members, is present the mountain metamorphics are thrust onto it. Here again the contacts are generally hidden but one good contact has been found, as follows:

Essex Junction

Half a mile east of the Drury brick yard (Burlington quadrangle) the Mountain Border fault crosses route, Vt. 15, in three

escarpments. The most westerly of these escarpments is made up of the Lower Cambrian, Brigham Hill graywacke, which strikes N. 21° E. and dips 45° southeasterly. The rock is cut by thin *lit-par-lit* injections of quartz and some feldspar.

Lying on the graywacke, by thrust from the southeast, are fine-grained, thinly-foliated, chloritic schists, weathering reddish, of which one is remarkable in that it shows both bedding and schistosity. The bedding dips 37° southeasterly; the schistosity, 84° southeasterly, indicating an upright fold. Sections show quartz-orthoclase sericite schists, much chloritized and containing, as accessories, albite, tourmaline, hornblende fragments, zircon, zoisite, and much iron oxide. No garnet or biotite is seen.

The two other escarpments, two-tenths and six-tenths of a mile farther east, respectively, are made up of various schists and gneisses, cut by *lit-par-lit* injections. All these metamorphics are members of the Green Mountain complex.

Now, in the thrusting in the Milton quadrangle, older formations have been invariably thrust upon younger ones. The situation at Essex Junction indicates, therefore, that the Green Mountain sequence is Pre-Cambrian in age. This conclusion is supported by the fact that the rocks of the Green Mountain sequence differ radically in structure, mineralogy, and chemical composition from those of the more western sequences. Furthermore, it will be shown that the Missisquoi formation in the Stowe valley appears to lie unconformably on the Mansfield rocks.

In a region of thrusting, where no Lower Cambrian rocks are found lying, in normal relationship, unconformably on an older formation (such as at Sucker Brook, at Lake Dunmore, where Lower Cambrian quartzite lies unconformably upon Pre-Cambrian, Mendon dolomite) such evidences of the Pre-Cambrian are all that could be expected.

East of the last escarpment the metamorphics plunge under cover to reappear on the north-south-running ridge at Essex Center (Plate 2). Here the mountain metamorphics are found inbedded with the Westford schist which soon replaces them to the east. At Jericho, by the bridge over Browns River, the Westford is well exposed but disappears under cover to the east. In Underhill township the mountain metamorphics reappear and were followed eastward to East Montpelier.

Aldis Hill

In his work on Aldis Hill Keith[1] found a schist resting by thrust upon the Lower Cambrian Cheshire quartzite which forms the hill. As shown on (page 21) the schist really rests on Brigham Hill graywacke, which in turn lies above the Cheshire.

[1] Structure and Stratigraphy of Northwestern Vermont; Arthur Keith, Guide Book 1, International Geological Congress, p. 63 (1933).

Keith called this schist Pre-Cambrian. Since the Cheshire extends along the Mountain Border fault, of which Aldis Hill is an outlier, it is difficult to see how a Pre-Cambrian member could occur here.

Hardscrabble Hill

Hardscrabble Hill, named by the writer for the Hardscrabble School, lies on the eastern edge of the Cheshire-graywacke ridge in eastern Milton, about two miles south of Milton Pond (Plate 2). The name is most appropriate.

From the western limit of the Mountain Border fault the Brigham Hill graywacke extends up the slope to the summit of the hill, where it forms the western limb of a southward-pitching anticline. East of the graywacke, and probably underlying it, are seen, in turn, the Cheshire quartzite and Rutland dolomite, giving the same sequence of formations that occurs in the Brigham Hill section and in the section across Milton village. The eastern limb of the anticline is missing so that the dolomite, dipping 55° southeasterly, is in hidden contact with green schists which dip generally 40° southeasterly. The schists extend to the eastward till they meet the Westford schist.

An eighth of a mile eastward, along the country road and in line with the ruins of Dolphus Bushey's house, a thrust ridge rises eighty feet above the road, with a steep escarpment to the west. The ridge is 60 or 70 feet wide and, with several outliers, continues to the south to an undetermined distance. Eroded traces extend to the north.

The ridge is made up of a dark, greenish-gray, fine-grained graywacke, entirely unlike the Brigham Hill graywacke. Microscopically the rock is seen to be a cataclastic mass of irregular fragments of quartz, of varying size, with lesser amounts of orthoclase and albite, set in a ground mass of fine quartz grains, and sericite which is much chloritized. Accessory minerals are almandite garnet, fragments of hornblende, small zircons, grains of magnetite, ilmenite altered to leucoxene, and iron oxides. No biotite occurs. The rock belongs to the Garnet zone of metamorphism. It much resembles in its petrography Clark's[1] Lower Cambrian Pinnacle graywacke.

On the face of the escarpment (Fig. 2) long, board-like inclusions of thinly-foliated, chloritic, sericite schist are seen, weathering reddish on the schistosity planes and resembling the schist described at the Essex Junction contact. The inclusions are as much as a foot in thickness and many feet long. The dip of the included member is 25° to 30° southeasterly. To the east and west the ridge is bounded by green schists. This is the only occurrence, known to the writer, of a graywacke (or, for that matter, a quartzite or a gneiss) including a schist.

[1] *Op. cit.*

FIG. 2. SCHIST INCLUSIONS IN THE GRAYWACKE, NEAR HARDSCRABBLE HILL

The Green Schists

Extending along the eastern border of the Lower Cambrian Cheshire-graywacke ridge (in the "Belt of mixed metamorphics," Plate 2) there is found a variety of thinly-foliated to more massive schists, some highly chloritic, others less so, nowhere in visible contact with the rocks of the Eastern sequence. Under the microscope the schists are seen to be generally composed of fine grains of quartz, orthoclase, plagioclase, and a little perthite, surrounded by sericite filaments, generally well oriented and chloritized to varying degrees. Tourmaline, zircons, hornblende, titanite, pyrite, magnetite, ilmenite more or less altered to leucoxene, and iron oxides make up the accessories. No garnet or biotite occurs.

In several reconnoissances across the State, west of the mountains—one on route, Vt. 104; another along the Missisquoi River on route, Vt. 105—these green schists have been encountered and are found to make up a considerable part of the terrain. They are thought to be Pre-Cambrian in age. (see p. 34). They belong in the Chlorite zone of metamorphism.

East of the Cheshire-graywacke ridge, containing Brigham, Bald, and Hardscrabble hills and Georgia Mountain, lie three north-running valleys, separated by roughly parallel ridges which constitute the foot hills of the Main Range of the Green Mountains. These valleys and ridges are occupied by the townships of Fairfax, Fletcher, Westford, Underhill, and Cambridge.

The Westford valley (Plate 2) is crossed by low, longitudinal, thrust ridges of schist and is drained by Browns River, a subsequent stream which flows through the center of the township and enters the superposed Lamoille at Fairfax. In 1929 the U. S. Corps of Engineers laid out a dam site on Browns River, for flood control, about a mile south of Westford village.

The valley has large deposits of glacial material, while glacial groovings and striations are noted along the road (Vt. 128) leading from Essex Center to Westford village.

The next easterly valley (Vt. 15, Plate 3), through which the now abandoned Burlington and Lamoille Railroad passed and the third, or Pleasant Valley, are drained by tributaries of Browns River. These valleys are also heavily glaciated.

Pleasant valley possesses some unusual glacial features. On the road running from Underhill Center to Jeffersonville one notes a typical U-shaped glacial trough, perhaps a mile wide, between Macomber Mountain and a spur of Mount Mansfield. It will be remembered in this connection that Lake Willoughby, in Westmore, also lies in a glacial trough but of much greater dimensions.

Opposite the cottage of the late Henry B. Shaw, and also in the pasture to the south, on the road running along Clay Brook from Underhill Center to the summer colony at Stevensville, lie several great erratics of what has been called pillow lava. The erratic in the pasture (Figure 3) measures 19 by 15 feet, by about 10 feet high and shows the elliptical markings, or "pillows," characteristic of this type of lava. The rock is studded with tiny octahedra of magnetite. Thin sections show an olivine basaltic lava, of volcanic origin, with the olivine largely altered to serpentine, which gives the rock its green color.

Professor H. S. Palmer, of the University of Hawaii, on examining the rock, denied that it was pillow lava, claiming that it was not an extrusive, as pillow lavas must be, but an intrusive. Be this academic question as it may, the fact remains that the nearest source of this type of rock, known to the writer or to the geologists at McGill University[1], is at Owls Head and Bear Mountain, near Newport, Vermont, far to the northeast. This evidence and other evidences to follow show that the Pleistocene ice movements varied widely in their directions. Professor J. W. Goldthwait, of Dartmouth College, in a recent conversation with the writer, did not believe, however, that such differences in azimuth of

[1] Written communication from Prof. T. H. Clark.

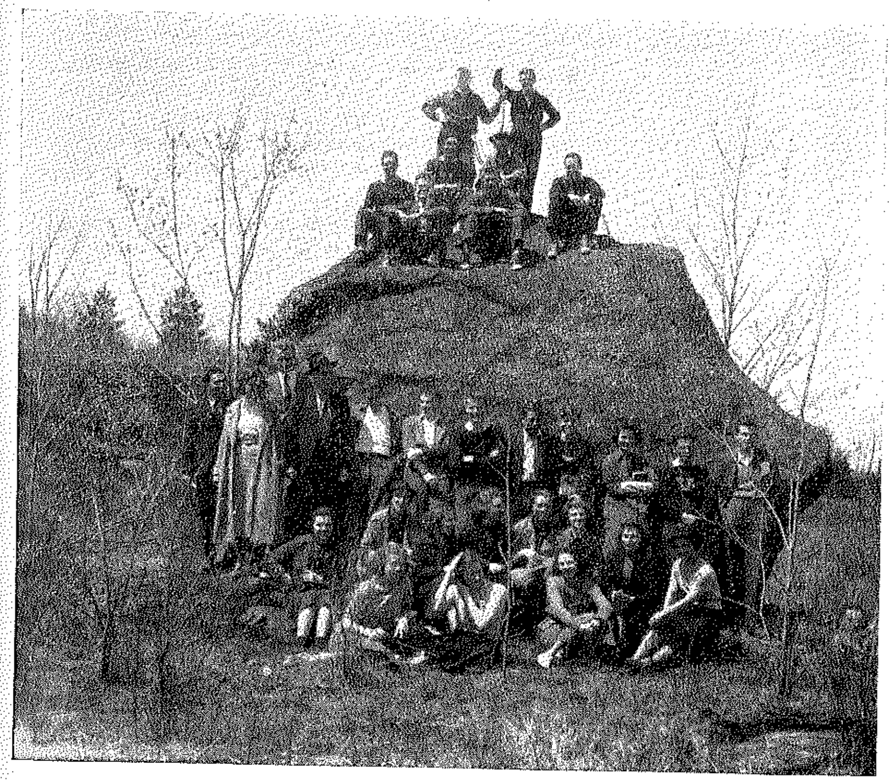

FIG. 3. GLACIAL ERRATIC IN UNDERHILL

glacial movements necessarily denoted several advances of the ice sheet in New England.

This region is full of glacial interest and, as suggested by the illustration, is visited by geology classes of the University of Vermont.

The Westford Schist

The Westford schist is one of the few groups of rocks in the Green Mountains sequence which is sufficiently homogeneous and extensive to be called a formation. It was named by the writer, in 1924, for its occurrence in Westford township.

The Lamoille River has cut its gorge at Fairfax Falls through some 240 feet of this rock, which strikes N. 55° E. and dips 78° southeasterly. The schist is dark gray, fine-grained, and thinly foliated. The average size of the sials is 0.55 x 0.29 mm. Sections show a dense mesh of fine sericite, well-oriented and including in its meshes elongated grains of quartz, orthoclase, albite, and a very little microcline. The quartz grains are crushed and show strain shadows. The orthoclase is considerably sericitized. Accessory minerals are fragments of hornblende, ilmenite or titanomagnetite altered to leucoxene, zircons, rutile and apatite needles, titanite altered to a yellow, amorphous mass and calcite, an occasional tourmaline, and iron oxides. The sections are only mildly chloritized. This schist extends northward along a ridge for an undetermined distance.

South of the Lamoille the schist is somewhat coarser grained, with fine, pebbly surfaces which are very characteristic. It shows the same mineralogy, with the addition of a few light-colored garnets. No biotite is seen in any of the schist sections. The rocks belong to the Chlorite zone, verging on the Garnet zone. The schist makes up the larger part of Westford township where it forms long, narrow, northward-trending ridges, markedly sculptured by glacial action.

The western border is generally concealed but east of Prospect Hill, in the northwestern corner of Westford, it is found in conformable contact with the "Belt of mixed metamorphics." As already noted, the Westford is found interbedded with the Green Mountain schists on the west side of the ridge which runs northward from Essex Center. Based on this relationship, the Westford is Pre-Cambrian in age and belongs to the Green Mountains series.

The green schists to the west, being in conformable contact with the Westford, may also be considered as Pre-Cambrian in age.

As stated above, these green schists have been encountered in two reconnoissances across the northern part of the State, west of the Green Mountains. Furthermore, Prof. Clark[1] found, in southern Quebec, the members of his Oak Hill series resting upon a basement of chlorite schist which he therefore presumed was Pre-Cambrian in age. He called it the Tibbit Hill schist. It may well be that the Vermont green schists belong to this formation.

The eastern border of the Westford schist is seen in Jericho, where Browns River has cut its small gorge. To the south the schist has been encountered on the road, Vt. 116, between the Checker House bridge and Essex Junction, and in Salisbury, route U. S. 7, in the road cut.

Southeast of Westford village, along the country road leading to the southeast, the Westford forms thrust ridges.

Along the country road, next north, the rocks of the Green Mountain series are found thrust onto the Westford schist in low escarpments. If it were not for the thrusting of this series onto the known Lower Cambrian Brigham Hill graywacke, at Essex Junction, one would conclude that the Pre-Cambrian

[1] *Op. cit.*

rocks began at the Westford thrusting and that the Westford schist was a Paleozoic member. But, on the whole, the writer concludes that both the Westford schist and the Green Mountain series, as well as the rocks of the "mixed metamorphic belt" are all Pre-Cambrian.

The belt of thrust faulting comes to an end with the "low escarpments" mentioned above. From here westward to the base of Arrowhead Mountain the thrust zone is six and one-half miles wide. To the Champlain fault it is eleven miles wide.

To the east, on the Mansfield quadrangle (Plate 3), the traverse crosses the eastern part of Westford township, Underhill and Cambridge (Mt. Mansfield quadrangle, Plate 3) and the townships of the Hyde Park quadrangle. In Underhill the country is rolling, being made up of northward-trending ridges and intervening valleys. Metcalf Hill (1,400 feet above sea level), Macomber Mountain (1,440 feet), and Hedghog Hill (1,560 feet) are the chief land marks. The rocks of this area are folded into anticlines and synclines, in places so highly compressed that the dips are vertical. The land gradually rises to the base of Mount Mansfield.

This relationship of thrust faults, followed towards the source of the thrusting by anticlinal and synclinal folds, is typical of regions of thrusting. It is seen on a smaller scale at the Rock Point thrust on the lake shore at Burlington.

The Green Mountain Series

The rocks of this series, along the traverse, are made up of a complex of schists and gneisses, dipping at high angles and so diverse in their characteristics that they cannot be brought into formations. They are gray to rusty-brown, and various shades of green, depending upon the amount of chlorite present. In a few places silvery-gray rocks, resembling the gneiss on the summit of Mansfield but without its structure, are noted. The schists are thinly-foliated to massive. The gneisses are generally coarser-grained but in places are so thinly foliated that identification is based on the thin sections, where it is determined by alternate bands of schistose and granulose minerals.

At the western part of the traverse the rocks are quartz-orthoclase-sericitic, more or less chloritized schists with accessories of almandite, epidote, detrital zircons, tourmaline, titanite, magnetite, ilmenite more or less altered to leucoxene, disseminated pyrite or pyrrhotite, and iron oxides. The chlorite includes penninite. The orthoclase is sometimes twinned and an occasional grain of plagioclase or perthite is noted.

Farther east quartz-orthoclase gneisses appear, with almandite and possibly grossularite, more or less biotite, epidote, tourmaline, zircon, etc., and with increasing amounts of magnetite.

Near the Mansfield end of the traverse the gneisses contain increasing amounts of garnet and biotite and a good deal of graphite. Magnetite is very abundant here, so much so that children of the summer colony at Stevensville "fish" it out of Clay Brook with magnets. The sections show that some of this magnetite is unaltered and probably detrital while, again, it is seen surrounded by hematite from which it has been reduced.

The rocks of this series belong to the Chlorite, Biotite, and Garnet zones but only a small amount of biotite is present.

Mount Mansfield

This is the culmination of the main range of the Green Mountains and lies along the border of Underhill and Stowe. The summit is a long, narrow, northward-trending ridge whose profile suggests a "caricature of a face," of rather an Hibernian type, with its forehead, nose, lips, chin, and even an Adam's apple. According to the late Daniel L. Cady, the Indians saw in this profile the likeness to a moose and so called the mountain Mose-o-de-be-wad-so.

East of Mansfield, and separated from it by Smugglers Notch, lies Sterling Mountain.

The summit ridge of Mount Mansfield is about one and one-half miles long and curves in a great arc convex to the west. At its narrowest point the ridge is only a few rods wide. The "chin," 4,393 feet above sea level, is the highest point in the State. It is a dimpled chin, made up of three rocky knolls. The elevation of the "nose" is 4,160 feet; of the hotel, 3,849 feet. Numerous open joints (geological!), some ten inches wide, occur along the summit. On the east side of the mountain, under the lower "lip," a huge cleft forms the Cave of the Winds. Here a great mass of rock, perhaps 100 feet long by 25 feet wide, maximum, has split off and hangs precariously on the mountain side, awaiting the time when it will fall into the Notch below, as many other large rock masses have done. A smaller cleft, on the west side, under the upper "lip" forms the so-called Subway. Great buttresses descend from the "chin" and "forehead" into the Stowe valley, while another buttress runs from the "nose" down into Stowe. It is along this latter ridge that the fine toll road, begun as early as 1857, is built with an average grade of 17 percent. The hotel, of 50 rooms and excellent table, attracts an ever increasing number of tourists and mountain climbers, drawn by the glorious panorama of the surrounding country, the many trails, and the invigorating mountain air. Of late years skiing has come much into vogue and week-end "snow trains" bring hundreds of people from urban centers to the region about the toll road and farther north, in Smugglers Notch, where ski runs have been laid out and larger ones are in prospect.

The following, rather quaint, appreciation of the views from Mansfield is taken from Hitchcock's Geology of Vermont (1861, page 877): "The chin furnishes one of the grandest and most extensive views in New England. Standing on the summit, on a clear day, the observer looks down upon the country extending from the base of the mountain to Lake Champlain as he would upon a map, and beholds in the outspread panorama an agreeable diversity of hills and valleys, forests and cultivated fields, villages and streams of water. Further along in the picture may be seen Lake Champlain, which at intervals is observed, far to the north and south, peering out in the blue distance like inlaid masses of highly polished silver, to give light and beauty to the scene. The valley of the lake may be traced for its entire length, beyond which arise the majestic and picturesque Adirondacks, which give romantic beauty to the background of the picture, and terminate the vision in that direction by their numerous pointed summits."

Mansfield is heavily wooded on its lower slopes but the upper part is only sparsely covered with spruce and balsams, while the summit ridge is bare. Sphagnum bogs are seen in the hollows and south of the "nose" ridge. North of the "chin" there are two tiny bodies of water, the Lake of the Cloude and Bear Pond. The mountain rocks, on the slopes as well as on the summit, are much broken in places, and in others present dangerous sloping surfaces, so that exploration is best carried on along the numerous trails which cross the mountain in various directions: The Halfway House and Sunset trails from the west, the Nebraska Notch and Maple Ridge trails from the south, the toll road and the Hazelton, Hell Brook, and Profanity trails from the east, and many others. The Long Trail[1] runs along the summit ridge.

GLACIATION

Mansfield was once covered by the Pleistocence ice sheet but the glacial *debris* ("till") has been washed down from the upper levels and is practically absent above the 3,100-foot contour. Many erratics, large and small, are to be found on the slopes and along the summit. Somewhat southeast of the "upper lip" knoll there are several great masses of gneiss of not distant origin: one, in the timber, over 30 feet long and 15 or 20 feet high; another 21 feet long, by 9 feet high, by 8 feet, and a third about half as large. A boulder of syenite, which probably had its home in southern Canada, was taken from along the toll road, some years ago, to the Stowe cemetery, where it serves as a war memorial. It had better have been left where it was as a true memorial of the ice age.

Faint glacial striae in the rocks by the hotel entrance show that the movement of the ice sheet was from N. 37° W. But other striae along the Hell Brook trail testify, as does also the

[1] See the Long Trail Guidebook, published by the Green Mountain Club, Inc., Rutland, Vermont.

great pillow lava erratic in Underhill, to the varied directions of ice movement.

It is interesting to read that Louis Agassiz, in 1840, advanced his theory of a glacial ice-cap[1]—"That, at a period geologically very recent (25 or 30,000 years ago, we now believe) the entire hemisphere north of the 35th. and 36th. parallels of latitude had been covered by an ice-sheet possessing all the characteristics of existing glaciers in the Swiss Alps," and that the advance of this sheet could account for the smoothing, polishing, and striating of the rocks, the formation of great U-shaped troughs (like those at Lake Willoughby and Underhill), and the transportation of sand and gravel, and huge erratics. Moreover, Agassiz came to America in 1846 and, in his travels, found the same glacial evidences that obtain in Europe. He argued that the glacial drift in America was contemporaneous with that in Europe. Furthermore, the first Vermont State Geologist, Professor Charles B. Adams, suggested, in 1850, as the cause of the observed glacial phenomena an ice-sheet 5,000 feet in thickness.

In spite of Agassiz's work, Hitchcock[2] clung to the old Noachian deluge theory and wrote of the erratics on Mansfield as having been "doubtless wrenched from their icy matrix as they were recording the history of the ice berg epoch upon these tablets of stone, whose record was to reveal to man that even Mansfield's lofty summit was once beneath the ocean, and ice bergs sailed majestically over it"—and (from Heaven knows where) rafted the boulders which, in grounding, striated the mountain top! In similar vein Hitchcock taught that the glacial trough in which Lake Willoughby partly lies was made by "powerful northern currents which, during the drift period, rushed with impetuous force through this deep gorge." The source of the "powerful currents" evidently was not investigated. Thus did the great deluge influence the geologic thought of the day.

THE ROCKS

Mansfield rocks are gneisses, schists, and quartzites. Of these the gneisses greatly predominate and are associated with the schist, while the quartzites lie below them. The gneisses are generally coarser-grained than in the valleys and the interbedded quartz is thicker. The sial grains are larger and secondary muscovite takes the place, to a large extent, of the scaly sericite. Megascopic garnets, delicate tourmaline needles, sizable fragments of ilmenite, magnetite, and pyrite are seen.

The coarsest gneisses occur south of the "forehead," along the Maple Ridge trail. Here the sections show sial grains, averaging 0.94 x 0.71 mm. in size. The rocks are quartz-orthoclase-muscovite-biotite gneiss, somewhat chloritized with diabantite. Accessory minerals are albite, possibly tremolite, light-colored garnets, zircon, epidote, titanite, apatite, magnetite, and ilmenite (or else titaniferous magnetite), somewhat altered to leucoxene.

[1] The First Hundred Years of American Geology; G. P. Merrill, Yale University Press (1924).

[2] Geology of Vermont, vol. 2, p. 879 (1861).

The west slope of Mansfield, studied along the Halfway House and Sunset trails, is made up of gneisses and schists. The gneisses are silvery-gray to dull-colored rocks, coarse in texture, and containing much included quartz, large grains of magnetite, and megascopic, delicate needles of tourmaline. Some of these rocks suggest metamorphosed conglomerates. The schists are thinly-foliated, silvery-gray rocks of much finer texture.

Both gneisses and schists have practically the same mineralogy. A composite of the sections would show quartz, orthoclase with a few carlsbad twins, muscovite, and sericite (the sericite predominating) as the essential minerals. The sial grains average 0.42 x 0.30 mm. Considerable chlorite, including diabantite, is noted. The accessory minerals are albite, hornblende fragments, almandite garnets, tourmaline, apatite, titanite, epidote, ilmenite altering to leucoxene, much magnetite, some pyrite and pyrrhotite, hematite and limonite.

On the Halfway House trail there also occurs a quartz–muscovite–sericite–hornblende schist. The section shows many porphyroblasts of unoriented, prismatic sections of hornblende, altering to limonite, possibly through siderite. A few grains of plagioclase, almandite, titanite, tourmaline, magnetite, ilmenite, leucoxene, and limonite form the accessories. Such schists are very rare in the region covered by this study. They probably represent metamorphosed diorites.

A large part of the summit ridge is made up of brilliant quartz-muscovite gneiss forming thinly-bedded drag folds (Fig. 4) overturned to the west and with an enormous amount of quartz, in thin beds lying within the foliations as well as, in places, cutting the folds. Some of this material is probably magmatic. Thin sections show quartz and orthoclase, in proportion 2:1, and contain a few grains of faint plagioclase. This gneiss is also found along the toll road down to about the 3,800-foot contour.

A composite of the gneiss sections shows bands made up of interlocking grains of quartz and orthoclase, in proportion 3:1, with albite and a few Carlsbad twins. The average grain size is 0.48 x 0.31 mm. These bands of sial alternate with bands of muscovite and sericite, well-oriented and much chloritized. The sials are much crushed and strained. The accessory minerals are magnetite, ilmenite more or less altered to leucoxene, apatite needles, hornblende fragments, garnets (chiefly almandite but also some of lighter color, probably grossularite), a good deal of tourmaline, some epidote and titanite, an occasional grain of zoisite, and a small amount of graphite.

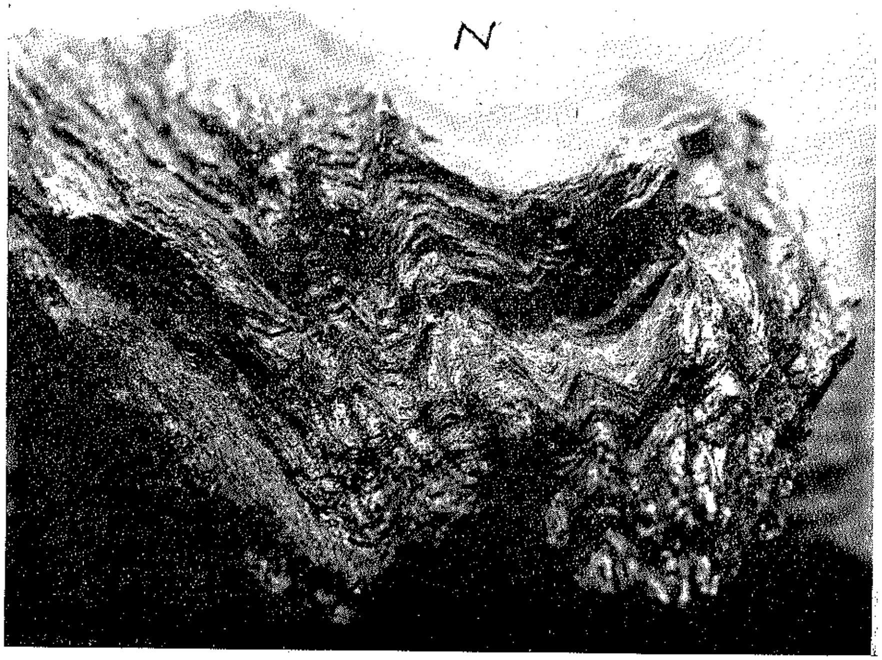

FIG. 4. DRAG FOLDING ON MOUNT MANSFIELD

This type of gneiss is very extensive, being found also on Camels Hump, Elmore Mountain, and on the summit of the Worcester Range.

The "nose" is largely made up of darker, highly chloritized, quartz-orthoclase-sericite gneiss. The sections show quartz and orthoclase (including some Carlsbad twins) in the proportion 4:5, sericite full of pyrrhotite and pyrite dust, and accessory apatite, tourmaline, almandite, and much magnetite. This dark gneiss also occurs around the "chin," a mile and a-half away, and suggests that the rock was once continuous along the whole summit ridge but has been removed by erosion, in which glacial scouring played its part.

Lying below the summit gneiss and found, at elevations around 3,400 feet, on the toll road, are very coarse-grained, thickly-foliated, quartz-muscovite gneisses, with delicate crenulations and megascopic muscovite, biotite, and almandite. The quartz grains are as large as 5 x 5 mm.; the average size in the sections is 0.61 x 0.43 mm. The sections show quartz, orthoclase (with Carlsbad twins and albite), in proportion 1:3, brilliant muscovite, much chloritized, a large amount of biotite, con-

siderably chloritized, magnetite, light-colored garnets, epidote, apatite, and a few zircons.

At still lower horizons, in the road quarry, elevation about 3,000 feet, are found nearly horizontal beds of light-gray quartzite, with megascopic tourmaline needles, intercalated with quartz-sericite schist. The section shows a granoblastic mass of quartz and orthoclase grains, in proportion 5:1, and with an average grain size of 0.59 x 0.40 mm., closely interlocked and with fretted boundaries. Minor amounts of muscovite, light-colored garnets (probably grossularite), tourmaline, apatite needles, and a few grains of magnetite make up the accessories.

Such beds are interpreted as metamorphosed sandstones and intercalated shales. Some of these beds are impregnated with copper carbonate.

It is to be noted that the Mansfield rocks fall into Harker's Biotite zone and Garnet zone, and into the Epizone and Mesozone of Grubenmann-Niggli. Biotite is not at all common but garnet, chiefly almandite, is abundant.

Smugglers Notch

The narrow valley between Mansfield and Sterling Mountain is known as Smugglers Notch and is one of the wildest and most picturesque places in the State. Above it, at its narrowest point, near the great spring, Mansfield's cliffs rise nearly vertically while, to the east, are seen the somewhat gentler slopes of Sterling. The fine highway, which climbs to 1,803 feet above sea level, brings thousands of motorists each season to enjoy the quiet and beauty of this mountain pass.

The valley widens markedly to the south and is heavily glaciated. Great deposits of till are seen along the highway while, in spite of great rock falls from the cliffs, which have no doubt obliterated most of them, glacial striations are still seen on the Hell Brook trail, trending generally parallel to the valley wall. These striations prove a glacial advance from the northeast, in contrast to the advance from the northwest, shown on the rocks near the summit hotel, to which reference has been made.

The Notch road is built along the Sterling side of the valley. East of it lies the deep valley of the Brewster River which has its source near the divide separating its waters from those of the West Branch. The latter stream flows southerly through the Notch and enters the Waterbury River at Stowe.

Smugglers Notch has been carved out of the Mansfield-Sterling massif by headward erosion of these two streams, aided by the erosive action of the ice sheet. It is, in fact, a coll or pass.

The rocks of the Notch are gneisses, quartzites, and schists. In Jeffersonville, to the north, the soldiers memorial has been carved in coarse gneiss whose polished surface shows large injections of pegmatite lying in the foliations.

At the entrance to the Notch road, close by, a light-gray, thinly-bedded rock occurs, forming the mountain side. Its strike is N. 46° E.; its dip, 73° westerly. The rock is so little metamorphosed that it might easily be classified, megascopically, as a sand stone, but the thin section shows it to be a quartzite. It is made up of a granoblastic mass of quartz and fresh orthoclase grains, in proportion 5:4, with fretted boundaries, tightly interlocked. Muscovite constitutes about five percent of the slide. Accessory minerals are magnetite, and ilmenite altering to leucoxene, a few almandite garnets, an occasional tourmaline crystal, and a few stubby zircons. The feldspars and muscovite are moderately chloritized. The rock is probably a metamorphosed sandstone which has been invaded by magmatic emanations.

In close contact with the quartzite is a silvery-gray, thinly-foliated, sericite schist. The section shows a crystalloblastic mass of nearly perfectly oriented sericite, enclosing a relatively small number of quartz and orthoclase grains. A feature of this slide is the development of the chlorite, diabantite, with its purplish interference colors. Minor constituents are many tourmaline crystals, a few zircons, and probably grains of beryl. Moreover, the section is full of fine rods of ilmenite and leucoxene, perfectly oriented in the planes of schistosity. The rock is probably a highly metamorphosed sandy shale, also affected by magmatic "juices."

In the area studied the writer has found a good many similar associations: quartzites lying within sericite schists.

Farther south Smugglers Cave, in the narrowest part of the Notch, is formed by enormous rock masses which have fallen from Mansfield's cliffs. The rocks are generally chloritized masses of quartz-sericite gneiss, containing small cubes of pyrite.

Outcroppings of rusty talc are found on the Hell Brook trail, representing alterations of a basic intrusive. Their continuation eastward is found in the talc deposits on Sterling Mountain.

Farther south in the valley, and a half mile north of the Mansfield toll road, the West Branch forms Bingham Falls. These are rather a series of cascades which the stream, running about on the strike of the gneiss, has worn into the rocks. Stream action has formed a narrow gorge with large pot holes and, with the sylvan surroundings, has produced a real beauty spot in the mountains. The dip of the rocks, 28° easterly, confirms the open anticlinal-synclinal structure of the mountains.

Sterling Mountain and Eastward

From Smugglers Notch exploration was carried on along the Green Mountain trail, which climbs upward to Sterling Pond (2,960 feet, a.t.[1]) and continues northeasterly, for some distance

[1] "a. t." means above sea level.

along the Sterling Range, crossing Madonna Peak (3,668 feet), Chilcoot Pass (2,920 feet), Morse Mountain (3,468 feet), White Face Mountain (3,715 feet), and stretching across the foot hills to the Lamoille River and northward. These mountains and valleys are heavily wooded and rugged, so that geologizing is perforce "sketchy."

The west slope of Sterling is made up chiefly of dark gneiss, often very graphitic, infolded with several beds of quartzite and a few beds of dark, graphitic, thinly-foliated schist. The dips range from 0° to 35° easterly and up to 14° westerly, suggesting open synclinal and anticlinal folds.

The Sterling rocks are much contorted and broken, as shown even in the rock sections. They are quartz-feldspar-sericite gneisses and schists and a few beds of quartzite. They are often highly graphitic but are not highly chloritized. Garnets, apatite needles, magnetite, and a good deal of ilmenite, almost wholly altered to leucoxene, are noted. Sizable fragments of ilmenite are seen along the trails.

There is an enormous deposit of talc on Sterling. It crops out along the trail before reaching Sterling Pond and is followed along the shore and eastward for over a mile. This is the only intrusive seen. As noted above, the talc crops out on the Hell Brook trail, thus showing the former unity of Mansfield and Sterling.

From Sterling Pond over Madonna Peak and Chilcoot Pass to Morse Mountain the trail runs about N. 25° E., roughly following the general strike of the rocks. Along the trail great masses of dislodged gneiss are seen which, by creep, have moved down the mountain slope without indication of thrusting. Massive quartzite continues to occur, infolded with the gneiss, and there is also a good deal of free quartz. The dips are prevailing easterly, averaging 30°. The thin sections of the rock show quartz-sericite-gneiss, much chloritized and carrying garnet, epidote, tourmaline, apatite, zircon, ilmenite altered to leucoxene, magnetite, and pyrite.

From Morse Mountain the trail turns easterly to White Face summit. The dips continue easterly, averaging 30°, and present long dip slopes. The gneisses are increasingly graphitic and, again, are infolded with quartzite. Considerable masses of free quartz are in evidence. The mineralogy of the rocks is about the same as before but biotite appears in some of the sections and graphite occurs in long, narrow bands in the quartz and feldspar. The sections show much contortion and crushing.

From White Face along the trail to the Lamoille River the gneisses and schists show prevailing dip slopes, averaging 40° easterly. On the lower slope of the mountain a bed of quartzite, five feet thick, occurs, infolded with the schists.

Structure

The original, primary structure of the Mansfield-Sterling massif consisted of open anticlines and synclines (Plate 3). These folds pitch gently to the south, at angles from 12° to 20°. Stream and ice erosion on the principal anticline has bifurcated the mountain mass, producing the Mansfield and Sterling ranges and carving out the valley known as Smugglers Notch. Today Mansfield is a synclinal mountain; Smugglers Notch, an anticlinal valley. That the mountain mass was once greater, laterally, is shown by the foot hills, Macomber Mountain, Hedgehog Hill, Metcalf Hill and other eminences, as well as by the fact that the Mountain Border fault extends along the western base of Mt. Pritchard, in the township of St. George, in longitude 73°, 8 minutes, while the longitude of Mansfield's "chin" is 73°, 3 minutes. This difference in longitude is equal to 4.2 miles. With this greater base must have gone much higher elevations, so that it is safe to say that the mountains were once far higher than at present.

The average dips of the major structure on Mansfield are 18° northeasterly and 20° southwesterly. The mountain is therefore a slightly overturned syncline, pitching from 12° to 20° to the south.

The "nose" is made up of synclinal beds, dipping on an average, 18° easterly and somewhat more, westerly, and pitching gently to the south. Erosion has produced a series of steps in these beds, up which one easily climbs to the summit.

Impressed on the primary structure are minor anticlines and synclines. On the mountain slopes, particularly along the toll road, and on the summit are seen myriads of delicate bedding crenulations (Fig. 4), of paper thinness, forming drag folds, somewhat overturned to the west and pitching at low angles to the south. Numerous thin beds of quartz and some orthoclase are infolded with the schist, while other sial masses cut across the schistosity, giving the rocks a striking appearance. In the illustration the delicate drag folds of muscovite schist strike N. 37° E., dip 14° southeasterly and 35° northwesterly, and pitch 12° to the south. In the schistosity are seen minute needles of tourmaline.

The two most prominent joint systems run N. 66° W. and N. 54° E. The former extends along the base of the "nose." Glacial erosion along this joint has formed the precipice, some 200 feet high which, with the pitching syncline, forms this feature of Mansfield's "face." Beneath the "chin," ice erosion along similar jointing planes has formed the three small escarpments which form the "Adam's apple."

Along the summit are many open joints, caused by the tendency of the rocks to creep down the mountain sides.

No thrusting has been found on Mansfield or Sterling—or, to anticipate a little, in the Worcester range. Large masses of dislodged rock on the west slopes of Mansfield and Sterling are due to creep. The mountain mass has moved westward as a whole and folded and thrust the rocks to the west into a series of anticlines and synclines whose westerly limbs lie upon the Westford schist or, farther south, upon the Brigham Hill graywacke along the Mountain Border fault, at Essex Junction.

Camels Hump

The mountain known as Camels Hump but which Champlain, in 1609, called far more aptly *Le Lion Couchant*, lies on the Main Range of the Green Mountains, about fourteen miles south of Mansfield. The whole profile of the mountain suggests a crouching lion with its majestic head facing the south. It forms a ridge about half a mile long and with a maximum elevation of 4,083 feet above sea level. Another eminence, Mt. Helen, about twelve miles farther south, is fifty-two feet higher but lacks the striking appearance of the "Hump." Lack of time and the inaccessibility of the mountain have prevented a detailed study, but investigations along the Montclair Glen and the Alpine trails (two of the many paths cut by the veteran Vermont mountaineer, Mr. Will S. Munroe) have brought out the salient features.

THE ROCKS

The summit of the ridge is made up of shining muscovite gneiss, similar to that on Mansfield, with its characteristic fine drag folds (Fig. 4) and content of almandite garnets and biotite. Lying below this gneiss there is another, rusty, thinly-foliated, with minute scales of muscovite on the bedding planes. The section shows elongated sials with tightly interlocking, sutured edges and intense strain shadows. The grain size averages 0.33 x 0.24 mm. Considerable muscovite is developed and there is much ilmenite, almost wholly altered to leucoxene. Some of this leucoxene shows intergrowths with hematite, forming Washingtonite. Perhaps five percent of the section is chloritized with penninite, showing the ultra-blue interference colors. Accessory minerals are small grains of beryl (?), epidote, zircon, apatite needles, and hematite. The rock was derived from an impure sand stone.

Down the Alpine trail, at elevation 2,825 feet, there occurs a dark-gray, fine-grained, very pure quartzite which, microscopically, is seen to be made up of quartz grains, highly compressed, strained, and fractured, together with a few laths of muscovite. This is the purest quartzite that the writer has seen in this traverse. It represents, originally, a very pure sandstone.

Farther down, at elevation 2,000, one finds a rusty, medium-grained, thinly-foliated quartzite, with minute scales of mica on the bedding planes. Sections show the same elongated, strained, tightly-interlocking grains of quartz and orthoclase, with a few laths of muscovite. Numerous almandite garnets, some of considerable size, and a good deal of biotite are noted. The biotite is seen altering to penninite and the garnets also show some retrogression. Tourmaline, epidote, apatite, considerable magnetite, and yellow ribbons of limonite constitute the accessory minerals. No leucoxene, which is such a common constituent of Vermont metamorphics, is seen.

The gneisses and quartzites occur here in the same order as on Mount Mansfield.

The Camels Hump rock, like those of Mansfield, belong in the Biotite and Garnet zones of metamorphism.

STRUCTURE

The great eighty-foot escarpment which forms the face of the "camel," or the "lion," is due to erosion along east-west joint planes, similar to the escarpments on Mansfield. Other, tiny, escarpments are noted at the top of the "face."

The escarpment gives a fine cross section of the mountain which is seen to form the west limb of an open anticline, dipping 34° northwesterly, whose east limb has been removed by erosion. Minor drag folds appear in the quartz-muscovite-gneiss pitching about 25° northerly. At the 1,950-foot level the eastern limb of the anticline was found, dipping 28° southeasterly.

Thus, Camels Hump was formerly a great open anticline, somewhat overturned to the west and pitching to the north.

The Morristown-Stowe Valley

East of the Main Range of the Green Mountains lies a broad valley bounded on the east by a range of mountains which, in the townships traversed by it, is called, variously, Rochester Mountain, Braintree Mountain and, in the region under discussion, the Worcester Mountains, of which Mt. Hunger, 3,554 feet, is the highest point. The prolongation of the Worcester Range, in Elmore, is appropriately known as Elmore Mountain. It is 2,608 feet above sea level. The region is shown on the Hyde Park and Montpelier quadrangles. (Montpelier quadrangle, Plate 4).

The valley is very narrow at its southern end, in Rochester, but widens to some eight miles in Morristown.

The Green Mountain ranges are cut by the superposed Lamoille and Winooski rivers. The Winooski water gap extends from Montpelier to Richmond, west of which it debouches onto the Vermont Lowland. In the valley a divide along the Stowe-Morristown line separates the small tributaries of the Lamoille from the Waterbury, or Little River, which flows into the Winooski one and one-half miles northwest of Waterbury. The West Branch

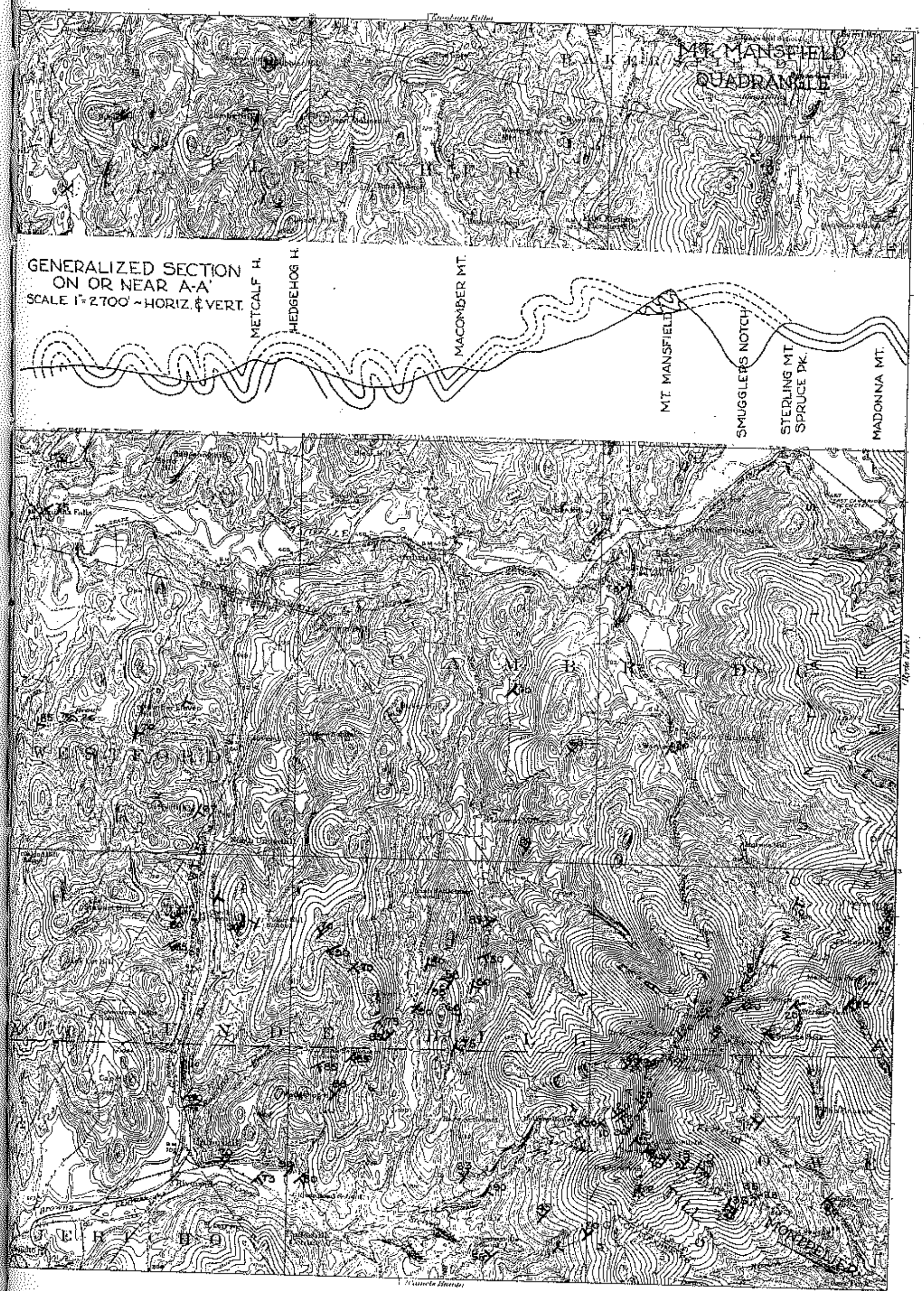

PLATE 3

of the Waterbury River rises in the divide in Smugglers Notch, while the east branch rises on the western slope of Worcester Mountain and tumbles down a fold of the mountain structure, forming Moss Glen falls.

GLACIATION

The valley is markedly glaciated. Banks of till, and kames are scattered over it while striations and groovings are still to be seen along the highway (Vt. 100) from Waterbury to Hyde Park, although many of the most distinct markings have been destroyed by road building operations. Elmore Pond, just east of Elmore Mountain, is of glacial origin while to the north, in Hyde Park and Eden, are many small glacial lakes and ponds of varying size. Lake Lamoille was formed by the damming of the river.

With the melting of the ice sheet several ephemeral lakes were formed in the valley, and their strand lines are still to be seen. These lakes have been described by Merwin[1], Fairchild[2], and Bigelow[3].

THE ROCKS

ELMORE MOUNTAIN (HYDE PARK QUADRANGLE)

Elmore Mountain consists of a ridge some three miles long by one and one-half miles wide, culminating at 2,608 feet. Just east of it lies glacial Elmore Pond. Elmore State Forest Park occupies the northern lake shore and a part of the Mountain. The mountain is heavily glaciated and thick till banks are seen along the road which the Civilian Conservation Corps has been building towards the summit. Where the ledges are uncovered they are seen to be glacially smoothed and striated. These striations strike North 55° West.

The rocks are predominatingly garnetiferous quartz-muscovite gneisses, similar to those on Mansfield and Camels Hump, associated with sericite schists and dull gneisses. Intercalated with these are beds of amphibolite. This amphibolite is, when fresh, a lustrous, black rock of schistose structure, showing fine needles of amphibole interspersed with lighter minerals. It alters readily to the pistachio-green epidote and, in places, the alteration has progressed so far that only thin bands of the amphibole remain, so that the rock becomes an epidote schist. Thin sections show a mesh of slender, fairly well-oriented prisms and needles of amphibole, much chloritized, enclosing brilliant grains

[1] Some Late Wisconsin Shorelines in N. W. Vermont; H. E. Merwin, Sixth. Rpt. Vt. State Geol. (1907-08).

[2] Post Glacial Marine Waters in Vermont; H. L. Fairchild, Tenth Rpt. Vt. State Geol. (1915-16).

[3] The Last Lake of the Stowe Valley; E. L. Bigelow, Eighteenth Rpt. Vt. State Geol. (1931-32).

of epidote, orthoclase, some of which is twinned, and a few plagioclase grains. Black grains of magnetite are scattered through the sections and an occasional tourmaline is seen.

The number of interbeds of amphibolite could not be determined on account of the overburden and growth, and limited time, but it is thought that several exist. The highest amphibolite found was about 75 feet from the summit; above this only the muscovite schist is seen. From the summit an interesting view of the surrounding country is obtained.

From the data obtained along the road and trail which climb the eastern side of the mountain, the amphibolites and schists are tightly folded, the dips ranging from 83° westerly, through 90°, to 88° easterly. A cross section of the whole mountain is needed in order accurately to determine the structure.

The Elmore rocks extend westward into Morrisville. To the south they have been followed to Middlesex Notch (Montpelier quadrangle), with the amphibolite no longer associated with muscovite schist but with sericite and chlorite, with which it forms a diminishing proportion and finally disappears. The line of outcrops runs along the base of the Worcester Mountains and forms low anticlinal ridges.

To the east of Elmore Mountain the amphibolite crops out along the road east of Elmore Pond and in the Worcester valley while, to the north, associated with muscovite schist, it extends continuously for an unknown distance. It was encountered, however, a mile and one-half to the north, in Wolcott, along the highway (Route Vt. 15) leading from Morrisville to Hardwick.

Fifteen miles north of Elmore Mountain, and in the same longitude, an amphibolite of similar appearance to that just described forms a capping over the chrysotile asbestos deposits of Belvidere Mountain. These deposits are being worked by the Vermont Asbestos Corporation.[1] Marsters[2] investigated the deposit but made no attempt to determine the origin of the amphibolite. Keith and Bain[3], working on the Belvidere amphibolite, find that it extends as far north as the Hazens Notch road and that it is made up of 35 percent dark, blue-green amphibolite and saussuritized plagioclase. They classified it as a "typical meta-diabase or pyroxene diorite." They found another body of amphibolite cropping out between North Troy and Newport.

From the study of the sections it is at once seen that the Elmore amphibolite cannot be classed as a meta-diabase or meta-diorite. The sections and the field relationships suggest rather a sedimentary origin for the rock. As will be shown later, the amphibolite and associated mica gneiss crop out also on the

[1] Twentieth Report of the Vt. State Geol. (1935-36).

[2] A preliminary Report on the Serpentine Belt of Lamoille and Orange Counties; M. F. Marsters, Fourth Rpt. Vt. State Geol. (1903-04).

[3] Crysotile Asbestos; S. B. Keith and G. W. Bain, Economic Geology, vol. 27, No. 2 (Mar.-Apr., 1932).

east slope of the Worcester Range. The muscovite gneiss associated with the amphibolite is a very coarse-grained, garnetiferous, quartz–muscovite rock with the muscovite flakes as large as 9 x 6 mm. The sections show quartz grains and broad muscovite laths, thickly studded with anhedral, almandite garnets. The garnets were much deformed after their formation and are chloritized, in some instances so much so that very little of the original garnet remains. Small grains of magnetite are scattered through the slide together with stubby rods and irregular grains of rutile. We have here a case of retrogressive metamorphism—see under Petrogenesis.

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Aside from the belt of amphibolite and muscovite already described, the rocks of the Morristown-Stowe valley (Plate 4) are predominantly quartz-sericite schists, all more or less chloritic and graphitic, with lesser amounts of quartzite and gneisses—this in marked contrast to those of the Mansfield range, in which gneisses prevail. The fine farming soil so covers the central part of the valley that outcrops are largely discontinuous.

The highway (Route Vt. 100) runs along a low ridge on which there is a broken chain of outcrops made up of thinly-bedded quartzite, two or three feet wide, flanked on either side by graphitic sericite schist with concordant quartz stringers. This represents ancient sand stones and shales which have been metamorphosed to the present rocks. The best outcrops of this chain are seen in North Laporte, about one and one-half miles south of Morrisville. The strike of the rocks is North 40° East and the dip, 75° northwesterly.

Some two miles south of Stowe village Gold Brook flows down from Stowe Pinnacle and enters the Waterbury River, flowing across dark, thinly-foliated graphitic schists. Free gold occurs in this brook and has been panned, off and on, for many years. Mr. Charles Simmons seems to have been the most consistent "placer miner," in recent years, and has recovered enough of the yellow metal to make one or more rings. Needless to say placer mining in Vermont is, at best, a diversion.

In general the schists vary so in appearance that it has not been possible to match them up and assign them to definite formations.

GNEISSES

Just south of Stowe village the road cut reveals high cliffs of thinly-foliated, graphitic, sericite-gneiss, striking North 47° East and dipping 83° southeasterly. This rock also is seen here and there along the highway to the south.

The section shows a most interesting condition: Narrow bands of fine-grained quartz alternate with broader bands of infolded sericite and graphite, forming delicate anticlines and synclines. In the incompetent beds are seen minute, overturned, pitching, drag folds, 0.20 to 0.40 mm. wide. These drag folds are cut by more steeply-dipping cleavages, outlined by fine filaments of graphite. Fine needles of chlorite, small grains of magnetite, and filaments of iron oxides form the only accessory minerals. Unfortunately the section was not oriented, so that the direction of the overturning and pitching could not be determined but, like most of the valley metamorphics, the overturning was probably to the west and the pitching, to the south. West of the highway the rocks are generally sericite schists, more or less graphitic and not visibly chloritic; while, east of the road, the schists are highly chloritic, with bright-green surfaces, this possibly in response to the amphibolite belt. In Waterbury Center these chlorite schists are very thinly foliated, almost of paper thinness, while farther north they are more massive. They all strike north of east and dip at high angles southeasterly.

On the west side of the Stowe valley and extending a distance of some 6.5 miles from the northwest corner of the Montpelier sheet, northeasterly through the south west part of the Hyde Park quadrangle, nearly to Morristown village, there is a belt of light-gray gneiss full of fine isoclinal dragfolds of quartz. The strike is North 50° East; the dip, 75° easterly. The gneiss lies infolded with rusty, thinly-foliated sericite schist. The section shows bands of fine-to-medium grains of quartz, beautifully outlined by limonite, alternating with bands of sericite and chlorite which are crossed by drawn-out stringers of limonite, derived from pyrite. A few grains of orthoclase, plagioclase, and magnetite constitute the accessories.

On the Brush Hill road, some four miles northeast of Stowe village, there is an interesting gneiss made up of dark-gray material, alternating with thin seams of sial. The section shows that the sials are quartz, and orthoclase which includes Carlsbad twins. The dark bands are made up of a mineral which has been so completely chloritized that no relicts of it remain. In the chlorite are seen non-oriented laths of muscovite and rhombs and anhedral crystals of carbonate. The whole section is covered with minute masses of hematite, derived from pyrite, of which a few relicts are seen. The U. S. Geological Survey kindly examined this section, among others, and thought that the abundance of chlorite, and carbonate (which may be ankerite) indicated an original rock high in magnesia, possibly a sandy dolomite.

From the Winooski water gap, at Waterbury, to the Lamoille River no roads or passable trails cross the Worcester Mountains.

Ascent, however, was made from the Worcester valley, to the east, and will be considered later.

Exploration up the west slope of the Worcester Range showed the same "quartz-sericite schist, all more or less chloritic and graphitic" (p. 50) as those of the Stowe valley, but with coarser gneisses. These rocks merge upward into a coarse quartz-muscovite gneiss similar to that found on Mansfield, Camels Hump, and Elmore Mountain, and form the summit of Mount Hunger. East of this summit and conformable with the quartz-muscovite gneiss, the "quartz-sericite schists, all more or less chloritic and graphitic" extend unbrokenly across the Worcester valley to the contact with the Ordovician phyllite (p. 60).

At Moss Glen Falls, Glen Brook tumbles for 150 feet over an eroded fold of a quartz-chlorite gneiss inbedded with a graphitic schist which forms broad bands, some over two feet wide. The broad bands, polished by stream action, are very striking and suggest ribbon gneiss till closer examination shows the graphitic nature of the interbeds.

To the north, in Morrisville and west of Lake Lamoille, Terrill Gorge has been cut to a depth of about 200 feet by Kenfield Brook. At the bottom is seen a dark, fine-grained, thinly-bedded quartzite, some twenty feet wide, flanked by graphitic schist. The rock strikes N. 56° East and dips 90°. The extension of the quartzite is seen at Cadys Falls.

The quartzites which crop out here and also along the highway south of Morrisville appear to underlie the valley schists.

Route, Vt. 15, from Morrisville to Hardwick, crosses the continuation of the Worcester Mountains to the north. In the railroad cut, somewhat east of the confluence of Wild Branch with the Lamoille River (east of the Hyde Park quadrangle), excellent evidence of tight folding in the gneiss is seen. (Fig. 5).

In Hyde Park the schists grow more graphitic till they become lustrous black, thinly-foliated rocks which will mark paper, like a lead pencil. An analysis of the schist showed 1.09 percent of carbon.

In Johnson graphitic schists and coarse gneisses abound. They strike about North 40° East and dip uniformly at high angles southeasterly. At Ithiel Falls, several miles down stream from Johnson, the Lamoille has cut a narrow gorge in dense gneiss. The gorge was only twelve feet wide and, during the 1927 flood, was responsible for backing up the river and flooding Johnson, with much loss of life and property. It is now being widened to prevent future disasters.

INTRUSIVES

No intrusives were found in the Morristown-Stowe valley but extensive basic igneous rocks occur in the extension of the valley

FIG. 5. TIGHT FOLDING IN WOLCOTT

both north and south. Talc lenses[1] derived from serpentine, which in turn was derived from peridotite or dunite, are known in Berkshire, Enosburg, Montgomery, Waterville, Cambridge, Johnson (the Johnson deposits are being worked by the Eastern-Magnesia Talc Company, of Burlington), Moretown (also operated by the Eastern-Magnesia company), Fayston, Waitsfield, Rochester, Stockbridge, Plymouth, Reading, Ludlow, Cavendish, Andover, Chester (the talc is being mined by the Vermont Mineral Products Company), Windham (the deposit is operated by the Vermont Talc Company), and Dover.

Serpentine bodies occur in Jay, Troy, Westfield, Lowell, Eden, Belvidere, Waterbury, Duxbury, Moretown and Windham. Verd antique (serpentine veined with dolomite) has been, or is being, quarried at Roxbury, Warren, Rochester, Stockbridge, Moretown, and Windham.

[1] The Talc and Serpentine Deposits of Vermont; E. C. Jacobs, 10th. Rpt. Vt. State Geol. (1915-16).

As regards acid intrusives, Keith and Bain[1] note that "Small masses of medium-textured granite cut the slates and serpentines at many places northwest of Lowell."

Small deposits of chalcopyrite (sulphide of copper and iron) occur in Richford, Berkshire, and Wolcott. They probably have no commercial importance.

Structure

From the high eastern slopes of the main range of the Green Mountains, across the Morristown-Stowe valley and up the western slopes of the Worcester Range, the dominant structure (cross section, Plate 4) is isoclinal folding, striking, on an average, N. 53° East, dipping at high angles (average 73°) southeasterly, and presenting long dip surfaces. In this structure are found occasional minor structures: drag folds, low, visible anticlines here and there, and eroded anticlines with dips changing from 80° westerly, through 90°, and to 73° easterly. As on the Mansfield quadrangle, the strike of the rocks in the Stowe valley and on the Worcester Range cuts across the topography.

No thrust faults were found in the valley or on the Worcester Range. Small, normal faults are seen, here and there, in the drag folds.

Now this abrupt change in dips from the Mansfield massif (average 29.5° easterly, to those of the Morristown-Stowe valley and the western slopes of the Worcester Range (average 73° easterly), and the change from the heavy, contorted, open-folded gneisses of Mansfield to the isoclinally-folded, lighter schists and gneisses of the valley, lead inevitably to the conclusion that the valley rocks lie unconformably against the Mansfield series; that they are younger and represent a new cycle of deposition upon the eroded surfaces of the Pre-Cambrian rocks which make up the Main Range of the Green Mountains and the terrains west of it. No contacts along the unconformity have as yet been found but, with the mountain slopes heavily forested and covered with glacial accumulations, this is not surprising.

The Worcester Range

MOUNT HUNGER

Mount Hunger (3,554 feet a.t.) is the highest point in the Worcester, or third, Range and lies in the southwestern corner of Worcester township. The summit affords a magnificent sweep of the whole horizon. To the north the low mountains of southern

[1] *Op. cit.*

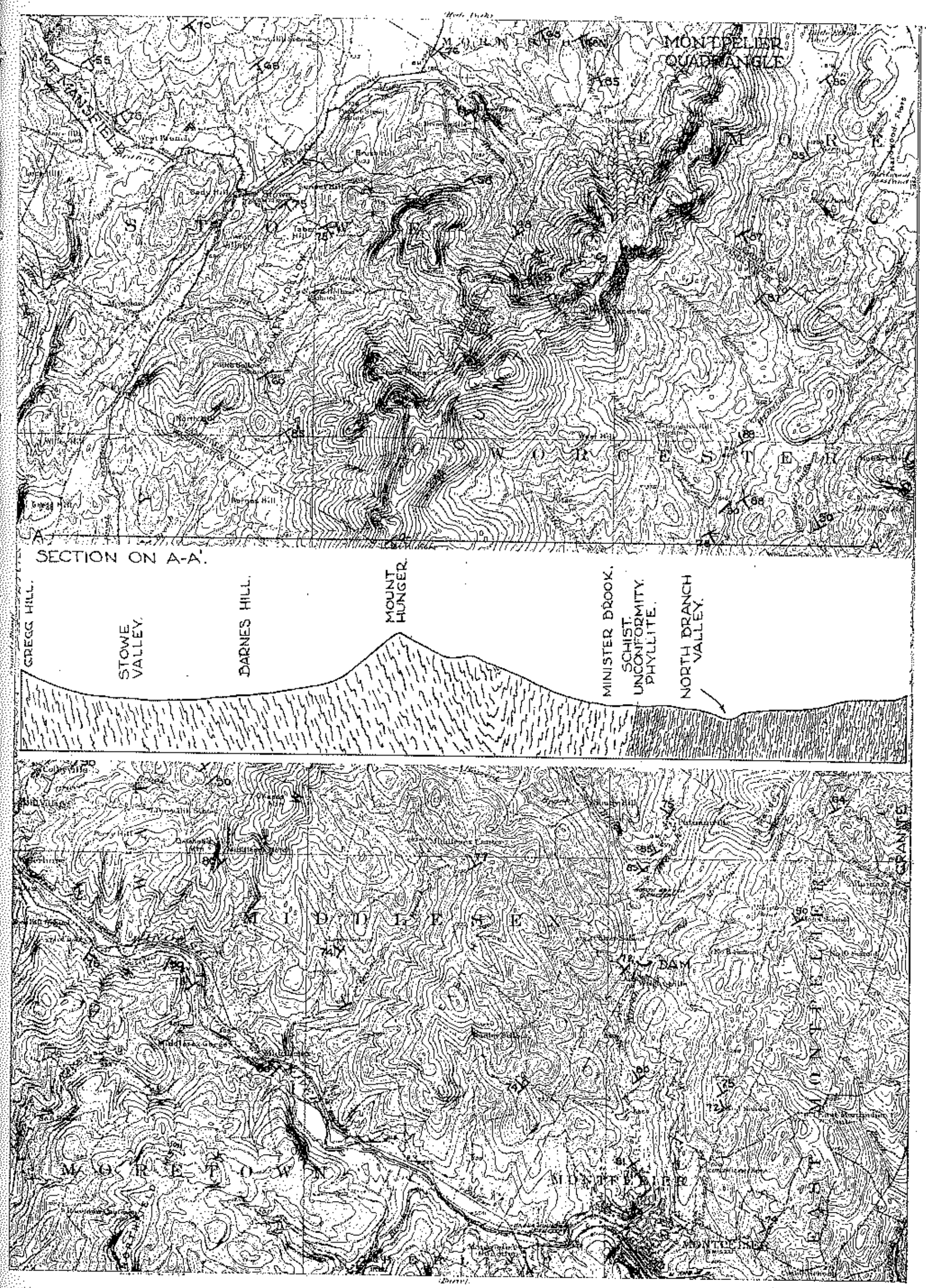

PLATE 4

Canada are visible; to the east, the White Mountains, capped by Mount Washington (6,290 feet); farther south, Mount Monadnock, N. H., and Mount Ascutney, Vermont; while to the south and west the ranges of the Green Mountains and the Adirondacks stand out clearly.

The three-mile trail up Mt. Hunger, from the southeast, begins at Daniel Leonard's farm, follows a wood road for about a mile and one-half and then, leaving the road, strikes through the woods to the base of the great summit dome, around and over which it climbs to the summit. The trail is a very poor one and should be improved, for the summit is full of both scenic and geologic interest.

From the summit, southward, White Rock Mountain (3,200 feet) and Burnt Mountain (2,800 feet) lie along the crest line; to the north Worcester Mountain (3,286 feet) forms the highest point.

GLACIATION

Glacial till covers the east slope of the mountain up to about the 2,700-foot contour, while erratics are found all over its surface though of much smaller size than on Mansfield.

The upper 500 feet of the mountain is a great dome of bare rock and is covered with the most extensive development of glacial striations and groovings that the writer has ever seen. These glacial markings vary from the faintest striations on the polished quartz surfaces (brought out by placing tissue paper on the smooth rock and rubbing over it with a soft lead pencil) to grooves some four or five inches across and two or three inches deep. The strike of the striations and grooves varies from (true) N. 6° E. to N. 14° E.

Mr. H. B. Chapin, Town Clerk, reports a similar condition on White Rock Mountain, while Professor Buchanan, of the University of Vermont, has found extensive glaciated surfaces on Burnt Mountain.

THE ROCKS

The summit dome and the eastern slope of the mountain, down to the 1,880-foot contour, are made up of quartz-muscovite gneiss similar to that found on Mansfield, Camels Hump, and Elmore Mountain. Presumably this gneiss extends along the entire summit ridge of the Worcester Range. At the 1,880-foot contour it merges, conformably, into the sericite schists and gneisses already noted (p. 52).

The gneiss is "peppered" with small almandite garnets. In no other place covered by this investigation has such a development of garnets been noted.

In the sections muscovite predominates and is seen making up microscopic folds in which lie sial grains and hundreds of minute almandite garnets. Bands of sial grains alternate with the muscovite, giving the gneissic structure. Almandite also occurs in large areas, bordered and cut by diabantite chlorite, into which it is retrogressing. There are also a few grains of green garnet (uvarovite). The whole section is covered with fine rods of leucoxene in which there are a few grains of unaltered ilmenite. No biotite occurs.

In the gneiss are seen small masses of a dull, pinkish mineral, not noted elsewhere in the Vermont metamorphics. A section shows these to be made up of thousands of minute grains of almandite garnet, varying in size from 0.18 x 0.16 to 0.03 x 0.03 mm.

STRUCTURE

The top of Mount Hunger is covered with small overturned drag folds (Fig. 6) beautifully outlined by the extensive quartz veinings in the gneiss. Again, in this place of superlatives, these folds form probably the finest structural display of this type in Vermont. The crenulations are not so delicate as on Mansfield but they run over the summit in broken lines, like forked lightning, in a most amazing manner. The folds dip 35° southeasterly, 80° northwesterly, and pitch to the south at low angles. Cleavage planes dip 75° southeasterly. The summit of Mt. Hunger forms the western limb of a syncline.

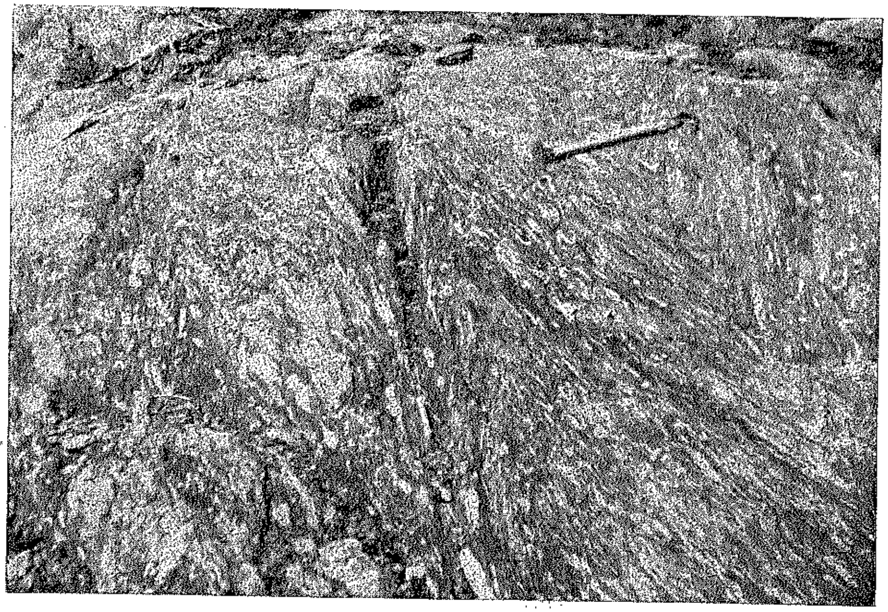

FIG. 6. DRAG FOLDING ON MOUNT HUNGER

The principal joints strike, roughly, N. 60° W., as is the case on Mansfield and Camels Hump. As already noted, glacial erosion along such joint planes has been responsible for the "nose" and other features of Mansfield, the face of the "Camel" (better called the "Lion") and also for the serrated crests of the Green Mountains in general.

A beautiful example of open jointing is seen on the summit of Mt. Hunger, where drag folds, once continuous across a rock face, are now separated by a distance of several inches, due to frost wedging and gravity acting along the joint.

No attempt was made to explore the western slope of the mountain, owing to lack of time and the danger of the smooth rock surfaces. But, in working up the western slope of Worcester Mountain from the Stowe valley, the quartz-muscovite gneiss was found at about the 1,700-foot contour with southeasterly dips of 56° to 70°.

The Worcester Valley

The Worcester valley lies between the Worcester Mountains, or third range, and the Fourth Range.

The Worcester River, or North Branch, has cut its valley deeply into the mountain structure and, with the rise of the region following the Pleistocene glacial epoch has, like many other Vermont streams, left terraces along its course. The valley is generally "U" shaped in section and is heavily glaciated. The river is classified as a subsequent stream but, instead of eroding headward into the soft phyllites which form the eastern part of the valley, it has cut diagonally across the more resistant schists and gneisses of the center of the valley and the western slopes. The stream may well be, therefore, a superposed tributary of the superposed Winooski River.

Following the 1927 flood, of unhappy memory, the Federal Government constructed a retention dam at Wrightsville, some four miles north of Montpelier, for the purpose of flood control. This dam is of earth and is 1,400 feet long by 90 feet high and, together with the dam on the Jail Branch, at East Barre, and that on the Waterbury River, has served well its purpose.

The rocks of the western side of the valley are, predominantly, the same "quartz-sericite schists, all more or less chloritic and graphitic" as those of the Morristown-Stowe valley, with lesser amounts of gneisses and some quartzites, but with more extensive intrusives. The schists and gneisses extend up the eastern slope of the Worcester Range to the 1,880-foot contour, striking from N. 60° to 67° E., and dipping from 72° to 80° northwesterly.

These rocks were studied and described by the late C. H. Richardson who followed them from the international boundary to the latitude of Bethel, and named them the Missisquoi Group[1] in 1919. He believed this formation to be of Upper Cambrian age,

This investigation shows that the Missisquoi formation also forms the Worcester Range and the Morristown-Stowe valley, and lies unconformably upon the Pre-Cambrian rocks of the main range of the Green Mountains. It is safe to say that the Missisquoi is of Cambrian age, possibly Upper Cambrian from its relationship to the Ordovician phyllites of the Worcester valley.

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Along the upper tributaries of Minister Brook, in Worcester township, the quartz-muscovite gneiss, frequently mentioned before, is exposed, associated with amphibolite, as it is on Elmore Mountain. The same gneiss is also seen along the North Branch, somewhat south of the dam. Here the muscovite is studded with almandite garnets as large as 5 x 10 mm. The section shows anhedral garnets penetrated and surrounded by chlorite into which they are altering. The groundmass is made up of quartz and orthoclase grains and long, narrow, deformed laths of muscovite. Stubby rods and irregular grains of rutile, a few detrital zircons, and grains of pyrrhotite make up the accessory minerals. The garnets, like those north of Elmore Mountain and Mount Hunger, show retrogressive metamorphism.

Along the valley highway are seen walls of shiny, thinly-foliated, sericite schists, much chloritized; and more massive, greenish-gray schists, splitting into thin slabs along glistening, micaceous bedding planes. The section of the latter is made up predominantly of quartz grains of varying size, and corroded, greenish-brown biotite (as large as 0.6 x 0.3 mm.), mostly anhedral but showing "001" faces here and there. The biotite is, in places, entirely chloritized, showing retrogression. Oligoclase, apatite needles, small, green tourmalines, rounded zircons, and much finely disseminated magnetite form the accessory minerals. This type of schist finds its counterpart in the Stowe valley. It is believed to be a metamorphosed sandy shale.

INTRUSIVES

North of Putnamville and just west of the highway there occurs a great wall of gray, well-jointed, massive schist, showing fine sericite on the bedding planes. It strikes N. 62° E. and dips 75° northwesterly. The section shows a granoblastic mass of albitic feldspar, in interlocking laths which are extensively replaced by chlorite. The dark minerals have been entirely chloritized. Numerous small cavities occur, where some soluble mineral has been weathered out. The accessory minerals are

[1] The Geology of Braintree, Vt.; C. H. Richardson, Twelfth Rpt. Vt. State Geol., p. 62 (1919-20).

numerous, small masses of titanite (the largest 0.5 x 0.4 mm.), small, rounded zircons, apatite needles, fragments of muscovite, quartz grains, large and small, and some iron oxides. Originally the rock was probably a diorite. It is now a meta-diorite.

In the bed of the river, south of the dam, a large, branching dike occurs, now completely altered to chlorite.

Excavations for the dam spillway, east of the structure, have uncovered a great sill, over 1,000 feet long and 28 inches wide, lying between a chlorite-sericite schist, which strikes N. 48° E., and dips 72° northwesterly, and a dark-green gneiss. The sill is now a dark-green, chloritic schist, with small inclusions of lighter minerals. The section shows a granoblastic mass of sodic plagioclase, pale-green, chloritized hornblende, greenish-brown biotite, and considerable zoisite. Much titanite is present. Quartz grains, a few grains of chromite, and some stubby apatite needles make up the accessory minerals. The original rock was possibly a diotite but the section suggests a more basic substance.

Handsome specimens of crystallized epidote are to be found in vugs in this sill.

The ortho-gneiss, which overlies the sill, is made up of dark, greenish-gray bands, three to five millimeters thick, alternating with narrow, black layers, one or two millimeters in width.

The sections show the lighter bands to be composed of small grains of quartz, albite, and perthite studded with minute grains of epidote and flakes of chlorite. Minor constituents are apatite needles, a few light-colored garnets, small zircons, and tourmalines. The darker bands consist predominantly of epidote grains, thickly sprinkled with magnetite, and some small, light-colored garnets. Biotite is sparingly present. Flakes of chlorite cover the whole section. The rock is a quartz-epidote-gneiss, to whose composition the sill has largely contributed.

GOLD

Small amounts of gold have been panned for many years in the Worcester valley. The story is current that some of the old California "forty-niners," after their return from the gold diggings, constructed sluices and riffles along Minister Brook and washed the stream gravels for the yellow metal. More recent "placer miners," using frying pans and other kitchen utensils in lieu of gold-pans, are washing the gravels of Worcester Brook and its tributaries, in their spare hours, and are winning very small amounts of gold. The writer was shown small nuggets three-eighths by one-eighth inches and finer grains. This notice is not intended to start a gold rush for gold washing here, as at Bridgewater and Stowe is, at best, what Perry has called a "holiday diversion."

Ordovician Phyllite

About a mile north of Montpelier, in the high pasture west of the Worcester valley highway, Missisquoi schists are found nearly in contact with fine-grained, thinly-foliated, Middle Ordovician phyllite which the writer named the Orleans phyllite, in 1921. On opposite sides of the hidden contact the average strike of the schist is N. 53° E.; of the phyllite, N. 43° E. Schistosity and bedding are here indistinguishable. The average dip of the schist is 81° northwesterly; of the phyllite 72° northwesterly. But along Elm Street, Montpelier, the phyllite, forming high cliffs, contains tight drag folds, outlines by the infolded quartz. The strike of the phyllite is about N. 50° E., the dip of the schistosity, about 70° northwesterly. The dip of the folds is about 68° northwesterly and the folds pitch about 30° to the north. The phyllite therefore lies under the Cambrian schists by underthrusting. This is about in line with Clark's Bunker underthrust.[1]

As regards the age of the phyllite, Richardson[2] found numerous beds of crushed graptolites in the phyllite and interbedded slate and limestone on Clay Hill, in the Sabin slate quarry, just east of Seminary Hill, in Montpelier, and in many other localities. Some of the graptolites were sufficiently well preserved to enable Dr. Rudolf Ruedermann, of the New York State Geological Survey, to identify *Climacograptus pavus* and other species of Ordovician age.

The phyllite is a black, greasy-looking, exceedingly finely-laminated rock, splitting perfectly along schistosity planes and weathering a rusty-yellow. The schistosity planes resemble the grain in wood. The sections show delicate bandings parallel to the schistosity and fine, wavy folding ("S" planes) of the bedding. The bandings are made up of very minute sections of sericite, in optical conformity, alternating with fine, elongated grains of quartz and some orthoclase. A few broader bands of quartz have been introduced. Larger, elongated fragments of biotite lie generally in the schistosity planes. They show scarcely any retrogression to chlorite. A few minute, light-colored garnets are noted. They show no retrogression. Elongated grains of ilmenite, considerably altered to leucoxene, apatite needles, a few rounded zircons, an occasional tourmaline, and fine graphitic dust (in some of the sections long filaments of graphite) make up the section. Only a few ottrelite sections are noted in the Montpelier phyllite, but in Barre and in the broad phyllite belt in the Lake Willoughby region, ottrelite is abundant and large almandite garnets are seen in the sections. The phyllite is seen to be a thoroughly reconstructed rock.

[1] *Op. Cit.*
[2] The Geology of Calais, Montpelier, etc.; C. H. Richardson. Tenth Rpt. Vt. State Geol. p. 144 (1915-1916).

Exploration along the Hillhead and other roads, on the Fourth Range, which forms the east wall of the Worcester valley, shows that the schists have disappeared and that phyllite and interbedded slate and the dark, Washington phase of the Waits River limestone have taken their place, with strikes from 53° to 59° northeasterly and dips from 50° to 80° northwesterly. Small granite intrusives occur in the phyllite while, somewhat east, a larger granite body is being worked by the Adamant Quarry Company. This is in the great belt of granite outcrops that extends from Bethel, through Randolph, Brookfield, Williamstown, Barre, East Montpelier, Calais, Woodbury, and Hardwick, in which the granite has intruded the phyllite and associated slate and limestone. Balk[1] notes that garnets, biotite and ottrelite are common to the phyllite wall rock and that garnetiferous amphibolites also occur.

Going back to Worcester village and working northeasterly along the road which runs up Worcester Brook and over the Fourth Range to Hardwick, one finds schists and gneisses for about two miles and then, near the eastern border of the Montpelier quadrangle, a road-cut in the glacial till reveals phyllite, thinly-foliated and much decomposed. It strikes N. 62° E. and dips 62° northwesterly.

Other "near-contacts" between the schists and phyllite were not encountered in the Worcester valley.

The late C. H. Richardson, in his many years of geological work east of the Green Mountains, established his "erosional unconformity" (see "Line of Unconformity," Plate 1) and traced it from the international boundary far southward through many townships. In Irasburg, in the bed of Lords Brook, he believed that he discovered a basal conglomerate which lay at the base of the Ordovician, in Vermont, and extended to the south as far as Springfield. Geologists have questioned the basal nature of this conglomerate but the fact remains that the line on Plate 1 follows approximately the boundary between the Ordovician and Cambrian formations. East of this line Ordovician Orleans phyllite, Memphremagog slate, Waits River limestone, and Vershire schist extend across the Vermont piedmont to the Connecticut; to the west, Pre-Cambrian and Cambrian formations reach practically to Lake Champlain.

Structure

As in the Stowe valley, the structure of the Worcester valley is predominantly isoclinal folds, striking N. 56° E. but dipping at high angles, prevailingly to the northwest. These northwesterly dips extend up the eastern valley walls into the Fourth Range.

In northern Worcester township and in Elmore, minor synclines and anticlines occur, with dips passing from about 85° south-

[1] A Contribution to Structural Relations of the Granite Intrusions of Bethel, Barre, and Woodbury; Robert Balk, 15th Rpt. Vt. State Geol. (1915-16).

easterly, through 90°, and to about 86° northwesterly. Close folding is seen in the gneiss at the eastern end of the dam spillway.

Comparing strikes and dips in the two valleys, we have:

Morristown-Stowe Valley	Worcester valley
Average strike, North 53° East	North 56° East
Average dip, 73° southeasterly	81° Northwesterly.

The Worcester Range is therefore a somewhat overturned syncline, carved out of the isoclinally folded Cambrian, Missisquoi formation by erosion.

The Ordovician phyllites in the Worcester valley lie under the Missisquoi formation by underthrusting.

The strikes of the rocks, cutting diagonally across the topography in the Mansfield and Montpelier quadrangles have been noted. These strikes, properly corrected for magnetic declination, were carefully plotted and are seen curving around to the northeast. They are difficult to interpret but may possibly indicate an ancient synclinal basin which pitches to the south.

The Fourth Range

The quadrangles east of Montpelier and Barre are as yet unsurveyed and mapping is therefore difficult. Time has not permitted the writer to study the ground in detail.

The range extends from western Randolph through eastern Roxbury, eastern Northfield, where it is called the Northfield Mountains, Berlin, along the boundaries between Middlesex-Worcester-Elmore-Wolcott and Montpelier-Calais-Woodbury-Hardwick, through eastern Craftsbury, Albany, and dies out in Irasburg. It is a low, poorly-defined, much-dissected range whose elevations have not been determined. Its length is about thirty miles. The range is made up predominantly of phyllite, with interbeds of slate and limestone, all of Ordovician age. In main structure it is an anticline whose steep, western limb forms the eastern wall of the Worcester valley. After a good deal of exploration the crest of the fold, in much crumpled phyllite and interbeds of the dark, Washington phase of the Waits River limestone, was found in northern Woodbury, on the shore of Greenwood Lake, with the eastern limb dipping 73° easterly. Farther south, in Calais, Marshfield and Plainfield, granite intrusions have so disturbed the phylitte that dips are unreliable. It is probable that the structure of this region is much more complicated than that suggested above.

The Fourth Range is an anticline, somewhat overturned, like the Main Range and the Worcester Range, to the northwest.

Summary

Summarizing, we find that the Main Range (including the Sterling Range) is an anticline whose rocks are of Pre-Cambrian age; the Worcester Range is a syncline, of Cambrian age; and the Fourth Range is an anticline, of Middle Ordovician age.

According to Schuchert, (p. 11) the folding and thrusting of the Green Mountains took place in late Ordovician time. This happened over four hundred million years ago. Since then the mountains have been peneplaned at least once. They are now undergoing erosion in a new cycle.

The Fourth Range does not properly belong to the Green Mountain massif but marks the western border of the Vermont Piedmont.

Traverse Along the Winooski River

An examination of the rocks along the Winooski River, on Route, U. S. 2, from Montpelier to Burlington (Montpelier, Camels Hump, and Burlington quadrangles) confirms the results of the traverse across the mountains and valleys.

In Montpelier the Orleans phyllite, with its isoclinal folds dipping about 70° northwesterly, is succeeded by the Missisquoi formation with about the same dip. The highly chloritic schists and gneisses of this formation are well shown along the highway to Middlesex.

The axis of the Worcester Range syncline is reached at the so-called Palisades, about two and one-half miles southeast of Waterbury, where drag folds in the schist and gneiss, which have been dipping northwesterly, become nearly 90°. The drags show minor faulting. The rocks are quartz-orthoclase-sericite gneiss, containing, as accessories, almandite garnets, many tourmalines, and much leucoxene and chlorite, but no biotite.

From the Palisades the dips are uniformly southeasterly. Seven-tenths of a mile northwest of Waterbury drag folds in the gneiss indicate the more open folding of the Main Range of the Green Mountains. The rocks are gneisses, schists, and quartzites, containing almandite garnets, many tourmaline grains, a good deal of magnetite, and much chlorite, but no biotite. Considerable veins of pegmatite are noted.

At Bolton the road crosses a minor anticline with dips ranging from 45° easterly, through 90°, and to 70° westerly. This is followed by a minor syncline, near Duck Brook.

At Richmond the country rock is quartz-orthoclase-sericite schist, with accessories of plagioclase, microcline, microperthite, almandite, titanite, leucoxene, and a good deal of dolomite. No biotite occurs.

From Richmond the rocks, in response to the northwestward thrusting, dip uniformly easterly, at angles varying from 75° to 87°, to the Mountain Border fault, which runs east of Brownell Mountain, and across the Lowland to Lake Champlain, where the Lower Cambrian Monkton and Winooski formations rest by thrust on the Ordovician shaly (Trenton) limestone of the Foreland.

No thrust faulting was noted between Montpelier and Richmond. The Green Mountain sequence seems to have moved northwestward as a unit, piling up the formations of the Eastern and Central sequences into the series of thrust slices which has been described.

Volcanics

In several places covered by this investigation thinly-bedded, chloritic schists were found which suggested metamorphosed volcanics. One of these places was along the country road running eastward from St. Albans, at a point one mile west of Fairfield (Enosburg Falls quadrangle) and another in eastern Westford.

Sections of the rocks were submitted to the U. S. Geological Survey who kindly examined them and reported that they might represent volcanics completely recrystallized and changed by metasomatic processes, but that the evidence was not conclusive.

Mineralogy of the Metamorphics

In this investigation some 325 thin sections of the rocks have been examined. The results may be summarized as follows:

Quartz is the most abundant mineral, generally appearing as interlocking grains, often with sutured edges, and showing crushing and strain shadows. It is generally colorless although the blue variety was seen in a few slides. It often contains inclusions of tourmaline, epidote, and graphite.

The feldspars are represented most often by orthoclase, including Carlsbad twins. The plagioclase is most often albite, with lesser amounts of oligoclase and, in a section of rock from Lincoln which is possibly volcanic ash, calcic plagioclase. Microcline is more rare and microperthite was noted in a few sections. The orthoclase is often kaolinized and sericitized. Apatite is common and is seen as fine needles.

Of the amphibole family, hornblende occurs as a hornblende schist on the western slope of Mount Mansfield and fragmantal hornblende is rather common in the metamorphics. Of course the amphibolites of the Morristown valley show the greatest development.

The pyroxenes are generally so altered that identification is uncertain. Enstatite was seen in a few slides.

The mica family is represented chiefly by sericite but there is also much muscovite and lesser amounts of biotite, these chiefly in the mountain rocks. Ottrelite is found in the phyllite of the

Worcester valley, and the Fourth Range, as well as in Barre and the Lake Willoughby region.

The red almandite is the most common member of the garnet family and it occurs in the metamorphics pretty much all the way from the Mountain Border fault to, and including, the Fourth Range. It is abundant on the Mansfield and Sterling ranges and reaches its maximum in amount on Mount Hunger where, besides appearing as individual grains, it occurs in pinkish-colored masses. The largest grains are seen just north of Mount Elmore and in the eastern side of the Worcester valley. A lighter-colored garnet, probably grossularite, is noted in some of the sections. The green uvarovite occurs in one or two of the sections from the Worcester valley. Chromite, the probable source of this garnet, occurs in the northern part of the State and increases in amount to the international border.

Of the chlorites, clinochlorite is the most common, diabantite is found in a good many sections; penninite in a smaller number. Other members are probably present but time has not permitted the use of heavy liquids for their determination.

Common epidote, or pistacite, is the most frequent member of the epidote family seen in the sections. Zoisite was found in a number of the slides and clinozoisite in a few. In the amphibolites the hornblende is, in places, extensively altered to epidote and chlorite.

Titanium-containing minerals are abundant throughout the metamorphic region. Of these minerals titanite, or sphene, and ilmenite (or possibly titanomagnetite) occur in many of the sections while rutile is much less common. Sizable fragments of ilmenite were picked up along the mountain trails. Where the mineral is titanite it is, in places, altered to an amorphous mass of leucoxene and calcite.

Of the pneumatolytic minerals [those requiring the hydroxyl (OH) radical, fluorine, or boric acid for their formation] stubby tourmaline crystals and needles are sparingly present in the Brigham Hill graywacke. They are abundant in the Westford schist, the "zone of mixed metamorphics" (Plate 2), and eastward across the mountains to the Fourth Range. They occur scattered through the sections, but in places in nests of crystals, indicating the proximity to igneous masses. Pegmatite veins (off shoots of granitic bodies), which also require "mineralizers" for their development, are found in Jeffersonville, and in the traverse along the Winooski River highway, while *lit-par-lit* injections occur in the gneisses near Essex Junction.

Detrital, stubby zircons are very abundant in the rocks from the Mountain Border thrust to the Worcester valley. Graphite begins to be abundant in Underhill and continues across the mountains and valleys to the end of the traverse. Sizable fragments are noted along the various mountain trails, especially on the Mansfield and Sterling ranges. The maximum development is in Johnson.

Pyrite is the most common sulphide. Besides being found in the sections, it occurs in cubes ranging from an inch to three-eighths of an inch in diameter. One or two specimens, sent in for identification, show tetra-hexahedral, striated faces. A good many pseudomorphs of limonite, after pyrite, are also received at the Geologist's office. Pyrrhotite, in the form of fragments or of dust, is frequently noted in the sections. Large masses are found in Ludlow.

A small occurrence of chalcocite and associated malachite was found on the Parrot farm, north of Malletts Bay, this summer. Malachite staining is seen on the toll road of Mansfield.

The iron oxides, hematite and limonite, as decomposition products, are seen in most of the slides.

Calcite or dolomite is noted in some of the sections. Ankerite is probably present in the gneiss of eastern Stowe.

Gold occurs in the gravels of Gold Brook, in Stowe, and in the stream gravels in the northern part of the Worcester valley.

Talc occurs along the Hell Brook trail of Mount Mansfield and around Sterling Pond. Its other extensive occurrences throughout the length of the State have been given.

There are other minerals in the metamorphics whose identification is uncertain. These will require separation from their associates and the use of heavy liquids, of known refractive indices, for their determination. They will be considered in a future Report.

Metamorphism of the Rocks

The region studied is one of regional, low-grade metamorphism (p. 26), the rocks of which belong in the Chlorite, Biotite, and Garnet zones and never rise to the Staurolite, Cyanite, or Sillimanite zones. In Grubenmann's classification (p. 27) the rocks belong to the *Meso*, or middle, zone.

The Brigham Hill graywacke, Westford schist, and "belt of mixed metamorphics" belong to the Chlorite zone, the lowest chlorite development being found in the graywacke; the highest, in the "mixed metamorphics." The Missisquoi formation of the Morristown-Stowe and Worcester valleys is also rich in chlorite and, of course, chlorite is found in varying amount all along the traverse.

Biotite begins to appear in the Underhill valley and continues along the traverse to, and including, the Fourth Range. It occurs in certain belts: In the Underhill valley it is found in considerable quantity; along the Main Range, sparingly. It is practically absent in the Morristown-Stowe valley and on Mount Hunger but appears in the Worcester valley and on the Fourth Range.

In the Worcester valley it is seen retrogressing to chlorite. The absence of biotite in places where almandite garnet is abundant is noteworthy and suggests that it has been used up in the formation of the garnet or that the biotite-making minerals are absent in these localities.

Almandite is the chief garnet, while grossularite and uvarovite occur here and there. Garnet begins to appear in the southern part of the Westford schist and increases in quantity in the Green Mountain series. It is rather plentiful in the Mansfield and Camels Hump rocks and in the Sterling Range. Garnet is practically absent in the Missisquoi formation but is found in large development in the muscovite gneiss of Elmore Mountain and just north of it, where almandite shows a large development and retrogression to chlorite. Almandite reaches its greatest development, as regards quantity, on Mount Hunger and in the east side of the Worcester valley; while, as regards grain size, its maximum development is seen north of Elmore Mountain and in the east side of the Worcester valley. Here, too, the garnet is retrogressive. Garnets also occur in the phyllite of the Fourth Range. Metamorphism thus increases in intensity to the east.

Dynamic metamorphism is seen in the schistose and gneissose structure of the metamorphics and has so obliterated the former structure of the ancient sedimentary rocks that bedding planes are difficult and, indeed often impossible, to recognize. Dynamic metamorphism has also been responsible for the coarsening in texture along the mountain crests, where solution of the quartz under pressure and subsequent recrystallization have produced very coarse gneisses, seen especially along the southern part of the Mansfield ridge.

It is believed that some of the biotite and garnet development, at least, is due to thermal metamorphism, the heat for which has been furnished by granitic intrusives. Indications of the presence of such bodies are seen in the occurrence of tourmalines in the rocks along the traverse and of pegmatite noted in various places, while the great granite batholiths in the Fourth Range stand nearest to the maximum development of the garnets.

This theory is supported by some thin-section studies in Brookfield and Barre. Bear Hill, in Brookfield, is formed by a fold in the Orleans phyllite and is eleven miles, in an air line, from Barre. No intrusives occur there.

The section of the Bear Hill rock shows a delicately-banded, schistose rock, made up of fine sials, and sericite perfectly oriented and highly chloritized. Long, narrow rods of magnetite, and titanomagnetite considerably altered to leucoxene are noted, lying chiefly in the schistosity, and there is a little pyrite or pyrrhotite. Several large porphyroblasts of penninite and other chlorite, muscovite, and sial grains occupy considerable areas. No garnet or biotite is present. Faint bedding planes, at about 60° to the schistosity, indicate that the rock occupied a position towards the top or bottom of a fold.

The second section was cut from the phyllite in Barre, on Millstone Hill and several hundred feet from the Wells and Lamson granite quarry. On one side of the section the texture is somewhat coarser and muscovite, to some extent, has replaced the sericite. Elsewhere in the section sericite and chlorite are greatly reduced in amount and the slide shows a mosaic of fine sial grains with minute laths of muscovite and fragmental sericite. The plentiful chlorite of the Bear Hill section is here much reduced in amount. Tiny tourmaline crystals and large apatite needles are noted. But the most striking change is in the appearance of biotite and garnet. The biotite occurs in prismatic and basal sections, lying in the schistosity and also cutting across it. Its maximum grain size is 0.78 x 0.33 mm.; its minimum, 0.05 x 0.02 mm. These biotite grains are numerous and make up perhaps six to eight percent of the slide. The single euhedral almandite garnet, 1.2 x 1.1 mm. in diameter, is only slightly chloritized. It includes grains of magnetite which have contributed to its formation.

The third section was cut from phyllite at the edge of the quarry. A small part of it is, in mineral composition and structure, like the preceding slide: phyllite studded with porphyroblasts of biotite and one or two almandite grains. Fine chlorite is present in moderate amount. Beyond a quite sharp line of demarcation there is an abrupt change: Chlorite has all but disappeared and the ground mass is a mosaic of fine sial grains in which there is a riot of biotite, in prismatic and basal sections (maximum size, 1.00 x 0.55 mm.; minimum, 0.03 x 0.01 mm.), many including, as before, grains of magnetite but smaller in size and less in amount than in the two preceding sections. Almandite garnets are very numerous, large (maximum size, 1.50 x 1.40 mm.; minimum, 0.03 x 0.02 mm.), generally anhedral, and contain numerous inclusions of orthoclase. There are also a few grains of uvarovite and numerous grains of grossularite, including a fine euhedral section. Numerous fine tourmaline crystals run through the section. A few laths of muscovite are noted and a small amount of leucoxene.

Thus metamorphism, gradually increasing in grade from the Chlorite zone of Bear Hill to the Biotite-Garnet zone of Millstone Hill, with its granite batholiths, is beautifully shown in the study of these three sections.

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Although metamorphism, in the areas covered by this investigation, never rises above the Garnet zone, higher grades of metamorphism are known in Vermont. Professor Doll, in his work in the Newport region, has found crystallized staurolite, and this mineral, associated with biotite and garnet, occurs in the old abrasive quarry at Gassetts, in Chester township. Moreover the writer has found erratics containing crystals of staurolite in Groton. Cyanite occurs in Irasburg where fine specimens have been obtained. Sillimanite has not been reported.

Further work on the metamorphism of the Vermont rocks will be undertaken and published in a future Report of the State Geologist.

Petrogenesis

Chemical Analyses[1]

	A	B	C	D	E
SiO_2	75.88	65.05	62.96	60.94	61.63
Al_2O_3	11.03	14.47	18.18	21.28	18.79
Fe_2O_3	0.57	2.37	4.04	0.86	0.78
FeO	2.24	4.04	3.87	4.14	6.14
TiO_2	0.52	0.72	0.54	0.78	0.69
MnO	trace	trace	0.08	trace	0.45
CaO	0.49	2.10	1.12	0.32	0.00
MgO	0.83	1.86	1.94	1.92	1.94
K_2O	6.18	3.22	2.23	4.24	3.26
Na_2O	0.94	2.86	1.57	0.58	2.87
H_2O–(105°C)	0.25	0.30	0.25	0.30	0.02
H_2O+	0.90	2.83	2.85	3.44	2.88
CO_2	0.00	0.00	0.00	0.00	0.00
P_2O_5	0.26	0.09	0.22	0.13	not det.
C	not det.	not det.	not det.	0.76	" "
SO_2				0.20	" "
Total	100.09	99.91	99.85	99.93	99.63

A, Brigham Hill graywacke
B, Westford schist
C, Mansfield gneiss (summit)
D, Hardwick phyllite
E, Lake Willoughby phyllite

The many minerals present in these rocks contain too many molecules in common to permit a satisfactory calculation of the percent of each mineral but, making the most liberal allowances for SiO_2 in the feldspars, biotite, sericite, garnets, and chlorite, we may arrive at the excess SiO_2 which forms free quartz. Doing this we find, for A, about 47 percent; for B, about 32 percent; for C, about 44 percent; and for D, about 38 percent.

Moreover, it is noted that the percent of MgO exceeds that of CaO in all the analyses but B; while K_2O exceeds Na_2O in all.

[1]Analyses A, B, C, D, by Herdsman, Glasgow, Scotland. Analysis E, by the writer. years ago.

According to Holmes[1], the double test of greater MgO than CaO and greater K_2O than Na_2O was found to indicate a sedimentary origin, as against an igneous origin, in 76 percent of the rocks investigated. Holmes also notes that another test, though of less value than the foregoing, may be applied, that of the percent of free quartz present. "If a metamorphic rock is found to contain over 50 percent of normative (free) quartz, there is good reason to suspect a sedimentary, rather than an igneous, origin." In our recasting none reaches the 50 percent figure, although A and C approach it.

As the result of all the evidence, field and laboratory, and especially the presence of graphite in A, C, and D, the writer believes that the rocks studied in this investigation, with the exception of the Westford schist, are of sedimentary origin. The case of the Westford is open to question.

It is seen that the Lower Cambrian Brigham Hill graywacke differs markedly in its chemical composition from the rocks B, C, D, E. It is more closely akin to the Cheshire quartzite with which it is closely associated, while the mountain rocks show a striking kinship in their chemical composition. B and C represent Pre-Cambrian rocks which have been thrust onto the Lower Cambrian; their analyses show a sort of chemical unconformity with the analysis of the graywacke.

The writer concludes that the Cheshire is a metamorphosed sandstone, in places very pure; in others, highly ferruginous. The Brigham Hill is a thrust micro-breccia rather than a mylonite. The schists and gneisses have resulted from dynamic and thermal metamorphism, resulting from mountain folding and from the presence of intrusive (chiefly granitic) bodies in the rocks.

Non-Technical Summary

To summarize what has been written, in language as free as may be from technical terms: The Green Mountains are made up of two chief members, the Main Range, with its associated Sterling Range, and the Worcester Range. Another, ill-defined range, which forms the eastern wall of the Worcester Valley, does not properly belong to the Green Mountains but lies on the western border of the Vermont Piedmont, which is a peneplain.

The mountains and intervening valleys are formed of metamorphic rocks—that is, rocks that were once conglomerates, sandstones, and shales but now, owing to the pressure to which they were subjected; the heat in the depths from which they came, and the heat from masses of igneous rocks intruded into them; and the chemical action of solutions and gases in the rocks, are chiefly quartzites, gneisses, schists, and phyllites.

[1]Petrographic Methods and Calculations; Arthur Holmes, Thomas Murby and Sons, London; and D. Van Nostrand, New York (1930).

From many sections of these rocks, cut to the thickness of tissue paper (about 0.03mm., or 0.0012 inch) and studied with the aid of the petrographic microscope, the individual mineral constituents are seen in their relationships to one another, the conditions under which they were formed, and the changes which have gone on in them—such as alterations to other minerals, progressive changes to higher grades of metamorphism or retrogressions to lower grades—are noted. From these studies and from the evidence of chemical analyses we judge whether or not the parents, so to speak, of these metamorphics were sedimentary of igneous—and the conclusion is that, with the possible exception of the Westford schist, they were sedimentary.

The rocks are vastly old. Those of the Fourth Range and, in fact, all of the Vermont Piedmont, which extends eastward practically to the Connecticut River, are phyllites, slates, and crystalline limestones, known by their fossils to be of Ordovician age, perhaps 440 million years old. North of Montpelier the phyllites have been thrust under the next older rocks (instead of upon them, as would be the normal relationship) which are the Missisquoi schists and gneisses, probably of Cambrian age (although no fossils have as yet been found in them) and some 500 million years old. This Missisquoi formation makes up the western side of the Worcester valley and all of the Worcester Range, extends across the Morristown-Stowe valley, and rests unconformably on the eroded edges of the most ancient rocks of all, the Pre-Cambrian, at least a billion years old. These most ancient metamorphics make up the Main Range of the Green Mountains, including Mount Mansfield, the Sterling Range, and Camels Hump, and extend westward to the Mountain Border fault, as shown on plates 3 and 2. This Mountain Border fault zone, which by no means always borders the present mountains (any more than the Champlain fault always follows the shore of Lake Champlain) is made up of the Cheshire quartzite, the Rutland dolomite, and the Brigham Hill graywacke, rocks known by their fossils to be of Lower Cambrian age, over 500 million years old. These rocks mark the transition from the phyllites, schists, quartzites, and gneisses of the Green Mountains to the less metamorphosed dolomites, slates, conglomerates, and breccias of the Vermont Lowland.

Farther west lies the Champlain thrust fault which marks another transition, this time between the "less metamorphosed" rocks of the Lowland and the practically non-metamorphosed rocks of the Foreland.

Having seen of what substances the rocks were made, let us inquire how and when the mountains were folded and upraised and the thrust faults were developed.

President Hitchcock was quite right in saying that the folding and thrusting force came from the Atlantic, that is from the southeast. The axes of the flutings under the Rock Point overthrust show this to perfection, while the axial trends of the mountain ranges also indicate it. The tangential thrusting forced the ancient strata into anticlines and synclines (swells and hollows) and overturned them somewhat to the northwest, so that the northwesterly dips are greater than the southeasterly. The tangential pressure also furnished the "dynamo" for the dynamic metamorphism which is seen chiefly in the foliated schists, phyllites, and gneisses.

This inconceivably great tangential pressure not only folded the rocks into mountains and lesser ridges but it also seems to have moved them as a whole (since no thrust faults have been found within the mountain mass) to the northwest. In the longitude of eastern Westford the rocks were incapable of sustaining the thrust, unfractured, any longer and so they broke and developed thrust faults: the two great ones already mentioned and many minor thrusts lying between them. The thrusting finally exhausted itself, probably by increasing friction with the underlying beds, so that the Foreland was but little affected by it. From Schuchert's time table (p. 11) it is seen that the Green Mountain folding is believed to have taken place in late Ordovician time, possibly some 400 million years ago.

Probably somewhat later than the folding came the uprising of igneous rock matter (magma) under such enormous pressure that it uplifted and penetrated the strata and finally crystallized to form great granite batholiths, and more basic bodies from which our serpentine, talc, and asbestos were formed. The heat of these batholiths and the volatile material emanating from them aided the thermal metamorphic action on the intruded rocks and extended it for considerable distances.

Hand in hand with mountain folding and uprise went the wearing down action of weathering and erosion until today we see the net result of these opposing forces of upbuilding and downcutting in the anticlinal Fourth Range, the synclinal Worcester Mountains, the division of the old anticlinal Mansfield mass into the synclinal Sterling and Mansfield ranges with the anticlinal Smugglers Notch between them, and the anticlines and synclines of Macomber Mountain, Hedgehog Hill, and the other foothills of the Green Mountains.

The Geology of Clay Point, Colchester, Vermont

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Introduction

Clay point consists of a rounded hillock of rock capped by the Champlain clays and is situated on the shore of Lake Champlain one mile north of the entrance to Malletts Bay, in the town of Colchester, Vermont. On the topographic map it is located in the southern part of the west subquad of the Milton quadrangle. The area considered in this paper lies about one mile west of the Champlain fault and comprises a shore strip from the extreme end of the point southeasterly for a distance of a quarter mile. This site is interesting for its display of varied geologic features within a small compass, especially those exhibiting rock structures. It is an excellent outdoor laboratory for students of both general and structural geology. Its proximity to the Champlain overthrust of which it is a subjacent part, is of further importance.

Stratigraphy

Of first importance are a series of intercalated, thin-bedded arenaceous limestones and calcareous shales of upper middle Ordovician age, the Trenton shale formation. A basic dike is intruded into these sediments and may be Cretaceous[1] in age. A deposit of Pleistocene marine clays and beach sands overlie the Ordovician rocks.

Petrography

The strata range from one half to ten inches in thickness and vary in shades of a dull gray, from a light shade on the weathered surface to an almost black on the fresh surface. The fine-textured shales possess a well-developed cleavage, and appear to have undergone a plastic condition. The shales comprise the great majority of the sediments, and interbedded with them are a few narrow layers of partially laminated shaly limestone and crossbedded arenaceous limestone. The crossbedding is distinctly marked by fine, rust-colored lines of sand on the weathered surface.

[1]Cambrian Succession in Northwestern Vermont, Arthur Keith, Rpt. Vt. State Geol. 14th of this Series, p. 136 (1923-24).

The dike rock is stained brown by iron oxide on the weathered surface and is black where unweathered. It is a medium-textured, homogeneous rock, and probably a camptonite.

Geologic Structures

The exposure is a part of the extensive shale formation directly underlying the Champlain Overthrust, and as a consequence of this position and the lithological character of the rock, it contains a splendid variety of structural detail, as the figures in the accompanying plates show. The most outstanding features are a large anticlinal fold, two overturned synclines, one recumbent fold, normal and reverse faults of different magnitudes, and a pronounced cleavage. These structures will be described presently in some detail, along with the less conspicuous features.

A general view of the south side of the outcrop (Plate I, fig. 5), discloses a broken anticline with displaced strata throughout the arched section, the majority of the displacements having occurred along the planes of cleavage in the shales and along fractures in the more massive thin-bedded limestones. The anticline plunges about 12° N1O° E and is overturned asymmetrically to the west. Plate I, fig. 2 shows a portion of its rounded crest which is also overturned. The structure in this anticline is somewhat complicated by steeply overturned west limbs cut through by at least three thrust faults, the locations of which are designated by letters in the figure. West of this series of thrust faults and bordering fault "a," lies a rather flat, symmetrical syncline overturned to the west (Plate I, fig. 7). The axis of this syncline plunges 38° N1O° E and the axial plane is inclined 70° SE. The gently inclined limbs are mildly undulating to the contact at thrust fault "a" (Plate I, fig. 7 and Plate II, fig. 1).

Approximately 210 yards southeast of the anticline and beyond the beach (Plate III, fig. 2), is a recumbent fold overturned to the west (Plate II, fig. 4). On the nose of the synclinal fold in Plate I, fig. 1, the thin layers of weaker rock are intricately crumpled and step-faulted (above hammer) in the direction of the cleavage. During folding the form of the weaker layers was determined by the more competent adjacent beds. Many interesting minor structures are frequently present on the limbs of the folds, especially in the incompetent members of a series. The anticline herein described, possesses some of these features.

Gravity faults in step-like fashion, ranging from displacements of a fraction of an inch to a little more than an inch, are numerous on the exposed limbs. The specimen illustrated in Plate I, fig. 3, is a typical example of these step-faults with small displacements. The specimen is composed of shale with an upper surface of thinly banded calcite. The differences in brittleness of the two substances affected the attitudes of the fault surfaces in each, the

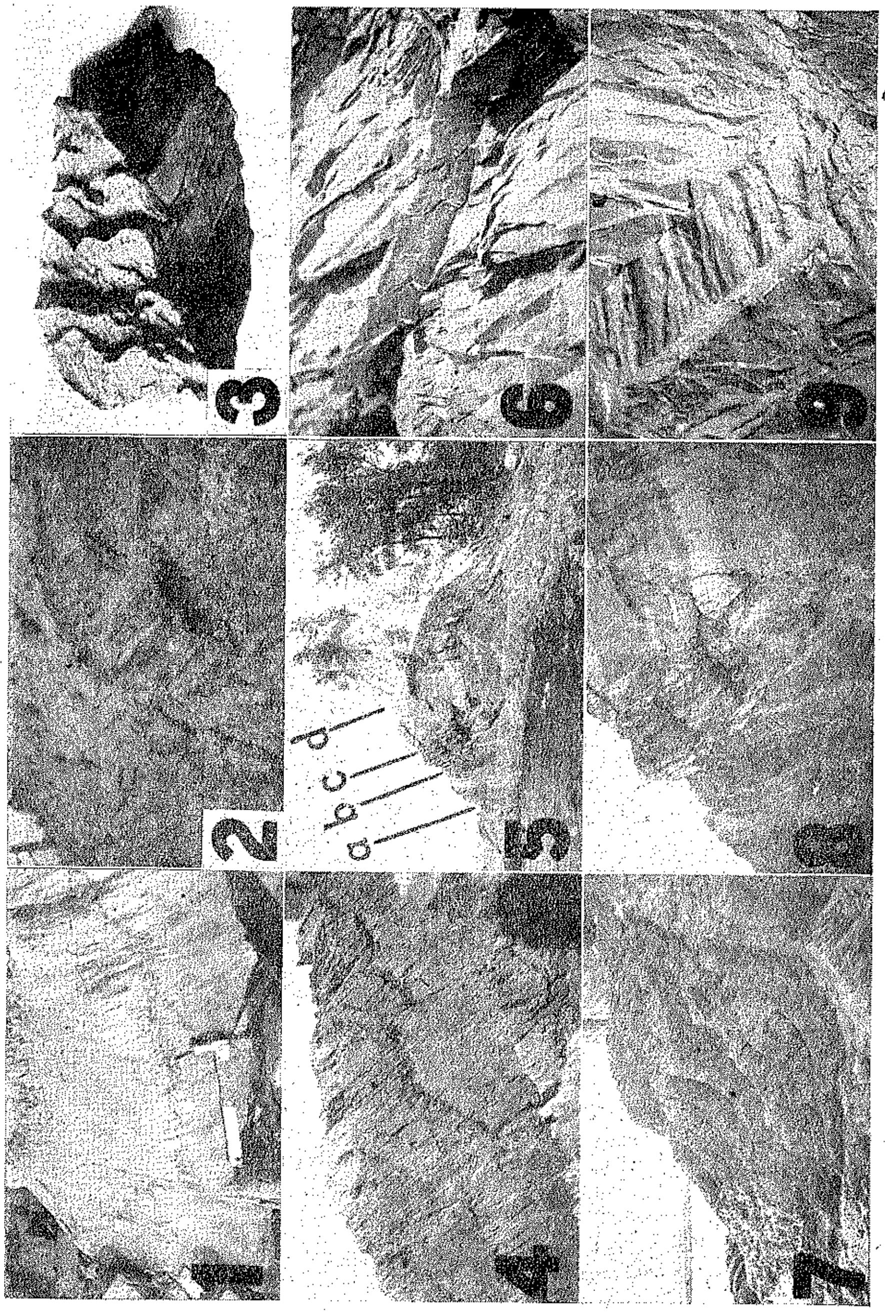

PLATE I

inclination in the more brittle calcite layer being much the steeper. It appears that during compression the more frangible calcite layer fractured as each successive section slid along the much less inclined cleavage of the shale. The separate blocks became tilted slightly toward the upthrow side, and where the calcite bands were faulted more than their thickness they have been pressed into the softer shale in an underthrust-overthrust relationship, depending upon the direction of pressure.

While the stratum was undergoing tensional strains during folding, as each stratum moved upward past the one below, there was a tendency to fault normally along the fracture and cleavage surfaces. At the same time the tensional forces were active upon it, the confined layer was also being subjected to compression. This is seen in the thrust relationship of the calcite band mentioned above. Not in all cases do the faults continue across the specimen, but they die out, an example of which may be seen on the surface of the lowermost faulted section. The miniature fault escarpments are sinuous in outline and, on the highest portion of the upper surface of the specimen, they form branching faults by merging. Slickensides on the surface of the specimen are the result of slipping along the bedding surface during the process of folding, and indicate the direction of the movement. These striations occur on the bedding and fracture surfaces in the exposure wherever a strong development of calcite has undergone movement. The slickensides have a general east-west trend.

The confinement of fractures to brittle layers is shown in Plate I, fig. 6, in which the dips of the fractures in the limestone strip are much steeper than those of the cleaved shales on either side. Faulting has occurred along some of these fractures and, in consequence of the filling of open fractures, calcite veinlets occupy many of them. Within the limestone stratum itself the fractures are not equally inclined, for in the lower laminated portion they dip in an opposite direction. This dip change may be due to structural reasons as well as to differences in degree of brittleness, since the laminated boundary is where the change in dip begins. A top view and bedding surface of this layer is shown in fig. 9 of this same plate. The surface is strongly crenulated, and when closely observed the crenulations appear to be related to the fractures into which they develop in the rock. The direction of elongation of the crenulations is the same as that of the cleavage in the adjacent shale, and athwart the direction of movement of the layer in folding. Plate I, fig. 4 is a "close-up" of several layers of the syncline in fig. 7, illustrating minor faulting in the cleavage direction. Throughout much of their lengths the brittle, arenaceous limestones exhibit "pinch and swell" structure, portions of which have been severed into separate lenses.

Besides the multitudes of minor displacements within the exposure, it is traversed by several large thrust faults, the surfaces of which begin with rather steep dips, becoming less so down the dip. The terminations of these faults at the earth's surface are indicated in Plate I, fig. 5, by the letters "a," "b," "c," and "d." These faults represent an imbricated structure and are the result of the overturning of the anticline, with the subsequent rupturing of the west limbs in a complicated manner. The severed anticline is a good example of a break thrust. The thrust fault zones are characterized by a pronounced development of calcite.

Thrust fault "a" strikes N8° W and changes in amount of dip from 55° E at its emergence to 38° E a short distance down the dip. The fault surface conforms generally to the direction of cleavage in the shale, rarely to the bedding. This fault can be traced northward for half the length of the exposure. Thrust "b" has a northerly strike and dips 33° E. Thrust "c" also strikes in a general northerly direction and varies in dip from approximately 41° E to 58° E down the dip, where it joins thrust "b." The surface common to both of these latter faults strikes N8° E and dips 26° E. The surfaces of these faults begin with steep inclinations, but at depth lose their steepness perceptibly. Fault "d" is vertical and follows a fracture rather than the cleavage in the shale. Downward, fault "d" merges with fault "c." The downward tapering block between faults "c" and "d," has the shape of a keystone. The light-colored layer at the top of fault "d" has been displaced approximately six inches. The manner in which these faults unite at depth, gives them an imbricated structure. Plate I, fig. 8 illustrates faults "b," "c," and the lower part of vertical fault "d." Plate II, fig. 1 shows thrust fault "a" on the west side of the exposure, the hammer handle leaning against the upthrow block.

The southeast-trending cliff beyond the beach in Plate III, fig. 2, is pervaded by faults and flexures of many descriptions. Plate II, fig. 5 illustrates a small clean-cut thrust with overlap, and a flaw fault. Fig. 6 in this same plate shows an example of drag along the surface of an apparent normal fault, the drag revealing the direction of the relative movements on the fault. Some of the large faults in this cliff have a steep westerly dip, while many of the smaller ones strike and dip at various other angles. These intricate and seemingly chaotic structures appear to be characteristic of such weak rocks as shales which have been subjected to strong pressures. From the attitude of the overturned folds and the majority of the large faults, and from the close horizontal relationship of this formation to the Champlain Fault, it appears that the latter was responsible for the pressures and resulting movements. The Lower Cambrian escarpment

of the Champlain Overthrust stands about a mile east of this exposure.

A series of prominent fractures with strikes ranging from N70° W to N85° W, traverse the whole exposure. These fractures change from vertical to extremely high northerly or southerly dips. In some instances they persist throughout the exposure, while in others they are discontinuous. They have a slightly curving strike and dip, and merge into each other in places. It is along one of these fractures that a basic dike, probably of camptonite rock, cuts the exposure. The dike strikes N75° W and dips 85° SW. It has a maximum width of eleven inches and extends a distance of about twelve feet when it pinches out. Two feet south of this pinched out terminus the dike again appears with a tapering end, and continues to the top of the exposure (Plate II, fig. 2). The pinched out ends of this dike serve as evidence against offset by faulting. Rather, the explanation of offset is found in the discontinuity of the fractures; that is, the fractures through which the molten material intruded, are discontinuous where the dike peters out, but connected in another direction.

There are no visible exomorphic effects in the shale, except at the tapering ends of the dike where the shale has been altered at the contact into a three sixteenth inch band of hornfels. The hornfels is cream-colored and possesses a very good conchoidal fracture. Although the cleavage of the shale has been practically obliterated in the hornfels there are sparse occurrences of elongated pyrites to indicate its direction. The shale bordering the hornfels is a little more massive, tougher, and darker than it is farther away from the contact. Occasional fractures cross the dike from side to side. A maze of less conspicuous fractures cut through the exposure.

An outstanding structure in this exposure is the cleavage of the shale. This cleavage has the characteristic of slaty cleavage, in that it possesses a fairly uniform strike and dip in a structural unit, as a fold. Its relationship to the bedding is strikingly shown in Plate I, figs. 1, 2, 4, 5, 7, and 8. In these views it can be seen that the slaty cleavage varies from perpendicularity at the crest and in the trough of a fold, to much less an angle to the bedding out on the flanks. The bedding and slaty cleavage almost coincide on the flanks of isoclinal (parallel limbs) folds. The slaty cleavage was formed during folding of the shale. As the adjacent beds slipped past one another the shale was induced to split into thin plates, a consequence of the parallel orientation of the platy and columnar minerals during metamorphism of the shales. In Plate I, fig. 5, the relationship of the slaty cleavage to the fold would tend to show a stress application substantially normal to the slaty cleavage, although some of the movement may have been rotational.

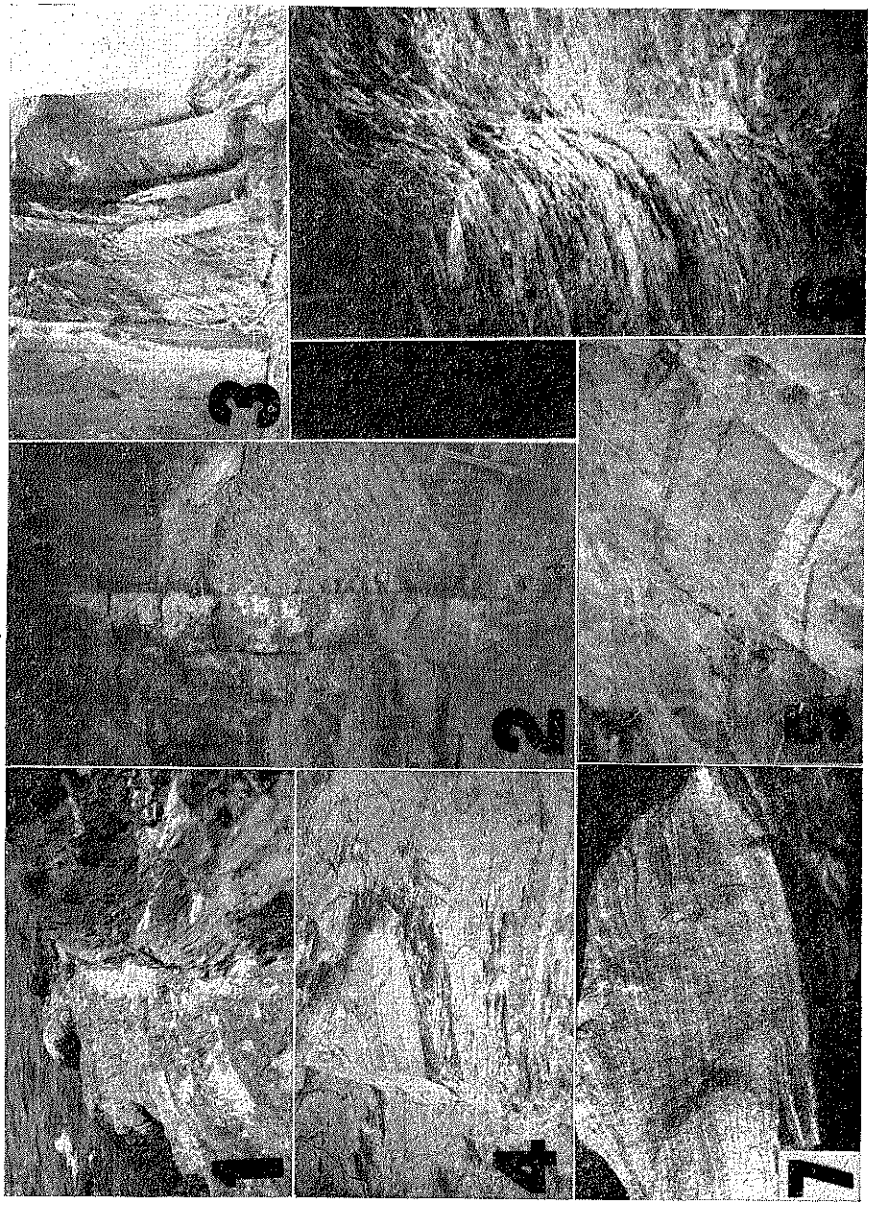

PLATE II

This secondary structure, slaty cleavage, is of special importance to the structural geologist. He uses it in determining major structures. Cleavage frequently denotes the strike and dip of axial planes in folds. Field evidence has shown that the cleavage in a fold coincides with the axial plane which bisects the fold and includes its crest. In Plate 1, figs. 2, 5, and 7, the axial planes dip to the right which is east. A knowledge of the relation of cleavage to folding will enable an observer to locate himself on a fold, determine the trend and angle of pitch, and the amount and direction of overturning. It will be recalled from above that cleavage and bedding in a fold have an angular relationship, perpendicular at the crests and in the troughs, and at some lesser angle on the limbs. Since folds terminate somewhere along their strike and, therefore, have a pitch, a horizontal section looks very similar to a vertical one and has the same application. Plate I, fig. 7 illustrates the similarity between both vertical and horizontal sections in the field.

Very often a geologist finds only a part of a fold exposed. It then depends on his ability to apply the above principles correctly to determine his position on that fold and, if possible, the kind of fold it is. This exposure has the advantage, in that the student can apply the structural principles to the more or less complete structures present, and so acquire a reasonably good working knowledge of structural fundamentals.

Cleavage is generally steeper than the bedding, which relationship would indicate that the fold is right side up. The unbroken portion of the anticline in Plate 1, fig. 5 displays this association. However, sometimes an occurrence discloses the bedding steeper than the cleavage, which would signify overturned strata. The broken section of the anticline demonstrates overturning, and the close-up in Plate 1, fig. 8 shows both normal and overturned beds. It is fortunate that the overturning in the anticline can be seen without the use of the above criteria, which in turn, serves as a check on them. Using the above criteria in Plate II, fig. 3, an overturned anticline lies to the left and an overturned syncline to the right (west). The younger formations lie to the west, since one traverses increasingly younger beds from the crest of an anticline to the trough of a syncline.

The angle and direction of pitch in a fold may be had from the trace of the bedding on a cleavage surface or from the bedding surface itself. Both of these methods are applicable in this exposure. Although the slaty cleavage has a fairly uniform northerly strike and easterly dip, it is found upon closer examination to vary somewhat as a consequence of faulting. Immediately under fault "a" the strike and dip of the cleavage is N10° W and 46° NE, respectively, and above this fault N15° W and 52° NE, respectively. Just below fault "b" the strike is N11° E and the dip 43° SE. Under fault "c" and close to it the strike and dip readings are N20° E and 68° SE, respectively. The cleavage in the still intact portion of the anticline has a general N10° E trend and dips steeply to the southeast, but near the contact with fault "c" the strike changes to a more easterly one, N23° E. The above data seem to show that the earlier formed cleavage was disturbed by later faulting.

Besides bedding which is so plainly delineated in this exposure by changes in color and shades, several other primary structures are observable. They are crossbedding, textural gradation, and possible mud-cracks. Crossbedding occurs in the arenaceous limestone, on the weathered surface of which it is definitely outlined by rusty, sandy lines (Plate II, fig. 7). Crossbedding is one of the best criteria for determining a stratigraphic sequence. If it is concave upward and truncated at the top, the stratum is right side up. Crossbedding also shows the beds in the broken sector of the anticline (Plate I, fig. 5) to be overturned. During deposition the coarser materials find their way to the bottom first, resulting in a gradation to finer sediments at the top. Plate I, fig. 6 exhibits a textural change with the coarser laminated layer at the bottom. Mud-cracks are formed when moist muds are exposed to the atmosphere and sunlight. The mud cracks into polygonal shapes as it contracts in drying. The fracture pattern in Plate III, fig. 4, which is on a bedding surface, resembles mud-cracks.

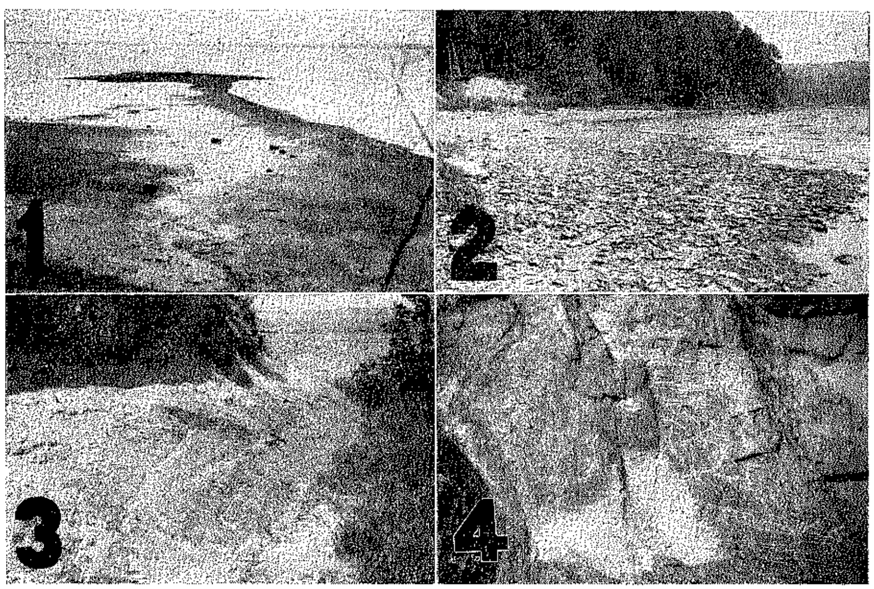

PLATE III

Historical Geology

The geologic history of this area begins with the deposition of the Ordovician sediments of Trenton time. Limy muds, occasionally arenaceous, were laid down in this part of the sea. At times mild currents gave rise to fine laminations and crossbedding in the more sandy layers. The sea bottom was probably not very deep here, as is evidenced by the crossbedding and possible mud-cracks. It was probably an extremely wide shore area, in which, when the tide receded, certain portions were exposed to the atmosphere. Although fossils are not found here because of metamorphism, they occur in the rocks of this formation elsewhere, and so it seems logical to assume life to have been present here also. After deposition of the Ordovician strata the region was raised above the sea, not to be submerged again until the end of Pleistocene time.

However, long before this latter submergence took place, the Ordovician sediments were subjected to great compressional stresses which imparted to them the slaty cleavage during folding, followed by faulting. Very likely all of the different kinds of structures now present were induced during a single orogenic process, but not necessarily in such profusion. These rocks probably experienced at least three orogenies, namely, the Taconic at the end of the Ordovician, the Acadian at the end of the Devonian, and the Appalachian at the end of the Paleozoic. It is likely that during one of these diastrophic periods the dike was intruded into the Ordovician sediments.

A great hiatus exists between the unconsolidated Pleistocene deposits and the Ordovician beds over which the former lie unconformably. Apparently this area did not receive deposits during that long time, because of the elevated condition of the land; instead, erosion was going on. Before the deposition of the Pleistocene beds the area was over-run by the continental glacier whose erosional effects are present on the outcrop as a smooth surface with grooves and striae. The direction of the markings in Plate III, fig. 3 is N5° W. Crystalline erratics lie strewn about on the beach.

The Pleistocene beds consist of marine clays (capping exposure, Plate I, fig. 5) containing clay concretions and fossil mollusc shells. A layer of beach sand in which the mollusc shells occur in even greater abundance, overlies the clays about 100 feet east of the exposure. The marine stage during which time the Pleistocene deposits were made, lasted from the time the receding ice mass reached a point in the St. Lawrence Valley to the rising of the rock threshold in the Richelieu spillway at St. Johns, Quebec. The position of the Pleistocene beds at the present time reveals uplift of the land since glacial time.

Of the more recent developments, shoreline features can be studied here with some profit. Plate III, fig. 2 illustrates a crescentic beach between two rock headlands. In Plate III, fig. 1, an island is tied to the mainland by a tombolo.

The Geology and Petrography of Vernon, Guilford, and Halifax, Vermont

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The report upon the geology and petrography of Vernon, Guilford, and Halifax is of necessity brief. The time available for detailed field work and petrographic study in the laboratory at Syracuse University has been altogether too limited to bring out all that might be desired as to structure and the original composition of the rocks involved. Some important discoveries that bear upon the mineralogical composition and the probable age of some of the terranes have been made, and it hoped that the results will throw some light on a field hitherto undescribed. The mode of origin of the rocks cannot be ascertained with certainty, in some instances, even with a most careful petrographic study. The metasomatic changes have been so complete that scarcely a trace of an original mineral remains and, in one instance at least, there is no trace whatever of an original mineral. The best example of this pronounced alteration can be seen in an irruptive rock in the extreme southeastern part of Vernon.

The high percentage of microcline, showing the characteristic grating structure, in rocks that are coarsely laminated is a strong argument in favor of an igneous origin. Such rocks in this report are listed as granite gneisses. It is difficult to determine the actual age of some of the terranes involved because no fossils have been found in the pre-Ordovician formations in eastern Vermont. The heavy burden of glacial drift that covers the area renders the correct interpretation of structure exceedingly difficult. In road cuts and river beds the best evidences of the structure are obtainable.

The area involved in this report lies between north latitude 42° 43′ and 42° 50′ and between the meridians, 72° 27′ and 72° 44′, west of Greenwich. The major portion of the area involved lies in the Brattleboro Quadrangle. The extreme eastern part is in the Keene, New Hampshire, quadrangle while the southern portion falls in the Warwick, Greenfield and Hawley Quadrangles of Massachusetts. The extreme western portion is included in the Wilmington Quadrangle in Vermont. It may seem strange to some

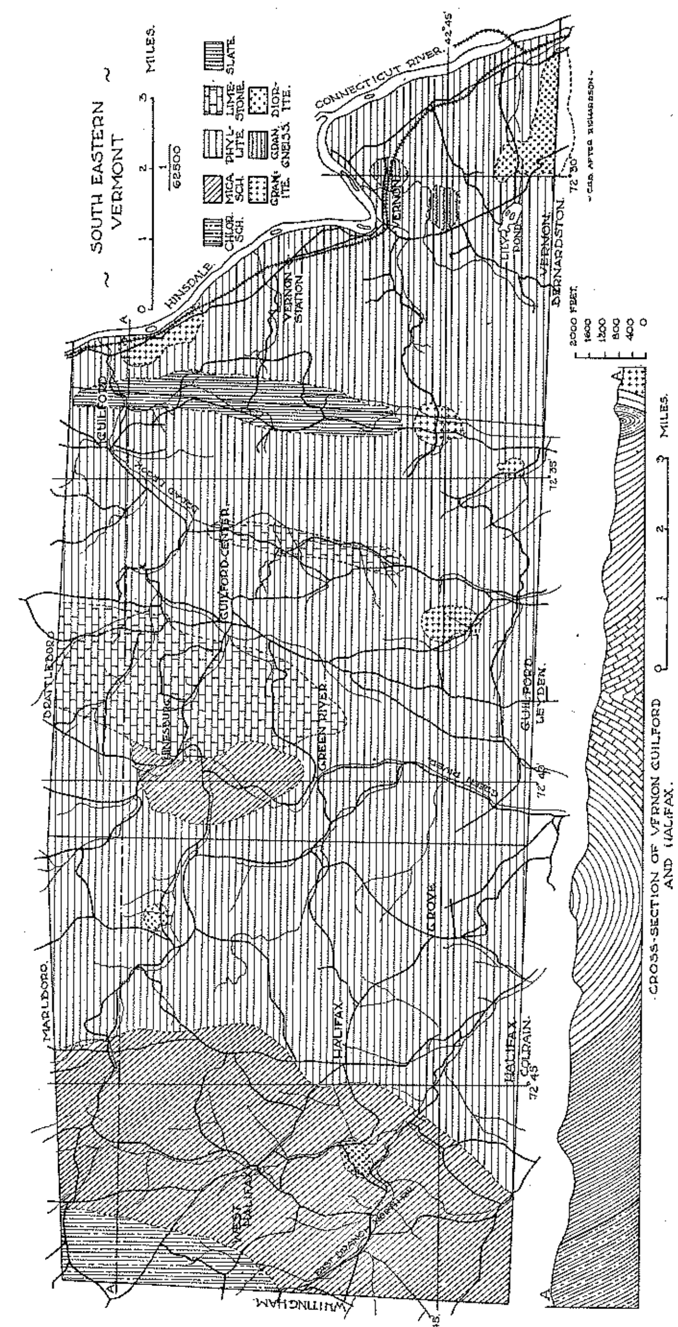

PLATE V

readers of this report that six different quadrangles should be represented in so small an area.

There are six definite reasons for the selection of Vernon, Guilford and Halifax for field work:

1. They all lie directly south of Brattleboro and Marlboro whose geology has been worked out by Professor C. K. Cabeen of Lafayette College.
2. They make Professor Richardson's work continuous, in the eastern half of the State, from Canada southward to the Massachusetts State line.
3. They carry the field work eastward to the Connecticut River for the third time in recent years.
4. Halifax, the westernmost township studied, contains the erosional unconformity between the Ordovician and pre-Ordovician (probably Cambrian) on the eastern side of the Green Mountains.
5. The presence of both acid and basic intrusives whose mineral composition has never been worked out and published.
6. The fact that no detailed field work has ever been done and no petrographic study ever made of the sedimentaries.

The detailed field work was essentially done during the summers of 1933 and 1934, although some work was accomplished with Professor C. K. Cabeen during the summers of 1930, 1931, and 1932. I wish to express my indebtedness to Carl Hugo Almfelt, a graduate student at Syracuse University, who has been of great assistance to me in my field work during the last two summers. The field relations of the different terranes in Vernon, Guilford, and Halifax are difficult to determine. The three townships are hilly, glaciated and in fact densely wooded. With a heavy glacial till and a dense growth of underbrush actual contacts between the different terranes are extremely difficult to find. Contacts were found on Windmill Hill in Westminster and on Putney Mountain but none has been discovered in Halifax.

An aerial map and a cross-section showing the distribution of the different terranes accompanies this report (Plate V).

The area involved in this report has, in the past, been mapped as purely sedimentary but both acid and basic intrusives have been discovered and, so far as possible, their locations shown on the aerial map. It is interesting to note that some of the rocks considered by earlier geologists as highly metamorphosed sediments are now definitely proved to be granite gneisses. The presence of a large amount of microcline in the microscopic slides substantiates this view.

Drainage

The drainage of the area involved in this report is to the east, south and southeast. The chief river is the Connecticut which flows in a southerly direction and marks the eastern boundary of the area. The east branch of the North River flows southerly and empties into the main North River a little north of Shelburne Falls, Massachusetts. Broad Brook flows easterly in the northern part of Guilford and Vernon and empties into the Connecticut River in the northern part of Vernon. Each of these three rivers receives several small tributaries which have only local names and need not be mentioned.

Topography

There are two broad U-shaped valleys traversing the area covered in this report. The major valley is that of the Connecticut on the east; the minor valley is that of the East Branch of the North River in the western part of Halifax. These are pre-glacial valleys. The numerous transverse valleys are in part pre-glacial and in part post-glacial.

Certain altitudes that may be of interest are given below. Some of them were taken with an aneroid barometer while doing the field work, others were taken from contour maps of the area involved. The lowest altitude is in the southeastern part of Vernon, 200 feet; the highest is on a round mountain in northern Halifax, which registered 2,034 feet. A round mountain in Halifax registered 1,949 feet. A mountain south of the same village registered 1,834 feet. Pulpit Mountain, in Guilford, is 1,249 feet. East Mountain, in Guilford, is 1,424 feet. Governor's Mountain, in the northeastern part of Guilford, registered 1,823 feet. The altitude of Vernon station is 310 feet. Vernon Center church 290 feet. South Vernon Junction is 275 feet.

Geology and Petrography

The geology of Vernon, Guilford and Halifax is intricate and complex. The rocks consist of highly folded and faulted metamorphics that are often invaded by intrusives of more than one period of introduction. These rocks range from quartzose marbles to feldspathic quartzites or gneisses, with no trace of a fossil content, and from phyllites to highly chloritic and epidotic mica schists—in fact some of the rocks listed as of sedimentary origin in this report are so highly metamorphosed that it is extremely difficult to prove that they were not of igneous origin. This holds especially true of some of the rocks now listed as hornblende schist and chlorite schist. The intrusives range from soda granites through diorites and gabbros to amphibolites. In the petrographic laboratory, under polarized light, the microscope tells us what the individual constituents in both the sedimentary and igneous rocks are now but it does not always reveal with certainty the mineral composition of the original rock. In some instances what constituents have been subtracted and what added, and under what condition various solutions were introduced, we do not know. The question naturally arises, were solutions rich in iron, aluminum, calcium, magnesium, and titanium introduced to form the hornblenes, zoisite, epidote and rutile now so abundant?

The sediments vary in age from the Cambrian to the Ordovician. There is no positive evidence of any pre-Cambrian or even Lower Cambrian formations in the area covered by this report, nor is there any evidence of any sedimentary rock younger than Middle Ordovician. The intrusives range in age from the Cambrian to the Carboniferous and possibly to the Triassic.

Cambrian

The term Cambrian as here used denotes a group of highly metamorphosed sediments which lies between the eastern foothills of the Green Mountains and the erosional unconformity that separates the pre-Ordovician terranes from the Ordovician. The Cambrian formations consist of a series of highly folded and faulted feldspathic mica schists, often sufficiently coarse textured to be listed as gneiss, feldspathic quartsites, chlorite, schists, hornblende schists, biotite schists, and sericite schists that were derived from the erosion of the Algonkian land mass to the west during Cambrian time.

That these terranes, listed as Cambrian, are post-Algonkian and pre-Ordovician in age is proved by three facts:

1. They all overlie the Algonkian gneiss that flanks them on the west.
2. They all underlie the Irasburg, Albany, and Northfield conglomerates which have been definitely proved by fossil content to be of Ordovician age.
3. The lowest group of Cambrian sediments is the Sherburne conglomerate.

Upper Cambrian

There is no evidence of Lower Cambrian rocks in the area covered by this report. Upper Cambrian rocks do occur in the western part of Halifax. The terranes listed as Upper Cambrian comprise a series of highly folded and faulted sedimentary rocks that have been invaded by basic intrusives. The schistose rocks may be listed as chlorite schists, hornblende schists, biotite schists, muscovite schists and micaceous quartzites.

Before taking up the general discussion of the above named terranes several significant questions may be raised.

1. Was the deposition of sediments continuous on the eastern side of the Green Mountains throughout Cambrian times?
2. Did deposition begin with the Sherburne conglomerate in Lower Cambrian time and cease with the Middle Cambrian?
3. Did deposition begin with the Upper Cambrian and cease with the uplift that came at the close of the Cambrian?
4. Is the Middle Cambrian entirely wanting east of the Green Mountains?

The field evidence is that deposition began in Lower Cambrian time with the Sherburne conglomerate as the oldest member of the series. The presence of an apparent conglomerate in the lower portion of the Bethel schist would imply that sedimentation was not continuous during Cambrian time. If this conjecture can be proved by subsequent field work in Windham and Townshend then it seems rational to assume that the break in the continuity came in Middle Cambrian time. The rocks listed in this report in the western half of Halifax must be Upper Cambrian.

Chlorite Schist

The chlorite schists are fine grained, green, schistose and highly metamorphic rocks. Chlorite or some related species of the chlorite group, is the dominant mineral, while epidote and magnetite are invariably present. Quartz grains and plagioclase feldspars are either wanting or sparingly present. In the extreme northwestern part of Halifax there is a broad belt of chlorite schist with strike north 40° east and dip of 45° southeast. The outcrop extends west into Whitingham.

Cavendish Schist

The Cavendish schist is a dark gray, fine to medium grained, highly metamorphosed, sedimentary rock. In Cavendish, the type locality, the essential minerals are quartz and biotite. The rock is often hornblendic and the hornblende sometimes replaces nearly all of the biotite. Among the accessory minerals epidote is very abundant. A plagioclase feldspar is invariably present, but usually in small amounts. Garnet, tourmaline, chlorite and magnetite are common. Zoisite, zircon, rutile or titanite are found in many slides.

A broad belt of this mica schist flanks the chlorite schist on the east in Halifax and extends across the entire township. The strike is north 40° east and the usual dip is from 45 to 50° southeast. The biotite is fresh and unchloritized.

Missisquoi Group

The Missisquoi group of terranes comprises highly garnetiferous muscovite schists, sericite schists, sericitic quartzites, chlorite schists and hornblende schists. This group of terranes has been followed southward from the international boundary on the north to the Massachusetts State line on the south, a distance of 150 miles. The mineralogical content of the sericite schists and sericitic quartzites in the northern half of the state is fairly constant, but in Bethel biotite begins to replace the sericite and in Halifax the rock becomes a biotite schist in some of its outcrops.

Sericite Schist

In structure the sericite schists are finely laminated, schistose and granular. In texture they are fine to medium grained. In color they range from a silvery white to a slightly greenish tint. In some instances the green color is due to the chloritization of biotite and in others to the chloritization of hornblende. In both instances the green color is intensified by grains of epidote which result from the interaction of the feldspars and the ferro-magnesian minerals. The only essential minerals are sericite and quartz. If the sericite is in excess of the quartz the rock is listed as a sericite schist, but if quartz is in excess of the mica it is called a sericitic quartzite. The normal accessory minerals are biotite, albite, garnet, magnetite, pyrite and apatite. The secondary minerals are epidote and chlorite.

On the Hinesburg-Reid Hollow road in the northern part of Guilford the strike was north 20 east and the dip was 45° west. By the concrete bridge there is a fine grained, very quartzose rock with strike north 20° east and dip of 45° southeast. One-half mile northeast of Green River there is an extensive outcrop of a medium to coarse textured biotite schist. The strike varies from north-and-south to north 30° west and the dip is 45° westerly. It does not correspond to any beds found in the Ordovician terranes but is identical with beds found in the Cavendish schist. It appears to be an outlier of the Cambrian or else the Cambrian has been brought up by a fault. It is flanked both upon the east and west sides by Ordovician limestones and phyllites.

Chlorite Schist

There are thin beds of chlorite schist in the Missiquoi group and in the underlying Cavendish schist that conform in dip and strike to the enclosing sedimentaries. Such beds are regarded as of sedimentary origin for the following reasons:

1. The extreme narrowness of the beds.
2. The presence of an appreciable amount of well rounded quartz grains.
3. Their conformity in dip and strike to beds of unquestioned sedimentary origin.
4. The absence of any alteration by igneous intrusions in the walls of the enclosing sediments.
5. The absence of any plagioclase feldspar that could not have been derived from sediments.

If the above interpretation is correct then the age of these chlorite schists would be the same as the age of the enclosing sedimentaries. These beds of chlorite schist do not occur in the Ordovician although there are some beds in the Ordovician that are chloritic from the chloritization of biotite.

The chlorite schists that cut across the sedimentaries are regarded as of igneous origin but they do not occur in Guilford and Halifax.

Hornblende Schist

There are lenticular beds of hornblende schist in Halifax but the arguments in favor of a sedimentary origin of these schists and of an igneous origin were given so fully in the 18th Annual Report of the Vermont Geological Survey, pp. 332-333 that they need not be repeated here.

Ordovician

The term Ordovician as here used embraces the series of sedimentary rocks that lie unconformably upon the east flank of the

Cambrian terranes. They consist essentially of limestones, slates and phyllites. The structure of the phyllites is anticlinal and synclinal.

Waits River Limestone

The Waits River limestone, or quartzose marble, does not occur in mapable areas in Vernon and Halifax. However, there are very narrow beds of limestone interstratified with the phyllite in these townships. In Guilford, to the west of East Mountain, and to the east of Guilford Center, there is a long narrow belt of the Waits River limestone. The strike is north 20° east and the dip is about 45° easterly. In the central part of Guilford there is a broad belt of Waits River Limestone. It lies east and south of Governor's Mountain. Some slides show 75 percent of calcite and 25 percent quartz. Some of the outcrops are susceptible of a good polish. The general strike is north 20 to 30° east. The dip on the east side is to the east 45° and on the west side the dip is 45° west. This formation does not extend far south of Green River.

Memphremagog Group

The Memphremagog group consists of slates, phyllites and quartzites. In the northern half of the state the slate has appeared as a continuous belt from Northfield to the international boundary on the north. South of Northfield the belt has been more or less broken. On the eastern side of the Ordovician terranes slate has appeared in nearly every township southward from Waterford to the Massachusetts State line.

Slate

There is a long narrow slate belt in the extreme western part of Vernon and the eastern part of Guilford. The strike varies from due north to north 20° east. The dip is invariably at a high angle sometimes to the east and sometimes to the west. Two miles south of Guilford there is a slate quarry with dip on the west side 85° west, and on the east side of 20° east. This quarry is traversed by a fault. On the fault plane the slate is much crumpled and broken.

At the intersection of the north-south road with the east-west road from Vernon the slate dips 85° west and the fault lies east of these quarries. Two and eight-tenths miles south of Guilford there is a large quarry on the west side of the road with dip nearly vertical. Three and seven-tenths miles south of Guilford the slate

on either side of the road dips nearly vertically.

Brattleboro Phyllite

The term, Brattleboro phyllite, has been applied to all the phyllites that flank the Cambrian terranes on the east in Halifax. Vernon and Guilford lie almost wholly on phyllites with interbedded limestone. The general strike of the phyllites varies from due north to north 30° east. The dip varies widely. In the northern part of Vernon, on the Broad Brook road, the strike is north 30° east and the dip is 50° west. Two miles up Broad Brook road there is a large exposure of phyllite with dips from 80 to 85° west. At the Broad Brook Falls bridge the phyllite has a strike of north 20° west while the dip is vertical. Above the bridge the strike is north 20° east. Six feet away the strike is north 10° east and the dip is 85° east.

One-fourth mile east of the north-south road, on the hill, there is an outcrop of highly metamorphosed, fine grained phyllite cut by numerous quartz veins, some two feet in width. One and seven-tenths miles south of Guilford there is an outcrop of slaty phyllite with strike north 20° east and dip 85° east to 85° west. Half way down the west side of the mountain there is a rich tourmaline vein one foot in width from which fine showy specimens can be secured.

East of Halifax Center there is an outcrop of a highly garnetiferous schist, probably phyllite. East of this outcrop there is an outcrop of garnetiferous phyllite with some crystals of hornblende.

Acid Intrusives

The acid intrusives are confined to Vernon and Guilford. They consist of granites and granite gneisses.

Granites and Granite Gneisses

Granite outcrops do not occur in Halifax but they are numerous in Vernon and Guilford. None of them is of extensive individual areas.

Two and nine-tenths miles south of Brattleboro there is a small outcrop of granite on the west side of the road leading south to Vernon. Three miles south of Brattleboro there is another small outcrop of granite. These two are probably connected. Four miles south of Brattleboro there is a much larger outcrop of granite in a fresh road cut. It is traversed by seven quartz veins some of which cut across the gneissoid structure of the granite. Some of them are three feet in width. Two hundred yards south of this outcrop and on an east-west road there is an abandoned granite quarry, from which much stone has been removed. The minerals in order of their abundance are oligoclase, quartz, microcline, orthoclase and biotite. The accessory minerals are apatite and zircon. The secondary minerals are epidote, white mica, kaolinite, chlorite and zoisite. The quartz is crushed and granulated. Seven-tenths of a mile south of Vernon there is an outcrop of gneiss that is very fine grained. One mile south of Vernon there is an outcrop of granite gneiss on either side of the road. The gneissoid structure is very pronounced.

One-half mile west of the River Road, on the first west road north of Vernon there is a small granite outcrop in phyllite.

There is a granite outcrop on the southern end of the Brattleboro Quadrangle, just west of the Vernon town line; but in Guilford, on the right hand side of the road going south, this granite is coarse grained and has been extensively quarried. One-half mile from the Guilford-Massachusetts road, on the first east-west road north of the state line, there is an outcrop of biotite granite. This granite is coarse grained and the area is not extensive.

Basic Intrusives

Basic intrusives occur in Vernon, Guilford and Halifax. They are associated with the Cambrian and Ordovician terranes. They consist of amphibolites, diorites and Gabbros.

Diorite

Just west of the amphibolite[1] outcrop there is an extensive outcrop of diorite. This extends south into Massachusetts and westward for some two miles. The rock is from fine to medium grained and massive. Its prevailing mineral constituents are hornblende, a plagioclase feldspar, oligoclase to andesine, and secondary calcite. It also carries some pyrite and magnetite.

In the western part of Halifax, on the east side of the river, there is an outcrop of a very massive diorite that cuts a black splintery mica schist at an angle of 70°. The strike of the rocks is here north 60° east and the dip is south.

In the extreme northern part of Halifax there is a diorite that cuts the Cambrian schists. It is fine grained and massive.

[1] Professor Richardson did not locate the amphibolite outcrop. ED.

Gabbro

In the southeastern part of Vernon, about two miles west of the Connecticut River, there is an outcrop of a very coarse textured gabbro. Its mineral composition is coarse hornblende, augite and feldspar (oligoclase to andesine). It is associated with the diorite mass that extends westward past Lilly Pond and is probably a phase of this great intrusive.

Paleontology

No fossils have been found in the pre-Ordovician terranes on the eastern side of the Green Mountains. The relative age, therefore, of these formations must be determined by their stratigraphic position, continuity and lithological characteristics. The pre-Ordovician terranes as they appear in Halifax are unquestionably post-Algonkian, for the base of the Cambrian series is the Sherburne conglomerate which overlies the Algonkian. The terranes underlie the Irasburg, Albany and Northfield conglomerates which form the base of the Ordovician in eastern Vermont. If the conjecture is correct that the Bethel schist carries a conglomerate bed in Windham, then the Cambrian terranes as they appear in Halifax are upper Cambrian, for they overlie the Bethel schist.

The Ordovician terranes here unquestionably overlie the upper Cambrian, with an erosional unconformity separating the two groups of formations as in northern Vermont. It is unfortunate that no well defined beds of graptolites were found in Vernon, Guilford and Halifax. However, several samples were sent from the abandoned slate quarries in Guilford to Dr. Rudolph Ruedemann, State Paleontologist, Albany, New York, for examination. Doctor Ruedemann writes, "These may well have been graptolites but they are too far gone to be recognized any more. These elliptical films all have a median line of depression. I have had frequently similar limonite patches in graptolite shales that originated from pyrite crystals and that have misled many."

I also sent two samples from Northfield, Vermont. Concerning these Doctor Ruedemann writes, "One slab contains undoubted graptolites. The long bodies are clearly Phyllograptus, like Phyllograptus angustifolius in outline. The smaller ones are forms of Diplograptus. By turning the specimens in the light one can clearly see the traces of the original structure, especially the thecal walls near the margins. I have seen, east of here, graptolites go through all stages of the disappearing act where the shales gradually change into phyllite and schist. The same must be true of these."

Concerning the second sample Doctor Ruedemann wrote, "The coral-like body is certainly most suggestive. Corals are rare in these early Paleozoic rocks. It might more probably have been a cephaloped. It suggests in outline one of the many Cyrtoceras forms of the Trenton formation, but of course retains no septa and therefore is inconclusive."

The Paleontological evidence was given so fully in the Biennial Report of the Vermont State Geologist, 1927-1928, that it need not be reproduced here.

Economics

There are no known commercial metallic minerals in Vernon, Guilford and Halifax or in their immediate environs. However, there are some non-metallic mineral products of commercial significance.

The granites of Vernon and Guilford are susceptible of a good polish and can be used locally for monumental or constructional work. A considerable amount of granite has been quarried in both Vernon and Guilford but the quarries are not exhausted.

In the Guilford valley there are many abandoned slate quarries. The slate has a fairly good rift and splits readily into slabs three-sixteenths of an inch in thickness. It is well suited for roofing purposes and constructional work.

One-half mile west of the Connecticut River, on the Broad Brook road, there are five gravel beds opened up for road construction. The supply of this glacial gravel is ample for many years.

The Cambrian Rugg Brook Formation of Franklin County

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Buff and salmon weathering sandy dolomites of Cambrian age have long been known to be present along the western border of Vermont, but it is only recently that geologists have come to realize that these "Red Sandrocks" (as the earlier investigators called them) include beds of several different ages. The stratigraphy and structure of the belt of Cambrian and Ordovician sedimentary rocks which parallels the eastern shore of Lake Champlain are so complicated that the determination of the ages and relations of the numerous formations present has been an unusually difficult task, which is only now nearing completion; and one of the most troublesome parts of the problem has been the determining of the age, the stratigraphic relations, and the most probable mode of formation of these dolomites, which, although now known to have been deposited at several different times in the Cambrian Period, all look so much alike that, even after careful study has demonstrated that they were deposited at different times, they still present some puzzling questions to the geologists who are trying to classify them.

At least four different more or less sandy dolomite formations are now known to be present in the Cambrian stratigraphic column of northwestern Vermont, and there are sandy dolomite beds in two of the other Cambrian formations of the region. Two of the four main dolomites—the Winooski and Mallett—are known from their fossils to be of Early Cambrian age. A third—the Milton—has recently yielded fossils which indicate that it was deposited in Late Cambrian times. The fourth—the Rugg Brook—has not yielded any fossils, and its age is consequently still doubtful. The other two formations, in which sandy dolomite beds occur (although the formations, as a whole, are not dolomites) are the Parker Shale and the Mill River Formation.

When first examined by geologists, the sandy dolomites of northwestern Vermont were all spoken of as the "Red Sandrock," and no idea was entertained that they were referable to more than a single formation. Recent studies by Professor Schuchert, Dr. Arthur Keith, and others have demonstrated that the Winooski and Mallett dolomites are distinct stratigraphic units, and that there are other dolomites still higher in the section.

At first it was thought that only a single dolomite formation was present above the Mallett, and for this Dr. Keith proposed in 1923[1] the name "Milton." Since 1923 it has been discovered that the Milton in its type district, near Milton, contains what appear to be Late Cambrian fossils[2], while some of the dolomitic beds farther north that had been included in the Milton by Dr. Keith have been found to underlie the late Middle Cambrian St. Albans Shale, and are consequently older than the type Milton. Dr. Keith still used the name "Milton" for these older beds in 1932[3], but in May 1933, Professor Schuchert (in his paper referred to above) placed most of them in the Parker Shale (which was known to have interbedded in it some sandy dolomite beds), and the rest of them in a new formation, which he called the Rugg Brook Conglomerate (op. cit., pp. 356, 359, 363, 365, 366, 368), and which he considered to be of Middle Cambrian age, since he knew that it was separated from the underlying Parker Shale by a sedimentary and erosional break and he thought that it was stratigraphically continuous with the overlying St. Albans Shale.

In the summer of 1933 the writer made a very detailed examination of the dolomites between the top of the Mallett Dolomite and the base of the St. Albans Shale, and discovered evidence which seems to him to indicate that there is a depositional and erosional break between the Rugg Brook and the St. Albans and that some of the dolomites which Professor Schuchert placed, in his 1933 paper, in the Parker Formation, really belong in the Rugg Brook, while others of them are of Late Cambrian age.

Professor Schuchert called the Rugg Brook a "conglomerate" because the beds which he assigned to it were conglomeratic. Some of the additional beds which the writer would add to this formation are also conglomeratic, but some of the others are not. For this reason the writer prefers to use the name "Rugg Brook Formation," instead of "Rugg Brook Conglomerate" for the whole stratigraphic unit.

Professor Schuchert defined his Rugg Brook Conglomerate as a dolomite conglomerate, which weathered a salmon color and was usually less than 20 feet thick. He stated that the type locality for the formation was on Rugg Brook, less than three miles southwest of St. Albans; and he added that the conglomerate occurred in at least two other localities—the Conner Farm (about a mile southwest of St. Albans) and near Rockledge (about three miles north of St. Albans). He said that the matrix of the conglomerate was composed of round-grained sand, cemented by dolomite, and that the boulders found in it, some of which were as much

[1]Keith, A. Cambrian succession of northwestern Vermont. Amer. Jour. Sci., 5th Ser., vol. 5, 1923, p. 112.

[2]Schuchert, C. Cambrian and Ordovician stratigraphy of northwestern Vermont. Amer. Jour. Sci., 5th Ser., vol. 25, 1933, p. 369.

[3]Keith, A. Stratigraphy and structure of northwestern Vermont. Jour. of the Wash. Acad. of Sci., vol. 22, 1932, pp. 371-373.

as two feet in diameter, were from the Parker or Mallett formations, or occasionally from the Winooski.

The writer would, as a result of his studies, now re-define the Rugg Brook Formation as a sandy, sometimes conglomeratic, salmon brown to buff brown weathering gray to buff colored dolomite. This dolomite is believed to outcrop along the strike only from a point three miles southwest of St. Albans to about four miles north of that town; and it not only does not outcrop anywhere nearly continuously for those seven or eight miles, but is actually absent entirely at some places along the strike, where the St. Albans Shale can be seen to lie directly on the Parker Shale. The greatest thickness of the Rugg Brook that is exposed, or can be surmised with any certainty, is about 75 to 100 feet. It varies greatly in thickness from place to place, and usually measures only from 10 to 40 feet from top to bottom.

The exposures usually stand up as knobs or ridges, as they have resisted erosion better than the Parker and St. Albans shales beneath and above them. The beds always dip to the east, but the dip varies from place to place because of the thrusting which has affected them. The southernmost outcrop believed by the writer to be referable to this formation is a small one, not far north of the road which runs east from Everett School to St. Albans Hill. The exposures which show the formation at its greatest thickness are about a mile southwest of the southwestern outskirts of St. Albans, on the Conner Farm and adjacent farms, where about 75 to 100 feet of sandy dolomite, often with pebbles of similar rock or of white weathering gray or buff sandstone, up to six inches or more in diameter, outcrop. The best developed conglomeratic bed in the known Rugg Brook is near the top of the formation, on the Conner Farm, where boulders of sandy dolomite and sandstone as much as four feet in diameter may be seen. At the base of the formation in this area the contact with the underlying Parker Shale is exposed, and can clearly be seen to be a disconformity. There are small exposures of the Rugg Brook on the road from St. Albans to St. Albans Bay, and for a short distance to the north; but for two miles northeast of that locality there are no good outcrops of Cambrian rocks, and the position of the St. Albans Shale and the underlying Rugg Brook have to be guessed at from float boulders and the position of the exposures of those formations northeast and southwest of that covered area. Then, from a point northwest of School 3, two miles north of the northern outskirts of St. Albans, the Rugg Brook is exposed almost continuously along the strike for about two miles, until it thins out and disappears a mile east-southeast of Swanton Junction. The two places where it can be seen in contact with the St. Albans Shale are close to, and half a mile south of, the northern end of this series of exposures, where the contact can be seen to be a disconformable one. The formation is repeated by thrusting west of this northern end of its area of exposure, and some of the western exposures are conglomeratic.

The Rugg Brook outcrops along the strike in a belt parallel with the St. Albans Shale. It does not show at the surface quite as far south as the St. Albans, whose southernmost known exposure is half a mile south of the road running from Everett School to St. Albans Hill; and it thins out to nothing a few hundred yards south of the northernmost known exposure of St. Albans Shale. The distribution of these two formations is, however, so nearly the same as to suggest either that the two formations are related in origin or that they are limited in their present distribution along the strike by the same cause. Professor Schuchert assumed in his 1932 paper that the Rugg Brook was the basal formation of the beds laid down during the depositional cycle in which the late Middle Cambrian St. Albans was deposited, and he therefore placed the Rugg Brook in the Middle Cambrian. The discovery of a disconformity between the Rugg Brook and the St. Albans makes this interpretation open to doubt, although it does not entirely disprove it. But the additional discovery that the two formations are cut off on the strike at both their northern and their southern ends by the Upper Cambrian Mill River Formation, so that the failure of both to extend farther is probably due to that fact alone, makes the similarity in areal distribution of the two of less significance. It is to be kept in mind in this connection that, although the Rugg Brook, as exposed, does not extend quite as far north or south as the St. Albans, it is always intermittent in its outcrop, and may, before having been eroded away, have extended farther in both directions. It should also be recalled that the disconformity above the Rugg Brook, and its discontinuous distribution, presumably mean that that formation was partly eroded away before the St. Albans was deposited on top of it.

The Rugg Brook beds must have been laid down in shallow marine waters. They are almost always sandy, and they sometimes include small lenses, and occasionally beds, of almost pure, gray-weathering sandstone, some of which are more than a foot thick. The grains of sand in these beds vary in size up to half the size of a pea. They are usually of normal size, however, and are, most of them, more or less rounded. Small pebbles of the gray-weathering sandstone are common in some of the more dolomitic beds. As they weather more slowly than the dolomitic matrix, they stand out in relief on the weathered surfaces of the latter. Professor Schuchert has stated that the Rugg Brook contains boulders derived from some of the underlying formations; but the writer has not been able to discover any boulders in this formation which he felt sure came from any beds beneath it. Its conglomeratic beds seem to him to be more probably intraformational, or at least mainly such.

In one outcrop, about one and a half miles southeast of Swanton Junction, angular blocks of Rugg Brook Dolomite, one of them one and a half feet long and six inches thick, can be seen in the lower part of the St. Albans Shale; but this is the only exposure known to the writer in which undoubted pieces of the Rugg Brook are to be found in the St. Albans Formation.

Dr. Keith[1] has stated that fossils, considered by Dr. Schuchert to be of Early Cambrian age, were found in the matrix of a conglomeratic bed of the Rugg Brook formation just north of the road running from St. Albans to St. Albans Bay; but the writer is informed by Professor Schuchert that this record is an error, and that these fossils came from the matrix of conglomeratic beds which are now considered to be in the Parker Formation.

Until fossils are discovered in the Rugg Brook Formation its age must remain doubtful, since it is separated by disconformities from the Parker Shale below and the St. Albans Shale above. It may have been deposited near the end of Early Cambrian times, or it may not have been laid down until sometime during the Middle Cambrian Epoch. As the St. Albans Shale is of very late Middle Cambrian age, a long time elapsed between the time of its formation and that of the Parker Shale. Without more conclusive evidence than is now available, we can say no more of the age of the Rugg Brook than that it is younger than the Parker Shale and older than the St. Albans. Dr. Keith[2] believes that the Shelburne Formation was deposited between the time of the formation of the Rugg Brook and the time of the laying down of the St. Albans. Since no fossils have been found in the Shelburne, however, its age relative to that of the Rugg Brook can not yet be determined with certainty. The two formations may possibly be of approximately the same age. In his paper published in 1932 Dr. Keith[3] stated that the Shelburne is underlaid conformably in the region around Burlington by a formation that he correlates with the Rugg Brook (which he at that time spoke of as the "Milton"); but the identity of this formation with the true Rugg Brook can not be proved at the present time, and the question of the ages of all of these formations must remain for the present an open one.

[1]Op. cit., p. 371.
[2]Op. cit., p. 361.
[3]Loc. cit.